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HEALTH CARE IN TRANSITION

Tipping the Boundaries

Health and Well-Being of Sustainable Development

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Editors

NOVA

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Tipping the Boundaries

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Contents

Foreword

I am delighted to present this indispensable edited book, "Tipping Boundaries of Sustainable Development: Concern, Advances and Applications Its Intersection with Health and Well-Being," edited by Dr. Sandeep Poddar and Dr. Waliza Ansar and published by Nova Science Publishers, Inc., USA. The book contains 18 chapters by eminent authors from different countries. The main theme of the book is focused on United Nations Sustainable Development Goals (SDGs). The book makes a global collaboration on green infrastructure strategies and scientific innovative research under a broad panorama.

The United Nations created the SDGs which act as a worldwide guide for nations to work together to build a better, more sustainable future. These objectives are intended to tackle a number of urgent issues, such as social stability, public health, climate change, technology, peace and security and the growing needs for energy, food, and shelter. The need for revolutionary action is more impeding than ever as the world deals with interrelated and surging problems including pandemics, harsh weather, and ecological destruction.

This extensive work emphasizes the need for ingenious solutions to guarantee a sustainable future and highlights the urgency of tackling environmental challenges. The writers have painstakingly investigated the most recent achievements in sustainability, offering a comprehensive analysis of how these advancements interact with improved health of planet Earth.

It emphasizes the significance of using a holistic approach, in which sustainable development is seen as an essential part of a larger agenda that aims to improve human health and well-being rather than as something to be seen in isolation. The delicate balance that must be maintained between environmental stewardship and heal this highlighted, emphasizing the necessity of interdisciplinary cooperation and innovative problem-solving.

This book explores the economic, environmental, and social components of sustainable development, delving into them to balance, overlap and integrate. It offers a comprehensive examination of several topics, such as the efficiency of voluntary carbon markets in reducing climate change, the effects of chemicals on biodiversity, the difficulties associated with waste management, and creative farming methods to counteract salinity in the soil. Every chapter provides information on sustainable development in ways to equate, redress and eradicate problems from the grassroots.

Although difficult, the struggle for sustainable growth was old, the goals were new and unavoidable. We can create the conditions for a more just, robust, and prosperous global community by encouraging cooperation and informed action. This book acts as a thorough manual, providing insightful viewpoints and workable answers to assist in accomplishing this important objective.

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Preface

Sustainable development is a comprehensive concept which must meet the needs of the current generation without compromising the future generations to get intragenerational and intergenerational equity. Without measurements, it is standing on three dimensional frameworks: financial, social and environmental (ecological) in a mutually reinforcing process. The Sustainable Development Goals (SDGs) - the mutual blueprint for every country to mutually build a superior and sustainable future for mankind in a pragmatic manner. In the meanwhile, the world is facing interlinked, interconnected and bouncing crises with derogative implications for peace and security, social permanence, public health, climate, huge demand on food, shelter and energy; fluctuating weathers, spurge of diseases and our fragile ecosystems. For some authors, sustainable development has turned to be just a matter of discussions, less relevance on socio-economic events and less focus on environmental aspects making the concept of sustainable development diluted. As global communities are gradually becoming the stakeholders it is imperative to transit from theory to practice. Decision makers must bring out actions and implementations at the international, national, community and individual strata through the United Nations (UN), governments of each country, private sector, public organizations to develop policies, education goals and directive on social, economic and environmental resource management to guarantee that everyone in ecosystem is aware, conscious and compliant.

Climate change is disrupting social well-being, national economies; increasingly frequent and intense extreme weather events and affecting lives and livelihoods. The catastrophic consequences of climate change are far beyond mere plans and promises. Urgent and transformative practical approach on sustainable development requires raising ambition, shifting to a climate-resilient sustainable development, well-being, underscoring the pressing requirement for synchronized endeavors to diminish carbon emissions and adopt sustainable methodologies to cut off climate cataclysm looming. It is imperative to pace and scale up current climate action plans, achieve net-zero emissions, reduce dangerous human interferences, employ science (artificial intelligence, high-resolution climate modelling, etc.) to supercharge progress, global collaboration and innovative ways to ensure a sustainable and equitable future for all.

During 1990-2021, the agricultural production index, temperature change, emissions intensity from rice, emissions intensity from cereals, emissions per value of agricultural production, emissions per area of agricultural land and total CO_2 emissions of Zambia were not only evaluated but a model was created to pinpoint relations (relationships are stable without the heteroscedasticity problem) between agricultural productions and emissions through four co-integrating equations. The econometric test for a single country like Zambia creates adequate reasonable scope for further research avenues in regional or global economies.

This chapter provides an in-depth analysis of the effectiveness of voluntary carbon markets (VCMs) and their role in mitigating climate change. By scrutinizing the transformation of native ecosystems into carbon offset projects, the chapter highlights the potential threats to biodiversity and ecosystem health. The database as well as relevant literature in this chapter was used to understand how the carbon currency-based land-use projects are classified and then delve into forestry and land use practices which encompasses all the afforestation/reforestation-based projects globally.

The extensive impact of chemicals on biodiversity includes habitat alteration, water and air pollution, bioaccumulation, endocrine disruption, and genetic diversity loss. This chapter discusses the consequences on ecosystems (direct and indirect), on species while highlighting mitigation strategies such as sustainable practices, improved waste management, regulatory measures, eco-friendly alternatives and international agreements like the Stockholm Convention.

Waste production is inevitable and will continue to increase as the population grows and the needs of daily life increase; therefore, waste must be handled appropriately so as not to pollute the surrounding environment and endanger public health. Each stage of waste handling must be monitored to ensure that the waste is processed properly and does not harm the environment and health. The challenge of handling and managing waste to avoid land pollution requires the awareness of all parties and playing their respective roles in preserving nature and the environment.

Salinization of agricultural land due to anthropogenic activity is a threat to global food production. Haloremediation using halotolerant and halophilic microorganism can prove to be beneficial in reducing salinity. This chapter discusses the potential of haloremediation in reducing soil salinity as a part of sustainable agricultural practices. The potential of halophilic bacteria and arbuscular mycorrhiza in remediation of saline soils and their future use in bioremediation of infertile saline and sodic soil were also discussed.

The intricate relationships between ecosystems, human activities, and public health are crucial to understanding and addressing today's environmental challenges and ecosystem disturbances. By intersections of different ecosystems, their complexities, functions and dynamics; the importance of risk and its management in each ecosystem needs to be emphasized to achieve sustainable development and enhance public health. To combat ecosystem degradation, it proposes ecological restoration, nature-based solutions, and technological integration, aiming to bolster resilience and mitigate risks.

Catalytic climate change, globalization and deforestation explore the rise of emerging infectious diseases. Sustainable development promotes growth that meets present needs of society while ensuring future generations can do the same while integrating environmental, economic, health, and social dimensions. In healthcare, sustainable development optimizes resources, reduces environmental impact, and enhances well-being, emphasizing quality care for future generations. The strategies and insights to navigate through the challenges of infectious diseases, pin-pointing their complexities, pave the way for a healthier, less vulnerable global health systems and more sustainable future.

Cardiovascular diseases (CVD) are a leading cause of death in the Indian subcontinent mostly in the low and middle-income settings. Therefore, it becomes a prime responsibility of researchers and medical practitioners to ascertain the causative factors and essential variables. A statistical model based on CVD datasets, some important covariates and employment of certain machine learning tools helps to draw inferences in the field of e-health and medical informatics for better clinical decision making.

The effects of urbanization on climate change, caused an imbalance in environmental dynamics, created habitat shifts and spurge on the emergence, resurgence of vector and water borne diseases globally. Many factors (extrinsic and intrinsic) have contributed to the emergence of these diseases causing morbidity, mortality and public health hazards.

Diabetes Mellitus has emerged as one of the leading non-communicable metabolic life-threatening chronic diseases with costly health complications and reduces life expectancy. Diabetes patients need healthy behavioural and psychological Self-Management using the Biopsychological Model for effective Glycemic Control, stay active, establish good communication and reduce complications. The biopsychosocial model bridges both cognition and emotion through a series of self-management processes.

In a cross-sectional study in a male Islamic boarding school in TAPAN, Tulungagung, East Java, during COVID-19 pandemic, the most common symptoms experienced by students were sneezing, nasal congestion, colds, muscle or body aches and headaches. Other symptoms were also noted. Some students may have COVID-19. Self-administered questionnaires were conducted with teachers to whom the researcher gave prior explanations. The analysed descriptively showing the frequency and percentage of each variable. Surveillance is needed in the school to trace and follow up the condition of the students and their families using swab PCR tests.

Patients benefit from maintaining consciousness throughout intubation, but they may experience a variety of adverse physical and mental consequences, such as pain, dyspnea, fear, and helplessness, loss of control, speech difficulties, and anxiety. The communication difficulties in intubated patients can be overcome by use of Augmentative and Alternative Communication (AAC) devices for better care giving and patient-centric management.

Neurodegenerative diseases involve neuronal degeneration and microvascular dysfunction, with progressive decline, compromising cognition and behaviour. These pathologies present similarities such as the aggregation of proteins in the central nervous system. Available treatment only alleviates symptoms. Non-pharmacological interventions must be implemented from diagnosis, such as mental and physical exercises and community support. Neurodegenerative diseases are a major problem in the healthcare sector, with implications for caregivers and the entire healthcare system. The burden that the disease causes for caregivers is considerable, with an impact on the family, economy and health.

Cancer is one of the world's most prevalent social and economic burdened diseases with high mortality rate. The chapter tried to cover major resources that can provide insight into the application of multi-omics data in the treatment of cancer. All throughput methods (like next-generation sequencing, ATAC-sequencing, ChIP-sequencing), proteomics, genomics, microbiomics, transcriptomics together blended to comprehend cancer. The increasing use of artificial intelligence, multi or single omics, bioinformatics may sometimes have serious clinical implications in computational oncology. The field is fast-growing and currently under development, with novel algorithmic approaches being constantly released, but we believe that the present account is a good starting point.

Smart healthcare is essential for personalized care. Nanomaterials are widely used in biosensing applications, with 2D-materials-based devices playing a significant role in disease management. The evolution of 2D architectures, deployment, challenges, and future directions of nanomaterials in smart healthcare research provides better insights for health science professionals.

Electronics, materials science, polymer engineering, and many other science and engineering fields have all been greatly impacted by nanotechnology. This chapter provides a comprehensive overview of research activity on the creation of nanofibers, basic knowledge of the electrospinning method, and properties of nano-structured fibrous materials and their applications.

To realize good clinical governance, all midwifery care was carried out by every midwifery personnel in the hospital according to the clinical assignment of the Director of the hospital. Credentialing is the process of evaluating midwifery personnel to determine the eligibility of granting Clinical Authority. Clinical Authority is obtained after going through a credential process carried out by the Midwifery Committee Credential Subcommittee together with Mitra Bestari. Recredentialing is the process of re-evaluating midwifery personnel who already have Clinical Authority to determine the feasibility of granting clinical authority. Midwives as one of the health workers play an important role in achieving health development goals.

Sustainable development is gradually becoming a necessity rather than luxury. Being multidimensional in nature, it requires multidisciplinary knowledge on society, disease, environment, economics, hi-tech gadgets, all-encompassing technology, healthcare and their solutions, and how they intersect, interact and intermingle. This book presents a kaleidoscopic account of the potency and drawbacks in the quest of sustainability, with special indication to the world scenario. It will give insight to the readers of different fields to enrich themselves likewise. It motivates readers to juggle towards truly inclusive environmentally sustainable pavement and choices. It also inspires them not to remain as ‘change-listeners’ but to be engaged in ‘change-drivers’ in a green world for themselves, near-dear ones, society, communities and for the mother Earth.

Dr. Sandeep Poddar
Dr. Waliza Ansar

Chapter 1

Climate Change as a Tripping Point: Traversing the Ripple Effects of Climate Change on Sustainable Development and Well-Being

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Abstract

The effect of climate change is one of the most pressing issues that people throughout the world face in terms of its consequences for sustainability, human health, and other elements of human life. The author contends in this chapter, "Climate Change Concerning Sustainable Development and Wellbeing," that "climate change" has reached a turning point for public and "planetary" health. Under the United in Science study, which looks at how climate change and severe weather will affect the goals, just 15% of the Sustainable Development Goals (SDGs) are on track. It demonstrates how weather, climate, and water-related sciences may aid in the achievement of goals such as sustenance and water security, renewable energy, improved health, sustainable oceans, and resilient cities. The yearly report incorporates feedback and expertise from 18 organizations. It is released ahead of the United Nations General Assembly's SDG Summit and Climate

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Ambition Summit. This study adds to the body of knowledge regarding making climate change a turning point for sustainability, health, and welfare.

Keywords: transmission, vector-borne and water borne disease, urbanization

Introduction

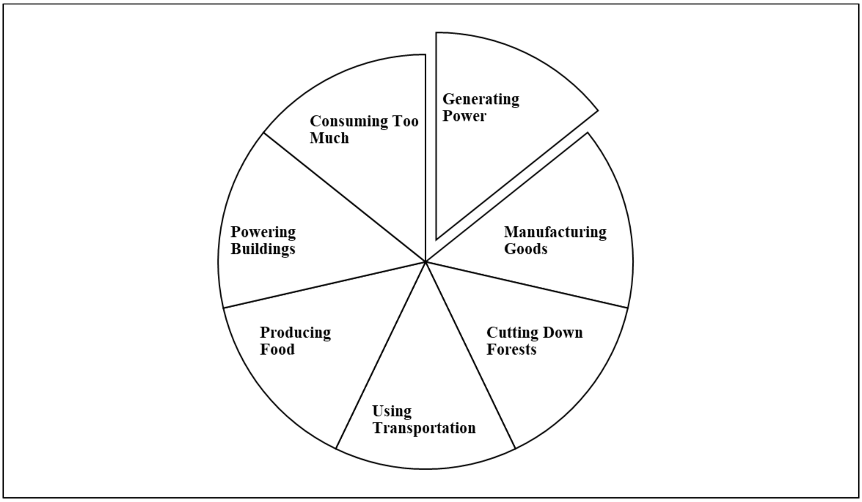
Changes in weather patterns can also be categorized as climate change. Greenhouse gases, which are produced by both biological systems and human activity, are the primary reason. To date, human-caused global warming has raised average temperatures by around 1.0° above preindustrial levels. At present emissions rates, forecasts show that this amount will approach 1.5°C by the years 30 and 52, peaking at roughly 4-6°C by the end of the century. In the past twelve months, the world has experienced 315 natural disasters, most of which were driven by climate change. Storms, fires, flooding, and storms caused more than $131.7 billion in property destruction (98% of total economic losses). Then it's the monetary expense. Almost all of the expenditures incurred by fires over the prior decade were amassed in 2018, and these costs are quite alarming. Food, water, and basic hygiene are all in jeopardy. The importance of water, food, health, ecosystems, human ecology, and infrastructure cannot be overstated. Furthermore, climate change has been regarded as the most dangerous to the food, water, health, environment, physical setting, and infrastructure sectors. The financial consequences incurred by wildfires in 2018 are about equal to the entire losses incurred by wildfires in the decade preceding 2018, raising concerns. Similarly, food, water, and basic cleanliness are required. Water, food, health, the surroundings, human ecology, and infrastructure are all extremely important. Beyond that, the food, water, health, setting, physical settings, and infrastructure sectors were initially recognized as being the most sensitive to climate change (around 1850). The use of fossil fuels as well as the loss of forests, has resulted in a considerable rise in the quantity of carbon dioxide in the atmosphere of the Earth (Masson et al., 2021). The growth in global demand for natural resources has corresponded with significant advances in people's quality of life across the world. The world, on the other hand, is struggling to keep up with these developments. The perceptible rise in average global temperatures, along with the increased frequency of severe thunderstorms, is changing ecosystems on a global scale, threatening whole plant and animal species. Due to diminishing rainfall, forests are becoming increasingly dry, increasing wildfires. Furthermore, both the North and South Pole glaciers are receding significantly. While weather refers to short-term, frequently changing conditions, climate refers to a location's long-term characteristics, whether temperate or tropical. Climate influences temperature changes, weather patterns, seasonal characteristics, precipitation levels, and the nature of meteorological events, including storm severity. The delicate interaction between weather and climate is critical, with climate change manifesting in higher temperatures, more frequent weather extremes, and more natural catastrophes (Fawzy et al., 2020; Andriati, Adha & Hadi, 2021). Fossil fuel combustion produces greenhouse gases, which act as a protective layer over the Earth, storing solar heat and boosting temperatures. Carbon dioxide and methane are the primary causes, which are created by activities like driving vehicles, heating houses with coal, and the destruction of forests. Agriculture, along with oil and gas production, is a significant source of atmospheric methane, which has a relevant impact on the entire footprint of greenhouse gases. Energy, manufacturing industries, modes of transport, and buildings all contribute significantly to greenhouse gas emissions into the environment. This complicated cross-over of different sectors highlights the diverse character of greenhouse gas emissions and the fact that environmental responsibility is shared in numerous ways across all businesses. A deep understanding of the sources of emissions not only demonstrates the necessity for cross-sectoral collaboration in promoting sustainable practices but also emphasizes the fact that greenhouse gas reductions are limited. Everyday solutions to this global crisis are initiated from the same starting point: when one wakes up and takes care of their own everyday lives (Kumar, 2021). Global warming and climate change are sometimes used interchangeably as indications of a continuing global shift. Global warming is the rise in average global temperatures, a process with far-reaching consequences for humans, wildlife, and ecosystems worldwide. Recognizing that the effects go beyond temperature rises, the phrase "climate change" is used to encompass the whole range of implications. Human actions, according to 97% of current climate scientists, are the major source of documented global warming since the mid-seventeenth century. Carbon dioxide levels in the upper stratosphere have increased from roughly 280 parts per million (ppm) before the start of the Industrial Revolution to 413 ppm by early 2020, a level never seen in human history. To mitigate global warming, scientists recommend returning to a safe amount of 350 ppm by 2100. With this sense of urgency, fossil fuels continue to provide more than 81% of the world's primary energy supply, mostly coal, oil, and natural gas. This reliance causes greenhouse gas emissions upstream as well (during the extraction of energy and production) and downstream (during energy use). The continuous reliance on fossil fuel-based sources of electricity is a significant impediment to achieving emission reductions, particularly keeping in mind, the world's expanding energy demand (Hashimoto et al., 2019). The harmony of energy that flows into and out of the planet's system determines the outside temperature of the planet. When sunlight touches the earth's surface, it may be reflected or absorbed. The planet is heated by incoming energy that the ground absorbs. After receiving some of the energy, the planet sends some of it as heat (also known as infrared radiation) into the environment. Solar radiation reflected in space does not heat the planet. Air pollutants absorb energy, blocking or inhibiting heat transmission into space. These gases are referred to as "greenhouse gases." They act as a blanket, making the ground warmer than it would otherwise be. This mechanism, dubbed the "greenhouse effect," is simultaneously biological and required for the survival of life. On the other side, the recent rise in greenhouse gases in the natural environment because of human activity has transformed the earth's climate, with severe repercussions for human health and welfare as well as habitats. Climate change has the potential to impact the health, food production capacity, housing, safety, and employment. Climate change has already made people in tiny island nations and other poor countries more vulnerable. Sea-level rise and invasion of saltwater have forced the evacuation of whole villages, while repeated droughts have put people in danger of starvation (Clayton, 2020). Tripping Point is a continuous tripping in an individual community's micro-level experience, not just the macro-level disruptive incident. Climate change's consequences exacerbate health susceptibility, necessitating a thorough examination of the complex link between community welfare and environmental constraints.

Methodology

The research examines the effect of climate change on long-term development and well-being in papers from databases such as Science Direct, Web of Science, and Google Scholar. The findings were organized by relevancy, publication date, and research requirements. Following the selection of 32 important publications, they are rigorously scrutinized and analysed to extract significant results, methods, and theoretical concerns. The information is offered to illustrate the common theme that would justify the objective of the study. The framework facilitates a thorough understanding of the subject.

Various Reasons for Climate Change

According to the conclusions of a United Nations sustainability assessment, coal, oil, and gas are undeniably the most significant contributors to global climate change, which account for more than 75% of global emission rates of greenhouse gases and more than 90% of total carbon dioxide emissions. As greenhouse gas excretionwraps around the Earth, the sun's heat is trapped. As a result, there has been an increase in temperatures and climate change. The rate at which global temperatures are rising is unprecedented in historical records. Temperature rises cause weather patterns to shift, disturbing nature's natural equilibrium. This presents several threats to both people and other types of life on Earth. Figure 1 displays the many sources of climate change.



Source: Authors' compilation.

Figure 1. Various Reasons for Climate Change.

- *Generating Power*: The depletion and subsequent utilisation of fossil fuels for power and heat considerably contribute to global emissions. The burning of coal, oil, or gas now provides most of the energy, creating powerful greenhouse emissions—carbon dioxide and nitrous oxide—that form a thermal blanket over the Earth, holding the sun's heat. Renewable sources of power, in contrast to fossil fuels, produce somewhat more than a quarter of global power while emitting little to no greenhouse emissions or pollutants.
- *Manufacturing Goods:* Manufacturing and industrial exhaust gases are mostly produced because of the burning of fossil fuels used to power different processes in the manufacture of materials such as steel, cement, electronics, plastics, textiles, and other things. Gases are pollutants of mining, industrial processes, and buildings. Manufacturing machinery is usually powered by coal, oil, or gas, and some materials, such as materials for plastics, need the use of chemicals generated from fossil fuels. The industrial sector generates considerable global CO_2 emissions, emphasizing its environmental importance.
- *Cutting Down Forests:* Because trees exhale the carbon they accumulate after being cut, the process of clearing forests for agricultural purposes, pastures, or other causes creates emissions. Each year, roughly twelve million acres of forest are lost. As trees lose their ability to absorb CO_2, nature's ability to regulate emissions in the atmosphere diminishes. Forest loss, along with changes in agriculture and land use, amounts to around one-quarter of total world greenhouse gas emissions, demonstrating the immense global effect of such activities.
- *Using Transportation:* Cars, lorries, ships, and aeroplanes are largely propelled by fossil fuels, making the automotive sector a substantial source of greenhouse gas emissions, Carbon dioxide, to be specific. The combustible process of petroleum-based assets is the principal driver of this element, such as gasoline, within engine compartments. Toxins from ships and planes are continually growing. Transport contributes to around one-quarter of global energy-related CO_2 emissions. Energy consumption for transport is expected to increase significantly in the future years, highlighting the critical need for sustainable solutions in this critical industry.
- *Producing Food:*Carbon monoxide, nitrogen oxides, and other greenhouse gas emissions are emitted by the agriculture sector

through a variety of processes, including logging and pastureland cow and sheep the combustion process, the creation and use of fertilizer products and manure for the cultivation of crops, and the collecting of energy to power agricultural machinery or fishing vessels, which is frequently done using energy generated from fossil fuels. All of this demonstrates that the cultivation of food has a substantial impact on climate change. Food packaging and distribution can contribute to the release of greenhouse gases.

- *Powering Buildings:* Over half of the energy utilized globally is absorbed by commercial and residential constructions. They continue to emit significant amounts of greenhouse gases since they tend to heat and cool by employing coal, oil, and natural gas. Increasing energy requirements for conditioning and processing, as well as increasing power usage for lighting, appliances, and other gadgets that use electricity, have resulted in a significant increase in CO_2 emissions from buildings.
- *Consuming Too Much*: Housing and energy use, mode of transportation, diet, and rubbish production; all influence greenhouse gas excretion. Clothing, electronics, and the usage of plastic are also on the rise. Private dwellings considerably help generate global emissions of carbon dioxide (CO_2). The way of life has a huge influence on the rest of the world. The wealthiest face the greatest burden: the richest one percent of the population contributes more to greenhouse gas excretion than the poorest 50% combined.

The Sun is the principal source of energy that influences the Earth's temperature. Solar energy flows through space, with just a small portion reaching the Earth's surface, while the remainder is reflected into space or held by the atmosphere. Notably, the Sun's energy output fluctuates throughout time, altering the dynamics of the climate (Naz et al., 2022).

The Milankovitch cycles, which include eccentricity, axial tilt, and precession, all contribute to changes in the Earth's orbit around the Sun. These cycles interact to control the solar heat entering the Earth's surface, influencing climatic trends such as ice ages over tens of thousands to hundreds of thousands of millennia. Ocean currents play a critical role in global heat distribution. Changes in ocean circulation caused by changes in sea surface temperature can result in shifts in warm and cold-water dispersion, which can have a substantial impact on regional climates. Because the seas operate as massive heat stores, even modest changes in circulation have a significant influence on world temperatures. Elevated sea surface temperatures, for example, might lead to increased atmospheric water vapor, potentially amplifying greenhouse gas emissions (Cheng et al., 2022). The manufacture of plastics from fossil fuels is a significant source of emissions.

Approximately 40% of worldwide plastics are used as packaging, and restricted plastic recycling exacerbates the climatic effect. Waste management practices, such as burning or disposal, add to emissions, making the plastic waste issue more important for environmental considerations than it may appear at first. The Intergovernmental Panel on Climate Change has cautioned that permitting global temperatures to increase by more than 2° Celsius (the Paris Agreement's final limit) might have disastrous repercussions. While scientists currently believe that reducing or stopping emissions can halt climate warming, tipping points complicate issues. A climatic tipping point occurs when tiny changes accumulate to become substantial enough to induce larger, more severe impacts. According to a Greenpeace investigation, scientists suggest:

- Greenland and Antarctica's polar ice sheets are crumbling - While slowly melting, the final collapse of the Greenland ice sheet may be unchangeable, and sea levels throughout the world may rise by up to seven meters, swallowing cities like Miami and Mumbai. Scientists are particularly concerned about the possibility of the West Antarctic ice sheet collapsing, which would have severe consequences for the world's coasts.
- Melting Arctic Permafrost - As temperatures rise, Arctic permafrost melts, exposing greenhouse gases such as methane trapped beneath it.
- Climate change is changing weather patterns: meltwater from Greenland's ice sheet enters the Atlantic, stalling the Gulf Stream and causing extremely cold snaps and colder winters in the USA and Europe. The oceans are also collecting heat from greenhouse gas emissions, endangering species and livelihoods worldwide, including the amplification of El Nio and La Nia weather events in the Pacific.
- The Amazon rainforest is being destroyed and burned to make space for agriculture, and it currently emits more CO_2 per year than it absorbs. If it dries out, billions more kilos of CO_2 will be released

into the sky, affecting rainfall patterns across South America and worldwide climate trends.

There is strong evidence that manmade activities like the use of fossil fuels and deforestation have had a significant role in the observed climate variations over the last century. Most importantly, it is vital to understand that human actions impact the environmental process, and hence efforts should be made to reduce greenhouse gas emissions. The ability to tolerate the negative consequences of climate change on topics such as environmentalism and resource conservation is crucial for the future of the planet.

Climate Change and Sustainable Development

In an increasingly complicated and fast-changing world, climate change has become one of the most important concerns. Climate change has ramifications for health, welfare, the environment, and the economy, in addition to the environment. It is impossible to ignore the influence of this complex crossroads on the pursuit of sustainable development goals. Climate change endangers biodiversity, destroys ecosystems, and wreaks havoc on the economy. Such challenges need quick response, with an emphasis on developing adaptable and long-term plans capable of dealing with a changing environment (Nerini et al., 2019).

Climate change will harm impoverished nations since their populations are the most vulnerable and unlikely to adapt quickly. Agriculture, human living conditions, health, biodiversity, and patterns of migration for animals will all be impacted. Climate change fragility and its implications for long-term development strategies are especially troubling for poor nations. Climate change legislation and the focus on equitable growth in developing countries have certain synergies, such as conserving electricity, green energy, delivery, and sustainable land use regulation. Local and national measures addressing transportation congestion, air quality, accessibility to electricity, and energy source diversification may assist in reducing greenhouse gas emissions (Moser & Baulcomb, 2020; Ghosh et al., 2020). The distributional repercussions of such programs are critical to their long-term viability and must be considered from the beginning. As a result, future prevention and mitigation agreements under the pact must take into consideration poor countries' various situations in terms of economic development, sensitivities to climate change, and capacity to adapt or reduce.

Recognizing how climate change may affect other development goals might be the first step in impoverished countries adopting economic options and integrated, regulatory mitigation of climate change. Possibilities for developing countries to collaborate with regional economic organizations to develop integrated approaches and capitalize on synergies between protecting the environment and other programs, such as those aimed at preventing degradation and maintaining habitat (Lam et al., 2020).

Climate change, with its fluctuations in temperature, precipitation, and appropriate circumstances, poses substantial threats to the diversity of life on Earth, endangering a wide range of creatures, habitats, and ecosystems. Such changes may result in habitat loss, displacement in the case of distribution, and death for the most susceptible species. These repeated ecological disruptions have ramifications for ecosystem services as well as human settlements that rely on natural balances. The strategy of sustainable development seeks to balance numerous criteria while appreciating the intricacies of ecological, social, and economic factors. Such illogical trends are exemplified by risky lending behaviours and an overreliance on non-renewable resources, both of which can create multiple economic meltdowns and significant alterations in weather patterns all over the world. Because of the continuing unsustainable patterns of development, these consequences are becoming more widespread and severe. As a result, the urgency of addressing these concerns and promoting sustainable development solutions becomes evident (Singh, 2022). Contrary to current IPCC research, the path of technological and socioeconomic development may have a greater impact on climate stabilization than climate policy itself. Setting climate objectives as part of a sustainable development strategy can result in significant carbon reductions while also garnering the attention of businesses, governments, and civil society.

Collaboration between the commercial, public, non-governmental, and scientific sectors is critical for the implementation of sustainable urban solutions. Considering these are inherently moral and political issues, public participation in establishing future growth trajectories and policy compromises is critical. Adopting a regional plan that includes cross-sector partnerships can result in the deployment of sustainable services and technologies, which contribute to local and global sustainability. The CIRS project in British Columbia exemplifies the use of sustainable building and urban development strategies, which have the potential for broader and deeper mitigation as well as adaptation benefits than climate policies alone. Internationally, sustainable development principles may be applied to replicate successful models in other cities and places. Choosing a sustainable strategy gives an economically and politically viable strategic framework for achieving climate change goals (Soergel et al., 2021).

The study emphasizes the objective of long-term development by interconnecting climate resistance, climate change, and adaptation. This interconnectedness enables the creation of reciprocal benefits and innovative methods to achieve a sustainable future. Climate resilience pathways begin with the adoption of a master plan that incorporates adaptation and mitigation actions to reduce anthropogenic interference in warming temperatures and accomplish long-term development goals. Strategic strategies based on scientific research can contribute to climate mitigation, while sufficient risk assessments are incorporated into long-term development adaptation strategies. Climate change management is always necessary for climate resilience improvement (Singh et al., 2022). The link between equitable growth and global warming is that climate change is a key hindrance to achieving sustainable development and addressing climate change is critical to protecting the world's ecosystem.

Climate change has been identified as the most significant hurdle to achieving sustainable development since it weakens national economies and human lives. The 2030 Programme of Action for Sustainable Development highlights the aim of nations that are developing and developed to conserve the environment. The author has highlighted in the study that weather patterns are shifting, and temperatures are going up, emphasizing the need to preserve lives and livelihoods via increased awareness and readily available solutions. Achieving environmentally conscious economic development via consumption and production will enable climate security while also addressing other environmental issues. Climate change is more likely to hurt vulnerable states, emphasizing the importance of understanding the consequences and developing plans to deal with them. ASEAN countries have financial, technological, and capacity-building hurdles in lowering emissions, emphasizing the need for technological innovation, regulatory safeguarding, and appropriate policies in climate change mitigation. For developing a more sustainable and fair society with zero emissions, a realistic strategy such as sustainomics, as well as cooperation from all countries, is advised (Kopnina, 2020).

The Impact of Climate Change on Well-Being

Climate change is a severe hazard to human health because it impacts the entire physical environment as well as related human and natural systems. This impact extends across social, economic, and healthcare dimensions, functioning as a risk multiplier that can undermine or reverse decades of health progress. The intensification and increasing frequency of weather and climate-related phenomena are highlighted by the escalation of storms, soaring conditions, floods, droughts, and wildfires caused by rising temperatures. These environmental difficulties have both direct and indirect health consequences, raising concerns about mortality rates, noncommunicable illnesses, the onset and spread of transmissible illnesses, and general health crises.

In addition, climate change affects healthcare personnel and infrastructure, posing challenges to achieving universal health care (UHC). Climate shocks and growing pressures, such as modifications to temperatures and precipitation patterns, droughts, floods, and higher sea levels, impair both environmental and social variables that influence physical and mental health. Climate change affects many areas of health, including access to pure air, water, and soil, in addition to the long-term viability of agricultural systems and lifestyles (Cianconi et al., 2020). The effect of climate change has a serious influence on people's health and well-being, resulting in injuries and deaths from catastrophic weather conditions such as heatwaves, wildfires, and floods. Allergic and pollutant impacts can exacerbate respiratory disorders, leading to increased hospitalizations and mortality.

Climate change reduces agricultural productivity, resulting in food scarcity and famine. The global warming phenomenon has the potential to influence the incidence and geographic distribution of infectious illnesses such as malaria, dengue fever, and Lyme disease. Droughts, rising ocean levels, and extreme weather all contribute to decreased mental health and social capital as an outcome of climate-related calamities. This causes increased stress, anxiety, and social disturbance (Ebi et al., 2021). Climate change influences human health, either directly or indirectly, with rising temperatures and poor air quality harming the heart and aggravating cardiovascular disease. Climate change-induced temperature rises can directly influence human health by raising the risk of cardiovascular disease. Air pollution, which is partly impacted by climate change, can indirectly affect the heart and aggravate cardiovascular disease. Higher temperatures combined with poor air quality can put additional strain on the cardiovascular system, eventually leading to heart attacks, strokes, and other cardiovascular issues (Vicedo-Cabrera, 2021).

According to the World Health Report, climate change is exacerbating heatwaves, wildfires, floods, tropical storms, and hurricanes, and their size, frequency, and severity are increasing. About 3.6 billion individuals live in climate-vulnerable places today. Climate change is expected to kill a total of 250,000 individuals every year between 2030 and 2050, primarily owing to malnutrition, stunted development, diarrhoea, and heat exhaustion. Direct health-care expenses are expected to be between $2 and $4 billion per year by 2030 (including spending in health-determination areas such as agriculture, water, and sewage). Areas with minimal health infrastructure, mainly in poor countries, will be the least prepared to plan for and respond to an emergency without outside assistance. Reducing greenhouse gas emissions through improved transportation, food choices, and energy use can have significant health benefits, most notably improved air quality (US EAP, 2023). Reduced sleep quality, as well as a rise in heat strokes and pregnancy problems. Significant effects on cardiopulmonary health, such as a greater chance of heart attacks and symptoms of asthma and a condition called chronic obstructive pulmonary disease. Warmer temperatures have resulted in a prolonged pollination season, which has worsened allergy-related rhinitis and asthma. Temperature rises have lengthened the propagation season of infectious illnesses, particularly water-borne infections transmitted by vectors. As an outcome of rising temperatures, rainfall, and flooding induced by climate change, infectious diseases have also begun to spread to new regions throughout the world.

Climate change's mental health consequences, such as melancholy and anxiety, are growing. Flooding and storms can induce acute stress as well as chronic post-traumatic stress disorder in some circumstances (Pettitt et al., 2022). Climate risks are growing quicker and becoming more severe sooner than projected, according to the findings of the IPCC's Sixth Assessment Report (AR6), posing increasing adaptation challenges as global warming continues. Notably, 3.6 billion people now live in locations that are particularly sensitive to climate change consequences. Despite their little impact on global emissions, low-income nations and tiny island states (SIDS) suffer the brunt of the health repercussions. During the previous decade, susceptible areas experienced a staggering 15-fold increase in mortality from severe storms when compared to less risky locations. Climate change has a variety of effects on health, like increased deaths and illnesses caused by severe weather such as sweltering hurricanes and floods, disruptions to food systems, a surge in zoonotic infections and illnesses transmitted through food, water, and carriers, and increased psychological challenges.

The changing climate also has an impact on several social aspects related to health, including employment, equitable treatment, access to medical treatment, and interpersonal connections. Women, children, ethnic minorities, marginalized groups, migrants or displaced individuals, the elderly, and those with pre-existing medical issues are particularly vulnerable to climate-related health concerns (Arias et al., 2021). Water shortages are one of the visible repercussions of climate change on health. (Droughts can be induced by climate change, resulting in water shortages and poor sanitation and hygiene due to a lack of water and pollution.), pollution-related issues with health (Climate change can cause subjected to heat stagnant air, which can result in dangerous levels of ozone and increased exposure to affecting UV radiation, expanding the risk of cancer of the skin, cataracts of the eyes, and immune-related problems), biodiversity threats (Climate change has ended up in a record-high rise in the rate of species extinction, halting nature's equilibrium and leading to conservation actions), floods, and cyclones (Hong et al., 2019).

Climate change causes rising sea levels, greater temperatures, fluctuating precipitation, and a rise in the intensity and frequency of some extreme weather phenomena. The consequences are harmful to health as they affect the food consumed, the liquids ingested, the air breathed, and the weather experienced. Individual attributes such as habit, age, gender, and economic position, as well as public health and safety agencies' ability to respond to or educate about these growing risks, will all influence the severity of these health issues. The consequences will differ depending on where a person lives, their sensitivity to health problems, their involvement in the effects of climate change, and how well they and other people communicate (Ma et al., 2022). Rapid environmental changes are having an impact on a variety of businesses, including air quality, humidity, and weather patterns, as well as food security and diseases. According to estimates, ambient air pollution caused 4% of deaths in South Africa in 2015. Despite significant regional diversity in the warming signal, most of South African indices rose in the late twentieth century (Chersich et al., 2018).

Environmental change's near-to-medium-term health implications will be primarily defined by population consciousness, the ability to withstand the present rate of climate change, and the effectiveness and speed of adaptability initiatives. Long-term outcomes will increasingly be determined by the size of inventive efforts taken today to decrease emissions and avert potentially irreversible calamities. Although no one is impervious to these dangers, those who face the brunt of the health implications are frequently those who give the least to the forces causing climate change and have the least ability to protect themselves and their children. People in poverty-stricken and destitute nations and communities bear a disproportionate share of the burden. Managing the health implications of climate change highlights the need for equity: those principally responsible for emissions should incur the highest costs in terms of reduction and adaptation, with a focus on fostering health equality and prioritizing disadvantaged populations (Manning & Clayton, 2018; Lawrance et al., 2021).

Initiatives Taken by Global Countries to Mitigate Climate Change

The changing climate is once again seen as a distant or hypothetical worry. Another international study found that a median of 51% of individuals believe climate change is currently causing harm, with an additional 28% expecting serious damage in the coming years. More than half of respondents in 39 of the 40 nations tested expressed concern about potential harm from climate change throughout their lives (the United Kingdom being an exception). A median of 40% of countries are highly concerned. With the Paris climate summit approaching, people are finally agreeing on what must be done to stop global warming. More than half of people in 39 countries (excluding Pakistan) believe that their country should sign a worldwide accord to reduce emissions. In comparison to nations such as China and the United States, where climate change worries are less severe, a huge majority support an international deal to decrease greenhouse gas emissions. Respondents, however, point out that tackling climate change requires far more than simply legal reforms; it necessitates significant changes in how people live. 67% of people worldwide believe that severe lifestyle adjustments are required to adapt to climate change. Only 22% believe that technology alone will suffice in the absence of significant changes. Most importantly, even in the land of technological progress, the United States, as many as 66% believe that genuine changes to their everyday lives are required. Most countries agree that wealthier countries should bear the lion's share of the burden of dealing with global warming. The vast majority of individuals feel that wealthier countries, such as the United States, Japan, and Germany, ought to help more than developing countries considering that they have produced virtually all of the world's greenhouse emissions to date." Some 38% approve of this statement, indicating that there is some agreement on the need for stronger efforts from formerly high-emitting countries.

Developing nations ought to do just as well as rich countries since they will be generating most of the emissions of greenhouse gases worldwide in the future." Six nations, with 50% or higher support, believe rising countries should do the same. Half of Americans agree, with 40% believing wealthier nations should do more. Overall, there is no relationship between a society's wealth and its residents' attitudes on this issue. In December 2015, 194 countries, including the European Union, signed the Treaty of Paris. This is the most fundamental international agreement on climate change. When world leaders ratified the agreement, they promised to keep global warming 'far below 2°C,' with a 1.5°C target. They also intend to boost global emissions as soon as feasible to reach a balance of human and natural-world emissions in the second half of the century, terminating in "net zero emissions." The industrialized world has also promised developing countries financial support to address climate change. Signatory nations have agreed to publish and implement voluntary commitments outlining their plans to reduce emissions and combat climate change. This relates to the 'global stocktake,' which will begin in 2023 and will be repeated every five years after that. Countries are legally required to submit their pledges under the Paris Agreement. The acronym for them is NDCs (Nationally Determined Contributions).

An international organisation monitors commitments and assesses the progress towards the goals of the agreement. This is the 'global supplies,' which will be done for the first time in 2023 and then each five-year period after that. Countries are legally required to submit their pledges under the Paris Accord. National norms and standards, on the other hand, must ensure and enforce the fulfilment of promises. By regularly monitoring progress on agreed-upon global goals, the global product process strategy pushes governments to raise their goals over time. This technique is one of the reasons why international relations experts anticipate that the Paris Agreement will be implemented. This strategy is one of the key reasons why international relations specialists believe the Paris Accord was a significant step forward in global climate adaptation and mitigation activities. It avoids the difficult problem of how to get a worldwide agreement on legally binding objectives for reducing greenhouse gas emissions by relying on individual commitments and transparent review processes. The goal of this plan is to prepare the way for a more feasible global climate change policy (Al-Ghussain, 2019).

International relations specialists consider the Paris Agreement an important leap forward in world climate change action due to its new method. It avoids the difficulties of forming a global convention on legally binding targets for reducing the emission of greenhouse gases by relying on individual pledges and open review processes. This novel technique is expected to pave the way for a more viable worldwide response to climate change. The United Nations Secretary-General is planning a Climate Ambition Summit, which will feature strong leadership from governments, companies, finance, local governments, and civil society (Michaelowa, 2019).

The Kyoto Protocol, which was signed on December 11, 1997, and subsequently adopted on February 16, 2005, established the United Nations General Convention on Climate Change, which now has 192 signatories. It requires developed and emerging nations to control and decrease greenhouse gas emissions based on mutually agreed-upon targets. In essence, the Convention compels these nations to develop and implement mitigation measures, as well as to report on their progress regularly. According to the objectives of the Convention, the Kyoto Protocol adopts an annex-based structure, uniting wealthier nations and assigning them greater duties under the banner of "common but distinct responsibilities and respective abilities" (Zakerinia & Lin Lawell, 2019).

The Montreal Protocol, which was established in 1987, is an international agreement to protect the ozone layer in the upper atmosphere. Its primary goal is to slowly phase out the production and use of ozone-depleting substances (ODS), which can be found in various products such as air conditioning, refrigeration, firefighters, and aerosols, presenting a threat to the integrity of the ozone layer. The Montreal Protocol, a creative and effective convention, is the first treaty that has been unconditionally supported by all countries. It has stimulated global investments in ground-breaking technology, many of which have been invented by American firms, effectively directing the ozone layer back to health (Barnes et al., 2021).

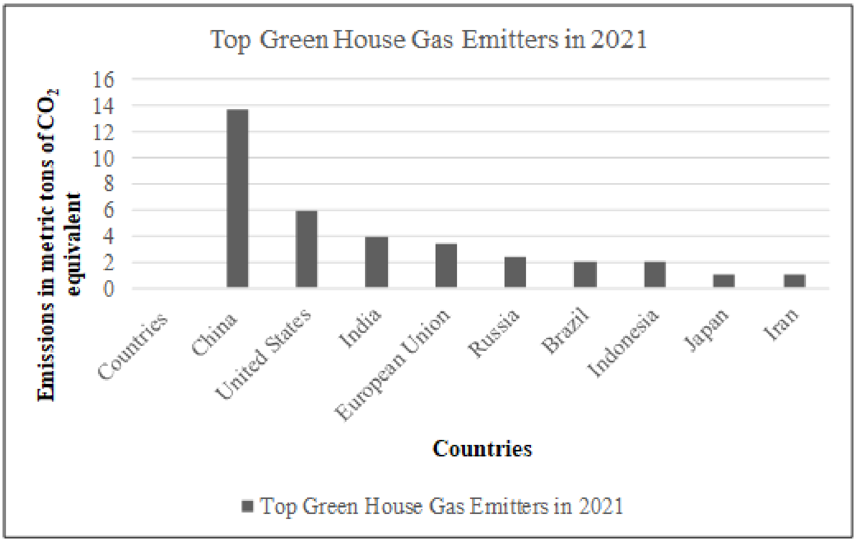
The ozone layer is essential for shielding humans from hazardous UV light, and its depletion has been linked to increased risks of skin cancer, cataracts, lower agricultural productivity, and changes in the ecology of the oceans. The United States has been a pathfinder, enacting significant domestic steps to phase out ODS such as CFCs (chlorofluorocarbons) and halons after signing the Montreal Protocol in 1988 and ratifying all five subsequent revisions. This tiering of ODS helped to avert a forecasted 2.5°C warming by the end of the era while also shielding humans from damaging UV rays.

In the words of the US, according to the Environmental Protection Agency (EPA), full implementation of the Montreal Convention could save Americans living between 1890 and 2100 from 443 million cases of fatal skin cancer, 2.3 million skin cancer-related fatal accidents, and over 63 million cataract cases, among other global benefits. If the Montreal Protocol is rigorously implemented, the Technical Assessment Panel expects near-complete ozone layer repair by the second decade of the twenty-first century (Goyal et al., 2019).

The Vienna Convention, established in 1985, is a legally binding pact in which states pledge to joint ozone research, scientific tests, information exchange, and the implementation of "appropriate measures" to reduce ozone-depleting activities. While its rules lack definite controls on ozone-depleting chemicals, nations considered a proposed protocol with specific substance-related targets during Vienna Convention discussions. However, no agreement was achieved. Under the United Nations Environment Programme, regional sea agreements developed a structure requiring nations to approve a framework convention and at least one rule. In contrast, the Vienna Convention moved forward on its own, becoming open for signing in March 1985 (Honegger et al., 2021).

Surprisingly, the Montreal Protocol was reached within nine months after official discussions began in December 1986, and it went into force on January 1, 1989. Before joining the Montreal Protocol, a state must first join the Vienna Convention. These accords, which established a pattern for UNEP, depict the structure of a contract that is followed by one or more protocols. The importance resides in tackling a long-term issue when the cause is current, but the consequences appear in future generations. Because the repercussions had not yet materialized, decisions were made based on the likelihood of damage. The agreements' adaptability is critical as scientific understanding improves. Recognizing that no one country or group could address the issue of ozone depletion alone, global cooperation was required.

Wealthier countries, forward-thinking nations claim, have traditionally been the most significant contributors to greenhouse gas emissions, arguing that their broad economic expansion has been mostly unregulated. They argue that these wealthy countries should bear a greater portion of the burden of tackling the climate catastrophe. Historically, the United States has been the leading emitter of greenhouse gases, closely matched by the European Union (EU).



Source: https://www.cfr.org/backgrounder/paris-global-climate-change-agreements#:~:text=In%20the%20context%20of%20this,countries%20to%20set%20emissions%20targets.

Figure 2. Top Green House Gas Emitters in 2021.

Figure 2depicts the top greenhouse gas emitters in 2021. The landscape has changed, with China, India, and the USA now being among the top annual emitters. Developed countries have argued that more needs to be done immediately to combat climate change. On an annual basis, countries must assess their progress in implementing the agreement through a system known as the global stocktake. The first of these reports, issued in September 2023, warned nations that "the entire world was not on track to become familiar with the Paris Accord's long-term goals." "Still, states have achieved significant progress throughout yearly UN climate conferences, including the landmark pledge to establish the Loss and Damage Fund following COP27 in Sharm el-Sheikh, Egypt. The fund intends to alleviate climate change inequality by giving financial help to poorer nations, which are generally the least responsible for global emissions while being the most vulnerable to climatic calamities. At COP28, governments agreed that the fund would first be held at the World Bank, with numerous affluent countries, including the

United States, Japan, the United Kingdom, and EU members, committing a total of $430 million. The UAE also offered $100 million, putting extra pressure on other high-emitting countries like China and Saudi Arabia to raise their contributions to climate change funds. At COP26, the United States and the European Union announced the Global Methane Pledge, which seeks to reduce methane emissions by 30% between 2020 and 2030. At COP28, oil firms pledged to reduce methane emissions from wells and drilling by more than 80% by the end of the decade, with worldwide monitoring measures to keep businesses responsible. Meanwhile, the United States pledged to cut methane emissions from the oil and gas industry by approximately 80% over the following fifteen years. There have recently been global initiatives to reduce methane emissions, which account for more than half of man-made warming today due to their increased potency and heat-trapping capabilities in the initial few decades after release (Setzer et al., 2022).

Result

The link between climate change and its influence on sustainable development and well-being is depicted in this narrative study. Climate change has a variety of consequences for global sustainable development. Rising temperatures, extreme weather events, and ecological imbalances all cause challenges in numerous sectors. Sustainable Development is an essential subject for global development, yet many challenges, such as climate-related dangers, are becoming more severe. Many efforts have been made to secure the supply of food and other necessities. Adapting multiple tactics to be congruent is required, and several governments have initiated worldwide initiatives. According to studies, it is critical to preserve climate resilience while pursuing sustainable development.

Discussion

Among the mounting concerns, the research focuses on the many methods of combating climate change and emphasizes the necessity of sustainable development. Action plans exhibited at both the global and local levels are critical (Al-Ghussain, 2019). Recent research has identified the strategies that are required on a global and individual level. The methods that have been considered and executed include, for example, investment in renewable energies and other initiatives to tackle climate change and its effects (Kumar, 2021; Fawzy et al., 2020). Nations are implementing various programs, ranging from renewable energy to ecological sustainability, displaying a collaborative approach to combating climate change. The link between climate change, sustainable development, and well-being raises the stakes for a comprehensive and coordinated strategy (Honegger et al., 2021; Ma et al., 2022).

Conclusion

Climate change's environmental consequences are becoming more apparent. Researchers attribute a large portion of this transformation to human activity during the last several decades. Controlling human effects is critical for mitigating climate change and maintaining a healthy ecosystem on Earth. This will need a coordinated effort to cut carbon emissions, implement sustainable practices, and prioritize environmental protection. The preservation of the planet's climate is a shared obligation, and collaboration is required to ensure an environmentally friendly future for our earth and its inhabitants. Climate action, as defined in the Paris Agreement, is a critical first step towards tackling the global catastrophe. Climate change, as a potent cause of cascading effects, fundamentally affects the space for sustainable development and prosperity. It disrupts food supplies, harms health indicators, weakens economic institutions, and shatters societal relationships. Despite this, there is a potential that things will change beyond recognition. Accepting creative approaches to addressing climate change, global collaboration, and creating a fair and inclusive future for everyone. The application of clean development strategies will assist us in connecting economic growth with environmental protection. International cooperation demonstrates that nations are pooling facilities to alleviate the consequences of climate change. Furthermore, emphasizing equality and inclusion ensures that marginalized communities are not excluded from transitioning to a habitable world, promoting social peace and collectivism. Adopting a new viewpoint is vitally crucial when it comes to avoiding the rippling effects of environmental changes. This necessitates a global knowledge of environmental protection, a willingness to engage in innovation, and tenacity in creating a sustainable future in which cohabitation with mankind is not only conceivable but inherent. Equipped to create a more sustainable and fair society for people of all ages will be possible if the now and the foreseeable future in the problems posed by global warming are recognized.

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Chapter 2

Agriculture, Food Security and Climate Change: A Case Study of Zambia

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Abstract

This paper tries to examine the impact on agricultural production index and variability of food supply per capita per day in Zambia during 1990-2021 by the determinants of temperature change, emissions intensity from rice, emissions intensity from cereals, emissions per value of agricultural production, emissions per area of agricultural land, total CO_2 emissions, value added in agriculture and food price inflation, respectively, to focus on the association between climate change indicators and food security. The paper observed that the cointegration test constitutes four cointegrating equations, while the VECM stated that in the long run, the index of agricultural production in Zambia is positively integrated with emissions per value of agricultural production, negatively integrated with emissions per area of agricultural land and total CO_2 emissions significantly at the 5% level. But this long-term relationship is divergent.

The temperature change exhibits a positive cointegration with the emissions per value of agricultural production, a significant relationship at the 5% level.

Using multiple regression analysis, it was found that the amount of food available per person per day in Zambia has a positive relationship with the value added in agriculture and the rate of food price inflation. On the other hand, it has a negative relationship with the amount of CO_2

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released from rice, cereals, agricultural production, and total emissions from 1990 to 2021.
The relationships are stable without the heteroscedasticity problem, while determinants face asymmetric shocks.

Keywords: agricultural production, food price inflation, food security, emissions, food supply, cointegration, long run causality, short run causality, vector error correction

JEL Classification Codes: C22, F53, F55, I32, O13, Q10, Q18, Q51, Q54, Q58

Introduction

An increase in temperatures generally intensifies droughts, floods, and greater weather variability damages huge crops and livestock (Ramasamy, 2011). Climate change caused huge yield losses in West Africa, which were caused by increased mean temperatures, while the potential moisture of land conditions as well as incremental CO_2 concentrations can regulate this effect (Sultan & Gaetani, 2016). The IPCC explained that the impacts of climate change on the food security of the world population are four folds: [i] loss of rural livelihoods and income; [ii] loss of marine and coastal ecosystems and livelihoods; [iii] loss of terrestrial and inland waterecosystemsand livelihoods; and [iv] food insecurity and breakdown of food systems. Sova, Flowers and Man (2019) asserted the same conclusion that climate change created a negative impact on food production via crop yield damage because it was observed that every 1°C rise in mean temperature led to a 10 percent decline in crop yields.

Agriculture contributes the most non-CO_2 emissions, accounting for half of global emissions; livestock contributes 15% of CH_4 emissions; and soil emits the second largest GHG emissions.

The rise in climate variability enhanced frequency and intensity of extreme events and retarded ongoing changes will surely induce stability in food supply, access, and utilisation.

The differences in seasonal variation, the rise in ecosystem productivity variance, increased supply risks, and decreased supply predictability must affect the stability of the food supply, all of which have influenced the cost of the supply chain and retail prices (FAO, 2015; Bekele et al., 2022). The number of undernourished people in 30 vulnerable countries to climate change was 398 million in 1990, which increased to 422 million in 2016, a clear increase of 6% (Watts et al., 2018). According to the World Health Organization (2014), the number of stunted children will rise from 7.5 million in 2030 to 10.1 million in 2050 because of climate change without adaptation. Additionally, the number of undernourished children under 5 years old is expected to increase by 4.8 million in 2050, contributing to the rise in global hunger due to climate change shock (Sanchez-Martinez & Berry, 2018).

Schmidhuber and Tubiello (2007) examined that the number of undernourished people will increase by 5-26% in 2080 due to the adverse impact of climate change, or the number will be 5–10 million (using B1 SRES) without climate change and 120–170 million (A2 SRES) in GCM climate projection. Using one GCM scenario, some projections revealed that by 2080, there will be a 5% reduction (by the B1 model), or -10 million to -30 million (by the A2 model), and a marginal increase of 13-26%, or 10–30 million people (using the A1 model). Thamaga-Chitja and Tamako (2017) recommended that a range of climate risks, such as rapid and uncertain changes in rainfall and temperature, have confronted Sub-Saharan Africa, reduced food production and generally increasing food price inflation and food insecurity.

The Farm model study from a survey of 277 households in 2018 as a baseline scenario to forecast for 2050 in dry and wet climates through the simulation method concludes that future livelihoods in rural Zambia show inverse relation with climate change. In the dry climate scenario, the rate of wealth reduction among the farmers was 27% as against 19% in wet climate scenario under the baseline factor endowment, where households can sustain their livelihoods through adaptation processes at the farm level (Stadtbäumer, Ruesink & Gronau, 2022).

In seven locations in Zambia, drought, floods, high temperatures, low rainfall, and other extreme climate events affect negatively on natural, physical, financial, human resources, households' livelihoods, food security, and human health, with high damages to small farmers (Riché, 2007). In Zambia, climate change is supposed to catapult the poverty gap, increase incidents of crop failure, change the length of the growing season, and lead to a decline in water availability by 13% within 2050 (Ngoma et al., 2019; Vergage et al., 2018). IFRC (2019) reported that 2.3 million people in Zambia had been suffering from severe food insecurity as a result of drought and communities' declining resilience. It is projected that climate change will lead to an increase in average temperatures, a decline in rainfall, affect agriculture in Zambia (lowering maize yield, staple crops, and farmer income), and hamper road infrastructure and energy, especially in southern and western Zambia (Detelinova et al., 2023).

The paper contains two sections. In section I, the agricultural production index of Zambia from 1970 to 2021 is influenced by the determinants of indicators of emissions such as temperature change, emissions intensity from rice, emissions intensity from cereals, emissions per value of agricultural production, emissions per area of agricultural land, and total CO_2 emissions, which have been analysed through trends, cointegration, and a vector error correction model. In section II, the key indicators of food security, i.e., the variability of per capita food supply per day in Zambia from 1990 to 2021, were influenced by the determinants of emissions and chief macro variables such as value added in agriculture, emission intensity from rice, emission intensity from cereals, emission per value of agricultural production, food price inflation rate and total CO_2 emission, which were analysed through regression analysis.

Important Research

Agricultural production, supply chain, and pricing are usually affected by climate change where in tropical regions production is likely to decline (Hertel, Burke & Lobell, 2010; Hertel & Lobell, 2014), while climate change generally influencesthe food security and livelihood ofpeople who are related to agricultural production and value chains (World Health Organization, 2020).

Climate change produces floods, snowfalls, and storms that generally damage crops, roads, bridges, transportation, and public distribution systems such as the food supply chain, as well as disrupting physical access to markets (Koetse & Rietveld, 2009; Nissen & Ulbrich, 2017). Floods, droughts, and storms caused 25% of the economic losses and damage to the agricultural sectors of the 48 developing countries during 2003–2013, according to a study by FAO (2015). It asserted that most of the dimensions of food security, like access, availability, utilisation and stability, might be affected by climate change. That's why the net impact on food security depends on the vulnerabilities of the affected system.

In India, 14% of people are undernourished. In fact, it was examined that food insecurity is higher in rural areas than in urban areas, and the empirical findings showed that 13.2% of the rural population consumes less than 1890 kilocalories per capita per day, which is not always secured because of shortfall in food production, climate shocks, low income, and a huge debt burden. Researchers examined the full relationship between rural food insecurity in India and the food productions of marginal and small land holders (MSSRF, 2008; World Health Organization, 2020; Bhuyan, Sahoo & Suar, 2020; Kumar, Padhee & Kumar, 2020). Even in rural areas, crop losses are affected inversely by food availability, apart from structural market behaviours (IPCC, 2014).

Gregory et al. (1999) concluded that global warming decreased wheat and crop production while the yield of rice declined by 5% per degree Celsius above 32°C. Moreover, Gregory, Ingram and Brklacich (2005) verified and concluded that climate change affects crop production, food price inflation, food markets, and the supply chain system, although the dimensions of the changes vary from region to region and from country to country because of the differential climatic environment. As a result, the determinants of food security vary consequently.

Fischer et al. (2005) applied the global circulation model and assessed for 2080 that Canada, Northern Europe, and Russia have enabled increased agricultural production despite the bad effects of climate change, but the USA, eastern Brazil, and western Australia were not able to enhance output.

Nelson et al. (2014) discovered that climate change has distant effects on the food security of those experiencing the initial shock, particularly through increases in food prices and volatility. However, changes in temperature and precipitation may trigger global food price increases until 2050, without considering the influence of CO_2.

The IPCC (2014) noted that an increase in droughts disproportionately impacts impoverished households and women, particularly in regions with high levels of food insecurity and inequality. It also severely harms indigenous people, who heavily rely on the environment and its biodiversity for their sustenance, particularly those residing in mountainous and hilly regions, the Pacific islands, coastal and other low-lying areas, and the Arctic regions. Food utilisation is one of the fundamental dimensions of food security. It calls for the need for "available and accessible food to fulfil the cultural, religious, health, and nutrition needs of the population" (Biehl et al., 2017Food should be safe to consume, prepared appropriately, and have adequate nutritional value.

Nelson et al. (2016) came to the conclusion that, despite the significant implications of climate change, which include non-productive components of the food system, recent research generally concentrates on agricultural food production as one of the fundamental determinants of food security, neglecting other determinants in the national and international impacts of climate change and the interest in health research within a broader framework. FAO (2018) found out a link between food insecurity and malnutrition. In Africa, 29.8% are severely food insecure, as compared with 6.9% in Asia, 9.8% in Latin America, and 1.4% in Europe and North America. Food insecurity, particularly among adult females in high-income countries, is associated with obesity, as poverty limits their access to nutrition. FAO (2018) assumed that climate change can negatively affect the four pillars of food security, such as availability, access, utilisation and stability, and their interactions.

The IPCC (2019) concluded that projected future climate change must affect food security. Food security and climate change have strong gender and equity dimensions, which are significantly higher. Since agriculture and the food system are both interlinked with the response to global climate change, high GHG emissions catapult food damage and waste through reduction in agricultural production. Briefly, increasing numbers of malnourished people and rising prices due to land-based mitigation will threaten food security. Ani, Anyika and Mutambara (2022) found that climate change has affected food security in Nigeria negatively, which instantly created continuous armed confrontations over natural resources, for which human security in the country during 2018–2019 was vehemently neglected.

Dasgupta and Robinson (2022) looked at how food insecurity and climate change changed over time using panel data from the FAO Food Insecurity Experience Scale (FIES) and climate data from ERA5-Land. The research observed that if the temperature rose by 1°C, severe global food insecurity enhanced by 1.4% in 2014 in comparison to 1.64% in 2019. Alternatively, a 1°C increase in temperature catapulted moderate to severe food insecurity by 1.58% in 2014, compared to 2.14% in 2019. Researchers discovered a heterogeneous impact of temperature anomalies on moderate-to-severe food insecurity. The probability of moderate to severe food insecurity in the world has risen from 19.3% in 2014 to 30.7% in 2019.

Objectives

The paper has emphasized two types of objectives through econometric models, namely [i] to examine cointegrating relationships among agricultural production index and the determinants of indicators of emissions such as temperature change, emissions intensity from rice, emissions intensity from cereals, emissions per value of agricultural production, emissions per area of agricultural land and total CO_2 emissions of Zambia from 1970 to 2021, [ii] to justify multiple regression relationships of variability of supply of food per capita per day among the value added in agriculture, emission intensity from rice, emission intensity from cereals, emission per value of agricultural production, food price inflation rate and total CO_2 emission of Zambia from 1970 to 2021. The paper focuses on the variability of food security in Zambia in relation to emissions and other macro variables during the specified period. Also, the paper scrutinised the linear, nonlinear trends, cycles, cyclical trends and stationarity of all variables.

Methodologies and Sources of Data

The linear trend line can be obtained from the simple semi-log linear regression model as expressed by:

$Log(y)=a+bt+u_i$ where y = dependent variable, t = time or independent variable, a and b are constants, u_i = random error.

The multiple regression model can be expressed as:

$$y = \alpha+\beta_i(x_i)+u_i$$

where y = dependent variable, x_i = independent variables for i=1,2, 3,…………n, β_i are the coefficients which are to be estimated and α is the constant and u_i = random errors. The stability test for CUSUM was done by using Brown, Durbin and Evans (1975) model.

Q-statistic of Ljung and Box (1978) can be found from the formula given below.

$$Q=T(T+2)\ \Sigma r^2_k/(T-k) \text{ where } k=1 \text{ to } s$$

The formula of the Autocorrelation Function (ACF) can be written as:

ACF=$\rho_s = a_1\rho_{s-1} + a_2\rho_{s-2}$ where s=1,2,3……………

And the formula of the Partial Autocorrelation Function (PACF) can be derived from the formula given below.

$\Phi_{ss} = (\rho_s - \Sigma\phi_{s-1,j}\rho_{s-j})/(1-\Sigma\phi_{s-1,j}\rho_j)$ where s=3,4,5, …., $\phi_{sj} = \phi_{s-1,j} - \phi_{ss}\phi_{s-1,s-j}$, j=1,2,3….s-1.

Hamilton (2018) regression filter equation can be written as:

$$x_t = \alpha + \beta_1 x_{t-8} + \beta_2 x_{t-9} + \beta_3 x_{t-10} + \beta_4 x_{t-11} + v_t$$

After regression, residuals v_t can be found out.

$$v_t = x_t - [\alpha + \beta_1 x_{t-8} + \beta_2 x_{t-9} + \beta_3 x_{t-10} + \beta_4 x_{t-11}]$$

The residuals v_t can be decomposed by applying STL (Seasonal -Trend decomposition using LOESS) method which will show the series of cycles, cyclical trend, seasonal variation, respectively of the series x_t which also follows random walk. Note that $v_{t+h} = x_{t+h} - x_t$ is the difference i.e., how the series changes over h periods. For h=8, the filter $1-L^h$ wipes out any cycle with frequencies exactly one year. Hamilton suggested for h=8 for business cycles and h=20 for studies in financial cycles. STL (Seasonal - Trend decomposition using LOESS) method is developed by Cleveland, Cleveland, McRae and Terpenning (1990).

Johansen (1988) cointegration test can be stated briefly as follows.

If x_t and y_t are non-stationary i.e., I (1), then there may be linear combination if $(\delta_1 x_t - \gamma_1 y_t) \sim I(0)$, or, the stationary residual ϵ exists in the regression of y and x. In the time series I (1) type, $x_{1,t}, x_{2,t}$……………$x_{k,t}$ there exists linear combination with a vector β such that

$\beta_1 x_{1,t} + \beta_2 x_{2,t} + \ldots\ldots\ldots\ldots + \beta_k x_{k,t} \sim I(0)$ where $\beta_j \neq 0$, j=1,2,3, …………. k

So that, x's are cointegrated to the order of C.I (1,1). Thus, OLS becomes,

$$x_{1,t} = \alpha + \beta_2 x_{2,t} + \beta_3 x_{3,k} + \dots\dots\dots\dots\dots\dots + \beta_k x_{m,k}$$

where p=m-k, p=stationary process, k=no of linear combination.

If k=0, p=m, the time series are not cointegrated. If 0<k<m, and 0<p<m, the variables are cointegrated. Moreover, if k=m, p=0, the variables are stationary where cointegration does not arise.

Now for testing of hypothesis,

In Trace statistic test, H_0: $k=k_0$ against H_1:$k>k_0$

If H_0 is rejected then there may at least one cointegrated equation.

In Max-Eigen statistic test, H_0:$k=k_0$ against H_1:$k=k_0+1$

Rejection of H_0 states that there exists at least one cointegrating equation.

In VAR model, the general var(p) model can be expressed as:

$$x_t = \mu + \phi D_t + \pi_p x_{t-p} + \pi_1 x_{t-1} + e_t$$

where t=1, 2, 3,………………. T

Obviously, VECM can be written as:

$$\Delta x_t = \mu + \phi D_t + \pi_p x_{t-p} + \tau_{p-1} \Delta x_{t-p+1} + \dots\dots\dots\dots\dots + \tau_1 \Delta x_{t-1} + \varepsilon_t$$

when t=1, 2, 3, …………T

And where $\tau_i = \pi_1 + \pi_2 + \dots\dots\dots\dots\dots\dots + \pi_{i-I}$

for all values of i=1, 2, 3, …………..p-1

In brief, the Wald (1943) test can be expressed as given below.

Assume Wald test statistic is defined as:

$$W = \frac{(\hat{\theta} - \theta_0)^2}{\mathrm{var}(\hat{\theta})} \text{ where } \theta = \text{parameter of the model,}$$

$\hat{\theta}$ = estimate of the parameter θ which has been obtained by Maximum Likelihood estimate and $\mathrm{var}(\hat{\theta})$ = variance of $\hat{\theta}$ respectively. If $\hat{\theta}$ is normally distributed which finally follows χ^2 distribution where probability value will be determined. This W is applied in generalised linear model. For testing of hypothesis,

$$H_0 : \theta = \theta_0 \text{ against } H_1 : \theta \neq \theta_0$$

If H_0 is not true, the value of W is zero. If the calculated value is greater than the hypothesised value, then the value of the test statistic will be large and H_0 will be rejected.

The data on agricultural production index during 1970-2021 (2014-16=100), temperature change in Celsius degree during 1970-2021, emissions intensity (CH_4 and N_2O) from rice and cereals during 1970-2021, emissions per value of agricultural production in kg/US$ from 1990 to 2021, emissions per area of agricultural land in ton/hectares from 1990-2021, value added in agriculture in million US$ from 1990-2021, food price inflation in per cent, variability of supply of food per capita per day in kilo calorie from 1990-2021 of Zambia were collected from FAO, and data on total CO_2 emissions in Kt from 1990 to 2021 of Zambia were collected from the World Bank.

Results and Observations

Section I: Index of Agricultural Production and Indicators of Emissions in Zambia

Trends

In Zambia, the index of agricultural production has been increasing at a rate of 3.39% per year significantly during 1970–2021 in a linear trend and it has a unit root whose break point is in 2008. The Hamilton decomposition model (2018) revealed that its cycle consists of 10 peaks and 9 troughs, and the cyclical trend consists of 2 peaks and 2 troughs. The temperature change in centigrade level from 1970 to 2021 has no unit root, while it had a unit root break point in 2009 and its cycle consists of 10 peaks and 9 troughs, while its cyclical trend has 2 peaks and 2 troughs. The series of emission intensities from rice during 1970–2021 has no unit root but has a break point in 1981.

Its cycle consists of 11 peaks and 10 troughs, while a cyclical trend has 2 peaks and 2 troughs. The emission intensity from rice has been dwindling at the rate of 20.86% per year, significantly. On the other hand, the emission intensity of cereals during 1990–2001 has been increasing insignificantly at the rate of 0.20% per year. Its cycle has 12 peaks and 13 troughs, while the cyclical trend has 1 peak and 1 trough, respectively. The emission per value of agricultural production has been significantly declining at a rate of 2.48% per year between 1990 and 2021, with a unit root break in 2008. The cycle has 5 peaks and 4 troughs, while its cyclical trend has 1 peak and 2 troughs. The emission per area of agricultural land has been diminishing at a rate of 0.02% year insignificantly while it had no unit root but broke in 1993. Its cycle showed seven peaks and six troughs, whereas its cyclical trend had two peaks and one trough. Finally, the series of total CO_2 emissions from 1990 to 2021 has been enhancing at the rate of 3.98% per year, which has no unit root but broke in 2010. Its cycle consists of 6 peaks and 6 troughs, while its cyclical trend has 2 peaks and 1 trough. Table 1 has arranged all these observations.

Table 1. Nature of trends, cycles and unit root

Variables	Unit root H0=…has unit root	Break unit root	Linear trend	Hamilton cycles	Hamilton Cyclical trend
y	Accepted, ADF=-2.84 (5% Level)	2008	3.39% per year, R^2=0.92, significant (5%)	10 peaks, 9 troughs	2 peaks, 2 troughs
X_1	Rejected, ADF=-6.44 (5% Level)	2009	Exists no positive integer	10 peaks, 9 troughs	2 peaks, 2 troughs
X_2	Rejected, ADF=-4.705 (5% Level)	1981	-20.86% per year, R^2=0.62, significant (5%)	11 peaks, 10 troughs	2 peaks, 2 troughs
X_3	Rejected, ADF=-6.2588 (5% Level)	1992	0.20% per year, R^2=0.012, insignificant	12 peaks, 13 troughs	1 peak, 2 troughs
X_4	Accepted, ADF-4.4255 (5% Level)	2008	-2.48% per year, R^2=0.82, significant (5%)	5 peaks, 4 troughs	1 peak, 1 trough
X_5	Rejected, ADF=-3.39 (5% Level)	1993	-0.02% per year, R^2=0.004, insignificant	7 peaks, 6 troughs	2 peaks, 2 troughs
X_6	Rejected, ADF=-1.9676 (5% Level)	2010	3.98% per year, R^2=0.62, significant (5%)	6 peaks, 6 troughs	2 peaks, 1 trough

Source: Calculated by Author.

Cointegration and VECM

The Johansen (1988) unrestricted cointegration rank test, based on the assumptions of a linear deterministic trend in the first difference series of the agriculture production index (y), temperature change (x_1), emissions intensity from rice (x_2), emissions intensity from cereals (x_3), emissions per value of agricultural production (x_4), emissions per area of agricultural land (x_5), and total CO_2 emissions (x_6) of Zambia from 1990 to 2021, reveals that Trace statistics recorded 5 cointegrating equations, while Max-Eigen statistics recorded 4 cointegrating equations, as shown in Table 2. Therefore, the variables have long-term associations between them, or they are cointegrated.

Table 2. Johansen cointegration

Hypothesized Number of Cointegrating Equations	Eigen value	Trace Statistic	0.05 Critical Value	Probability**
None *	0.998403	362.7764	125.6154	0.0000
At most 1 *	0.900514	176.0282	95.75366	0.0000
At most 2 *	0.818137	109.1036	69.81889	0.0000
At most 3 *	0.630479	59.67305	47.85613	0.0027
At most 4 *	0.455936	30.80215	29.79707	0.0382
At most 5	0.337165	13.15017	15.49471	0.1094
At most 6	0.041345	1.224504	3.841466	0.2685
		Max-Eigen Statistic		
None *	0.998403	186.7482	46.23142	0.0000
At most 1 *	0.900514	66.92455	40.07757	0.0000
At most 2 *	0.818137	49.43060	33.87687	0.0003
At most 3 *	0.630479	28.87090	27.58434	0.0340
At most 4	0.455936	17.65198	21.13162	0.1434
At most 5	0.337165	11.92566	14.26460	0.1135
At most 6	0.041345	1.224504	3.841466	0.2685

Source: Author's Calculation.
*Rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) p-values.

The estimated VEC equations revealed a positive correlation between the increase in agricultural production index in Zambia, the increase in emissions intensity from rice, the increase in emissions intensity from cereals, and the increase in emissions per area of agricultural land. Conversely, a negative correlation was found with the increase in temperature change, the increase in emissions per value of agricultural production, and the increase in total CO2 emissions, all of which were insignificant at the 5% level. On the other hand, there is a significant positive correlation between the increase in total CO2 emissions and the increase in emissions intensity from rice and cereals at the 5% level, while there is a significant negative correlation between temperature change, the intensity of emissions from rice, and the emissions per value of agricultural production during the period of 1990-2021 in Zambia. Table 3 lays out all the observed relationships.

Table 3. Observations from vector error correction model

Error Correction	$d(y_t)$	$d(x_{1t})$	$d(x_{2t})$	$d(x_{3t})$	$d(x_{4t})$	$d(x_{5t})$	$d(x_{6t})$
C.E.1	0.243609	-0.047835	-0.013512	-0.002883	-0.093255	0.001851	34.93628
tstatistic	[1.081]	[-2.649]*	[-1.026]	[-1.150]	[-0.702]	[1.121]	[3.867]*
C.E.2	0.967695	-1.191468	-0.075262	-0.011652	-2.703948	-0.006265	393.7877
t statistic	[0.279]	[-4.296]*	[-0.372]	[-0.302]	[-1.326]	[-0.247]	[2.838]*
C.E.3	1.786369	-0.799561	-0.797095	-0.104202	-0.559667	-0.050407	201.9475
	[0.382]	[-2.133]*	[-2.916]*	[-2.002]*	[-0.203]	[-1.470]	[1.077]
C.E.4	35.21370	0.077255	-4.524023	-1.695070	-25.97686	0.257032	-1824.290
t statistic	[1.053]	[0.028]	[-2.315]*	[-4.555]	[-1.318]	[1.048]	[-1.360]
$d(y_{t-1})$	-0.012892	0.023406	-0.020018	0.002688	0.022521	-0.002224	6.616837
t statistic	[-0.038]	[0.881]	[-1.034]	[0.729]	[0.115]	[-0.916]	[0.498]
$d(x_{1t-1}))$	-2.541493	0.328579	0.055549	0.023759	2.011153	-0.002520	-235.1810
t statistic	[-0.920]	[1.484]	[0.344]	[0.773]	[1.235]	[-0.124]	[-2.123]*
$d(x_{2t-1})$	1.659009	0.277076	0.012460	0.020287	-0.011132	0.021050	-36.85590
t statistic	[0.401]	[0.836]	[0.051]	[0.441]	[-0.004]	[0.695]	[-0.222]
$d(x_{3t-1})$	1.310366	0.284491	2.158099	0.406056	3.817636	-0.103472	2038.375
t statistic	[0.049]	[0.133]	[1.393]	[1.376]	[0.244]	[-0.532]	[1.917]*
$d(x_{4t-1})$	-0.200456	0.058771	-0.094605	-0.003746	-0.168751	-0.001384	-49.97071
t statistic	[-0.338]	[1.238]	[-2.735]*	[-0.568]	[-0.483]	[-0.318]	[-2.105]*
$d(x_{5t-1})$	52.73871	-4.014864	1.818793	-0.518804	-6.050239	-0.128528	1173.543
t statistic	[1.561]	[-1.482]	[0.921]	[-1.380]	[-0.303]	[-0.519]	[0.866]
$d(x_{6t-1})$	-0.005346	1.33E-05	0.000519	3.59E-05	0.000369	1.91E-05	0.047840
t statistic	[-1.259]	[0.039]	[2.090]*	[0.759]	[0.147]	[0.614]	[0.280]
C	3.904562	-0.008185	-0.140138	-0.019133	-1.211462	-0.001506	86.30467
t statistic	[2.182]*	[-0.057]	[-1.339]	[-0.960]	[-1.148]	[-0.114]	[1.202]
R-squared	0.337480	0.613655	0.765290	0.744260	0.416641	0.405276	0.668809
F-statistic	0.833545	2.599131	5.335476	4.762178	1.168707	1.115106	3.304490
Akaike AIC	7.236297	2.189883	1.557810	-1.759499	6.179189	-2.594638	14.61999
Schwarz SC	7.796776	2.750362	2.118289	-1.199020	6.739668	-2.034160	15.18047

Source: Calculated by Author.

*=significant at 5% level., d=first difference.

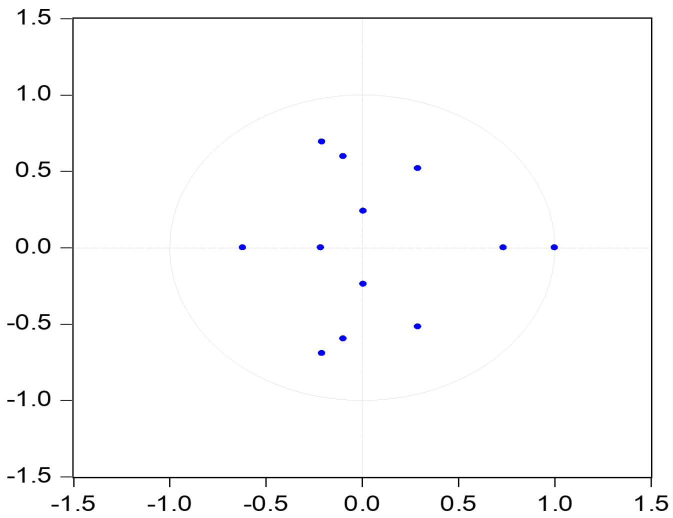
The Vector Error Correction Model showed 3-unit roots, and all other roots are less than one. So that the model is considered as stable and non-stationary. The values of roots are shown below in Table 4.

Table 4. Values of roots

Value of Root	Value of Modulus
1.000000	1.000000
1.000000	1.000000
1.000000	1.000000
0.734457	0.734457
-0.208488 - 0.692702i	0.723397
-0.208488 + 0.692702i	0.723397
-0.618752	0.618752
-0.097494 - 0.597565i	0.605466
-0.097494 + 0.597565i	0.605466
0.289659 - 0.518596i	0.594007
0.289659 + 0.518596i	0.594007
0.005888 - 0.239357i	0.239429
0.005888 + 0.239357i	0.239429

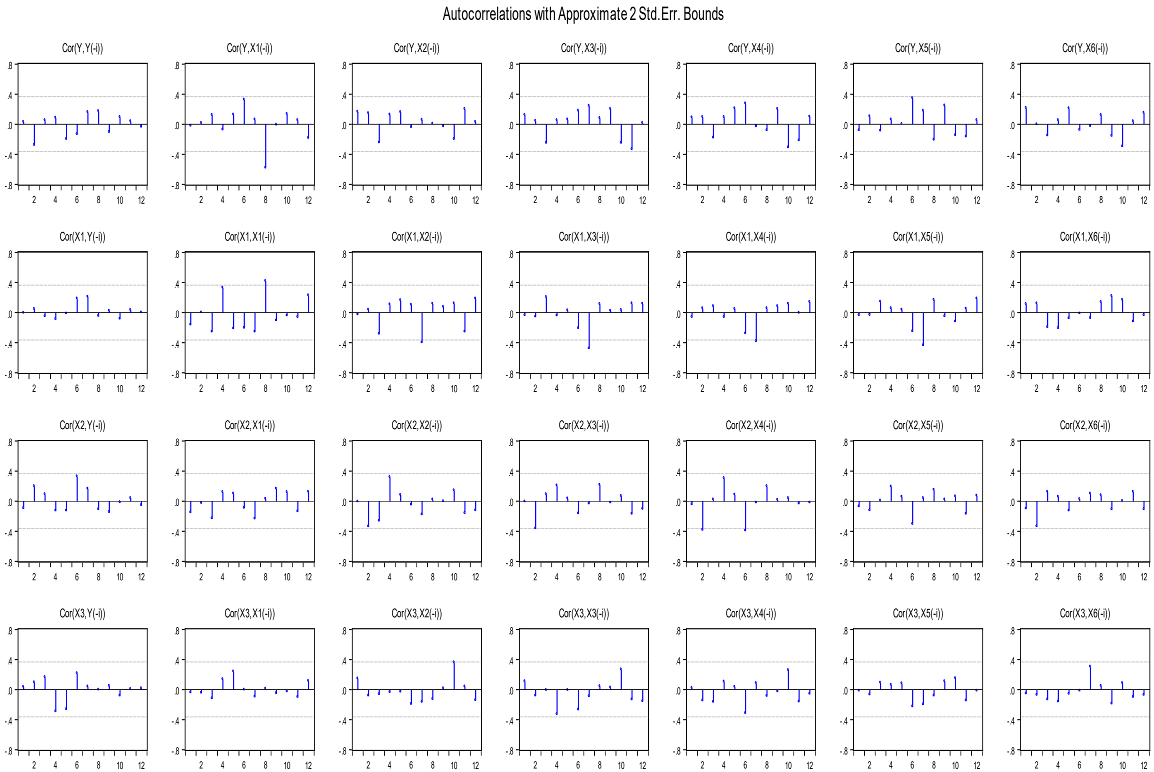
Source: Author's Calculation.

The model is found stable because all the roots lie on or inside the unit circle. It is shown in Figure 1.



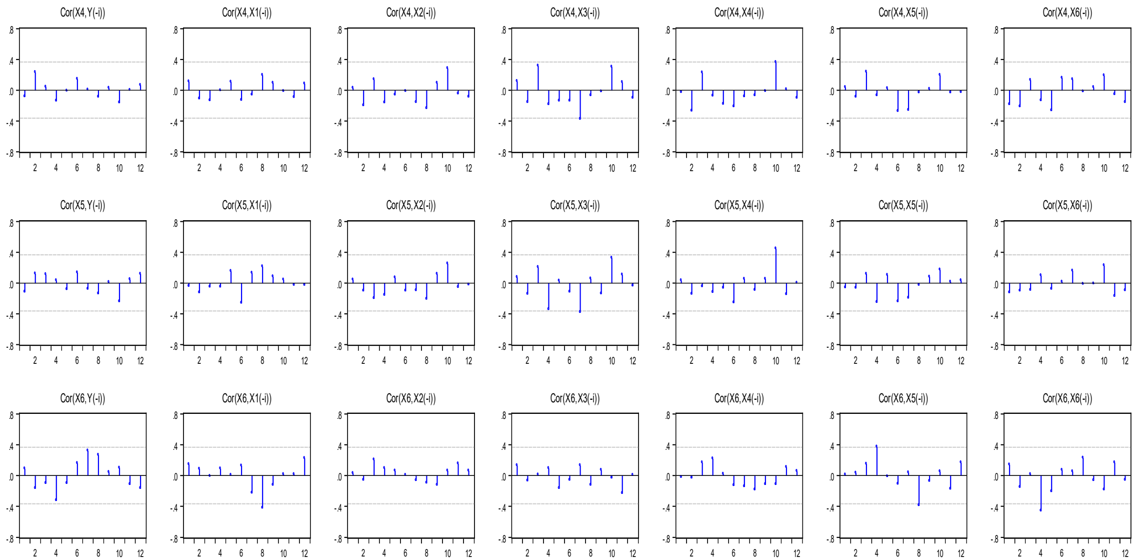
Source: Plotted by Author.

Figure 1. Unit Circle.



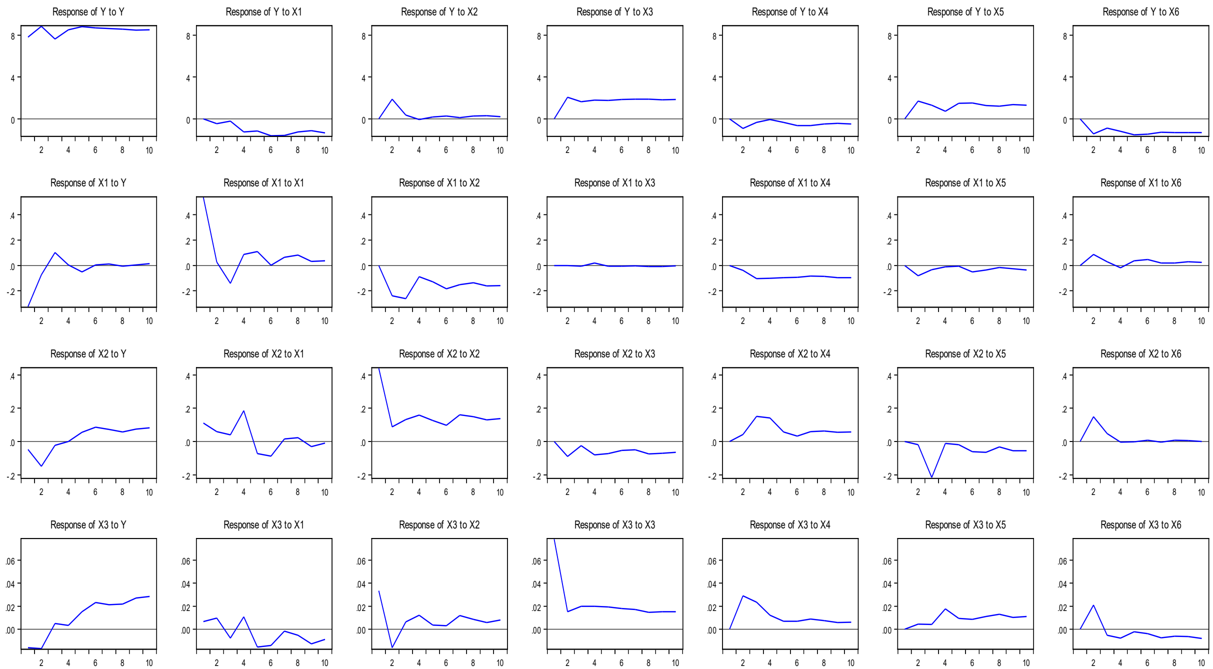
Source: Author’s own.

Figure 2a. Correlogram.



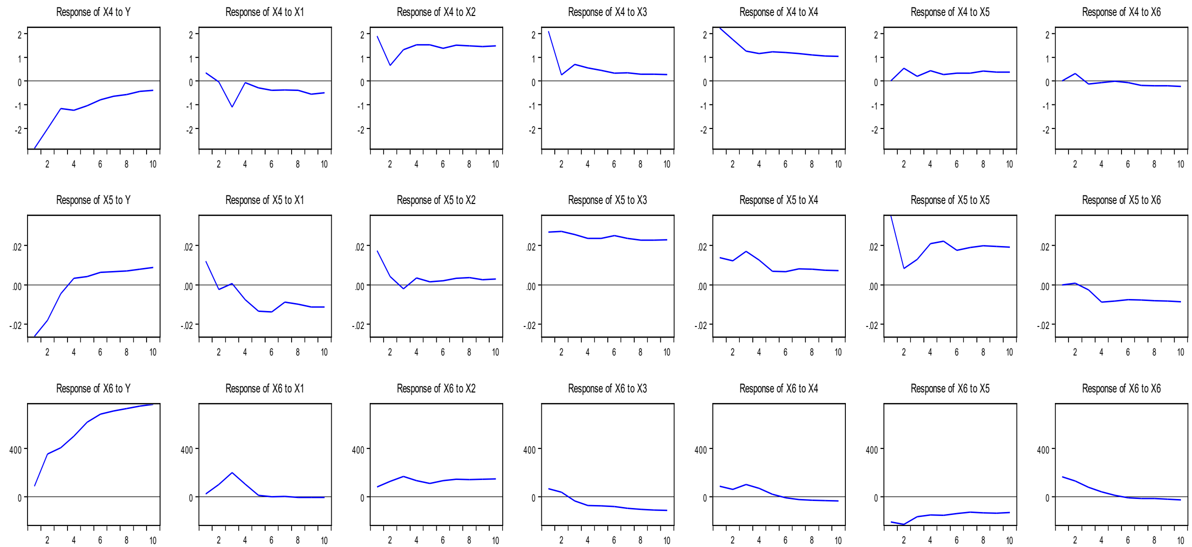
Source: Author’s own.

Figure 2b. Correlogram.



Source: Author's own.

Figure 3a. Impulse Response Functions.



Source-Author's own.

Figure 3b. Impulse Response Functions.

The Vector Error Correction Model has shown autocorrelation problems since the vertical bars have indicated both positive and negative values which varied continuously. It is shown in Figure 2a and Figure 2b.

The impulse response functions measured by Cholesky's one standard deviation imply that the response y to x_2, the responses of x_1 to x_3, x_5, x_6, the responses of x_2 to x_1, x_4, x_6, the responses of x_3 to x_1, x_4, the responses of x_4 to x_3, x_6 and the responses of x_6 to x_1, x_4, x_6 have been converging and even crossing on the equilibrium line, as shown in Figure 3a and Figure 3b above.

With the help of the Wald (1943) test, the paper found out the short run causalities from the system equations. There are uni-directional short run causalities from the emissions per value of agricultural production (x_4) to emissions intensity from rice (x_2), from total CO_2 emissions (x_6) to emissions intensity from rice (x_2), from temperature change (x_1) to total CO_2 emissions (x_6), and from emissions per value of agricultural production (x_4) to total CO_2 emissions (x_6), respectively, which are significant at 5% level. Their values have been given in Table 5.

Table 5. Short run causality

Short run Causality from … To…	Value of $\chi^2(1)$	Probability	Accepted/rejected
Causality from emissions per value of agricultural production (x_4) to emissions intensity from rice (x_2)	7.480	0.0062	H0 = No causality is rejected
Causality from total CO_2 emissions (x_6) to emissions intensity from rice (x_2)	4.372	0.0365	H0 = No causality is rejected
Causality from temperature change (x_1) to total CO_2 emissions (x_6)	4.508	0.0337	H0 = No causality is rejected
Causality from emissions per value of agricultural production (x_4) to total CO_2 emissions (x_6)	4.433	0.0352	H0 = No causality is rejected

Source: Calculated by Author.

The long run causalities have been verified by the following cointegrating equations which are given below after estimation.

$Z_{1t-1} = 0.243y_{t-1} + 0.987x_{4t-1} - 140.177x_{5t-1} - 0.00844x_{6t-1} + 146.479$
(1.08) (1.97)*(-2.63)*(-4.43)*
$Z_{2t-1} = -0.047x_{1t-1} + 0.0999x_{4t-1} - 0.5025x_{5t-1} + 2.42e^{-05}x_{6t-1} - 3.039$
(-2.64)* (3.19) * (-0.151) (0.204)
$Z_{3t-1} = -0.0135x_{2t-1} - 0.0821x_{4t-1} + 3.007x_{5t-1} - 0.00017x_{6t-1} - 3.78$
(-1.026) (-4.99) * (1.71) * (-2.77) *

$$Z_{4t-1}=-0.0028x_{3t-1}-0.00103x_{4t-1}-0.7756x_{5t-1}-2.92e\text{-}05x_{6t-1}+1.027$$
(-1.15) (-0.456) (-3.22) * (-3.39) *

The cointegrating equation 1 implies that in the long run, the index of agricultural production in Zambia during 1990–2021 is positively integrated with emissions per value of agricultural production and negatively integrated with emissions per area of agricultural land and total CO_2 emissions significantly at 5% level. But this long-run relationship has been diverging away from equilibrium at the speed of adjustment of 24.3% per year since the coefficient of y_{t-1} is positive and its t value is also insignificant at 5% level.

The cointegrating equation 2 states that in the long run, the change in temperature is positively integrated with the emission per value of agricultural production significantly at 5% level but insignificantly related to total CO_2 emissions, while negatively related to emissions per area of agricultural land at 5% level, where its cointegrating equation converges to equilibrium significantly at the speed of adjustment of 4.7% per year because the coefficient of x_{1t-1} is negative and its t value is significant at 5% level.

In the long run, the cointegrating equation 2 demonstrates a significant positive integration with the emission per value of agricultural production at a 5% level, but a negligible relationship with total CO_2 emissions. Conversely, it shows a negative correlation with the emissions per area of agricultural land at a 5% level. This cointegrating equation significantly approaches equilibrium at a rate of 4.7% per year due to the negative coefficient of x_{1t-1} and its significant t value at the 5% level. The cointegrating equation 4 reveals that the emissions from cereals are negatively integrated with emissions per value of agricultural production, emissions per area of agricultural land, and total CO_2 emissions significantly at 5% level in the long run during 1990–2021 in Zambia. The equation has been converging towards equilibrium insignificantly at the speed of adjustment of 0.28% per year since the t value of the coefficient of x_{3t-1} is insignificant at 5% level.

In the following Figure 4, the cointegrating equations have been depicted neatly.

Source: Author's Own.

Figure 4. Cointegrating Equations.

Section-II

Nexus Between Variability of Food Supply per Capita per Day and Its Determinants

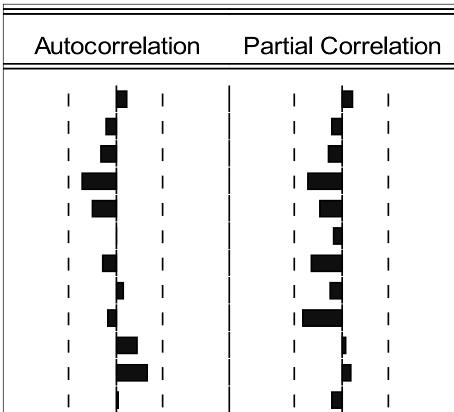
Multiple variables regression equation among the variability of per capita food supply per day in kilocalories (K), value added in agriculture (y_1), emission intensity from rice (y_2), emission intensity from cereals (y_3), emission per value of agricultural production (y_4), food price inflation rate (y_5) and total CO_2 emission (y_6) during 1990-2021 in Zambia has been estimated below.

$$K= 74.922+0.0149y_1-8.133y_2-22.335y_3-26.046y_4+0.15406y_5-0.00023y_6$$
$$(3.75)\ ^*\ (2.88)\ ^*\ (-1.93)\ ^{**}\ (-2.67)\ ^*(-0.580)\ (0.388)\ (-0.158)$$

R^2=0.791, F=9.48*, SC=8.21, AIC=7.869, DW=1.689, n=22, **=significant at 10% level, *=significant at 5% level.

The above estimated regression equation implies that the variability of per capita food supply per day in Zambia is positively associated with value added in agriculture and the food price inflation rate, in which the former is significant at 5% level and the latter is insignificant, while the per capita food supply per day is negatively related with emission intensity from rice, emission intensity from cereals, emission per value of agricultural production, and total CO_2 emission, respectively, during 1990-2021 in which the influence of emission intensity from rice and emission intensity from cereals are significant at 10% and 5% levels, and the rest is insignificant at 5% level. The high R^2 and significant F and DW indicate a good fit for the regression equation. Thus, there is a significant negative influence of emissions on the variability of the supply of food per day per capita in Zambia during the specified period since climate change affects agricultural production negatively.

The residual test of the regression equation for the correlogram on autocorrelation and partial autocorrelation functions suggested that it has seasonal fluctuations since the values of Auto Correlation Functions and Partial Auto Correlation Functions vary from positive to negative values continuously, which have been plotted in Figure 5 with the help of Box and Jenkins (1978) model.



	AC	PAC	Q-Stat	Prob
1	0.100	0.100	0.2513	0.616
2	-0.085	-0.096	0.4419	0.802
3	-0.131	-0.115	0.9212	0.820
4	-0.311	-0.303	3.7571	0.440
5	-0.207	-0.203	5.0922	0.405
6	0.000	-0.067	5.0922	0.532
7	-0.114	-0.274	5.5536	0.593
8	0.079	-0.101	5.7879	0.671
9	-0.068	-0.351	5.9762	0.742
10	0.196	0.046	7.6744	0.661
11	0.282	0.090	11.489	0.403
12	0.025	-0.086	11.523	0.485

Source: Plotted by Author.

Figure 5. Auto Correlation Functions and Partial Auto Correlation Functions.

Moreover, Breusch test (1978) and Godfrey test (1978) for serial correlation LM test as renowned with Breusch-Godfrey serial correlation LM test for residuals revealed that no serial correlation at Ho is accepted in which probability of $\chi^2(2) = 0.75$ of observed R^2 is accepted where all the results are given in Table 6.

Table 6. Breusch-Godfrey serial correlation LM test

F-statistic	0.170224	Probability of F (2,13)	0.8453
Observed R^2	0.561439	Probability of $\chi^2(2)$	0.7552

Source: Calculated by Author.

The Auto Regressive Common Heteroscedasticity test for heteroscedasticity in lag 1 for residuals showed that it has no unequal variances where the probability of $\chi^2(1) = 0.34$ of observed R^2 is accepted. The results are shown in Table 7 below.

Table 7. Heteroskedasticity test: ARCH

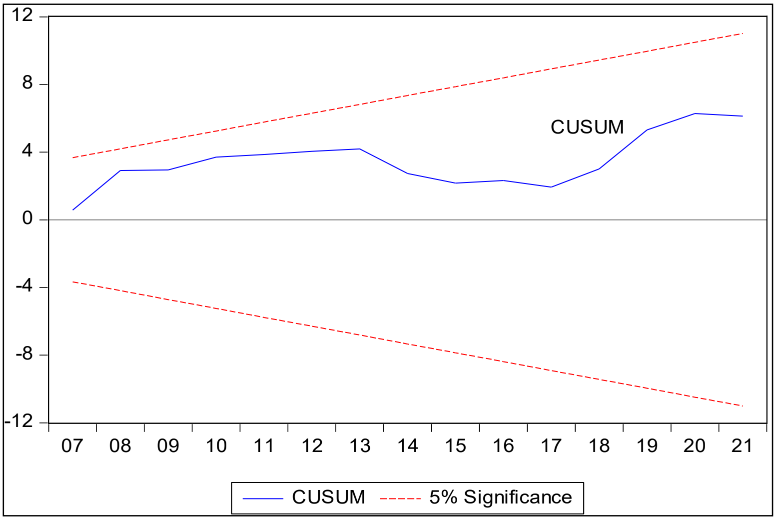
F-statistic	0.858951	Probability of F (1,19)	0.3657
Observed R^2	0.908304	Probability of$\chi^2(1)$	0.3406

Source: Author's Calculation.

The stability test of the residuals implies that the line on the cumulative sum (Brown, Durbin & Evans, 1975) passes through ±5% significant level, which confirmed that the multiple regression model which relates the food supply per capita per day with its determinants during 1990-2021 in Zambia is stable. It is depicted in Figure 6 below.

Finally, the variability of food supply per capita per day and its 6 determinants during 1990-2021 in Zambia have been confronted with asymmetric shocks because the correlations matrix of the residuals of all the variables obtained from linear trend model showed 22 negative correlations and 20 positive correlations where six correlations are above 0.50, and the rest 12 are above 0.40-0.50. There are 5 negative correlations among K' and y_2'……y_6', and one positive correlation between K' and y_1' in which the values of 4 correlations have shown greater than 0.40. Again, y_1' has produced 5 negative correlations with y_2'…..y_6', and one positive correlation with w' in which the values of 3 correlations have shown greater than 0.40. Even, y_2' has released 3 negative correlations with k', $y_1'$and y_5' including 3 positive correlations with y_3', y_4', y_6', in which their values are less than 0.40.

While there are 2 negative correlations among y_3' and k', y_1' and 4 positive correlations among y_3' and y_2', y_4', y_5', y_6', where the values of 3 correlations are greater than 0.40. And y_4' has 2 negative correlations with k', y_1' where the values of correlation are greater than 0.40 and, has 3 positive correlations with y_2', y_3', y_5', where 2 correlations are greater than 0.40. Again, y_5' has 3 negative correlations with k', y_1', y_2', and 3 negative correlations with y_3', y_4', y_6' where the values of 2 correlations are greater than 0.40. Similarly, y_6' has 2 negative correlations with k', y_1', and 4 positive correlations with y_2', y_3', y_4', y_5' where the values of 4 correlations are greater than 0.40 respectively. The correlation matrix is given in Table 8.



Source: Author's Own.

Figure 6. Stability Test.

Table 8. The correlation matrix

	k'	y_1'	y_2'	y_3'	y_4'	y_5'	y_6'
k'	1	0.45457	-0.30260	-0.73092	-0.49258	-0.28440	-0.4363
y_1'	0.45457	1	-0.22308	-0.36730	-0.18845	-0.51739	-0.71226
y_2'	-0.30260	-0.22308	1	0.05084	0.15518	-0.07893	0.05297
y_3'	-0.7309	-0.36730	0.05084	1	0.4984	0.2847	0.4390
y_4'	-0.49258	-0.18845	0.15518	0.49840	1	0.01846	0.1957
y_5'	-0.2844	-0.5173	-0.0789	0.2847	0.01846	1	0.43152
y_6'	-0.43639	-0.71226	0.0529	0.43900	0.1957	0.4315	1

Source: Calculated by Author.

Discussions and Policy Considerations

Since the index of agricultural production is negatively integrated with emissions per area of agricultural land and total CO_2 emissions in the long run in Zambia, the government must apply all sorts of techniques to reduce emissions from agriculture as envisaged by COP27, COP28, IPCC and FAO, as well as policy should emphasize to increase crops per hectare applying scientific farming.

Since in Zambia, emissions from the agricultural sector have a significant negative impact on food security, especially on the variability of the per capita per day food supply, the reduction of CH_4 and N_2O from agriculture is urgent. Therefore, the most effective methods for reducing emissions from agriculture include soil management through nitrification and denitrification, tillage and irrigation practices, the use of biochar and lime, plant treatment with arbuscular mycorrhizal fungi, appropriate crop rotations, integrated nutrient management, and crop management techniques such as tillage, irrigation, and rotation (Hassan et al., 2022; Poddar, 2024). Moreover, the results showed that the CO2 emissions reduced the food supply in Zambia, which requires mitigation and adaptation as advised by COP28. Since the value added in agriculture enhances the food supply, acceleration of growth through rising agricultural productivity, crop diversification, irrigation management, and the introduction of more renewable energy resources might be useful. Controlling food price inflation will also enhance the food supply at a faster pace. The World Economic Forum (2023) suggested diversifying food production, investing in food storage systems, educating and training food preservation systems, upgrading water management, practicing sustainable farming, supporting small farmers, increasing organic carbon in soil, following an early warning system, being aware of challenges to food security, and emphasizing research and development for climate-resilient food crops. Nelson et al. (2010) projected from the model that wheat yield in 2030, 2050, and 2080 with the base year 2000 as an impact of climate change is expected to decline by 1.3%-9% in 2030, 4.2%–12% by 2050, and 14.3%-29% by 2080 respectively. The authors prescribed hiking agricultural productivity to reduce suffering by emphasizing free agricultural trade, enhancing physical and human capital, increasing the efficiency of land, water, and manures, and mitigating GHG in agriculture, respectively. The expectation is that the AfSIS project, The Living Standards Measurement Study-Integrated Surveys on Agriculture, financed by the Bill and Melinda Gates Foundation, will improve African food security and address climate change problems. The CGIAR process will provide a better understanding of human-environment interactions. In order to address climate change and food security, Campbell et al. (2016) suggested practicing stakeholder engagement, designing and testing portfolios of options, achieving social inclusion for those vulnerable to climate change, and addressing adaptation and mitigation together at both local and international levels. Moreover, Noiret (2016) felt that Civil Society Organizations (CSO), the Adaptation of African Agricultures initiative (AAA), and the Global Alliance for Climate Smart Agriculture (GACSA) have agreed to promote agricultural production increases to face the ill-effects of climate change (Pal & Poddar, 2024). On the other hand, the Committee for World Food Security should face the challenge of food security for international negotiations with the help of FAO and UNFCCC.

Conclusion

The paper concludes that the long run association among agricultural production index, temperature change, emissions intensity from rice, emissions intensity from cereals, emissions per value of agricultural production, emissions per area of agricultural land, and total CO_2 emissions of Zambia during 1990-2021 produced four cointegrating equations which imply that in the long run, the index of agricultural production in Zambia is positively integrated with emissions per value of agricultural production, negatively integrated with emissions per area of agricultural land, and total CO_2 emissions significantly at 5% level. But this long-term relationship is divergent. The change in temperature is positively integrated with emissions per value of agricultural production which is significant at 5% level. Per capita food supply per day in Zambia has been positively associated with value added in agriculture and food price inflation rate, while it has been negatively associated with emission intensity from rice, emission intensity from cereals, emission per value of agricultural production, and total CO_2 emission respectively, during 1990-2021. The residual test showed no heteroscedasticity or serial correlation problems, but the model is stable, despite the variables revealing asymmetric shocks. Panel regression and cointegration might produce better results for the linkages over a specified period. As a result, the econometric test for a single country, Zambia, provides enough reasonable scope for future research in regional or global economies.

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Conflicts of Interest

There is no conflict of interest for the publication of the paper.

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Chapter 3

A Review of the Ecological Effects of Forestry and Land-Use Practices Driven by the Carbon Credit Economy

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Abstract

Global financial trading systems use voluntary carbon credits to quantify carbon emissions. The VCM is a voluntary and unregulated market within which national and international private registries generate and verify carbon offset initiatives such as Renewable Energy (RE) projects and Afforestation/Reforestation (AF/RF) endeavours. Notably, uncharacteristic native ecosystems such as grassland biomes are increasingly chosen as afforestation sites, often due to their mis-categorisation as *wastelands*. This chapter aims to delve into the VCM, utilizing publicly available databases to examine the scope and efficacy of Forestry and Land Use projects. Additionally, it aims to assess the impact of such projects on native biodiversity, highlighting the threats arising from an expanding global carbon-centric perspective.

Keywords: carbon credits, voluntary carbon market, carbon offset, afforestation/reforestation, grassland ecology, REDD+

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Introduction

In December 1997, the Kyoto Protocol, hereafter referred to as *the Protocol*, marked a historic milestone as the world's inaugural legally binding framework aimed at curbing and limiting global greenhouse gas (GHG) emissions. However, it wasn't until seven years later, on February 16, 2005, that the Protocol officially came into force.

The Protocol, initially ratified by 192 nations, outlined commitments for 37 developed, economies-in-transition, and European Union (EU) party states to avoid, reduce, and remove GHG emissions. Based on the principle of "*common but differentiated responsibilities*," these commitments are individual and distinct to each party state.

The significance of the Protocol lies in Article 17, which codifies the concept of Emissions Trading (ET) as a mechanism to limit and reduce GHG emissions by party states.

Thus, a new token emerged: a GHG-emissions-based commodity. Much like currency, it is divisible, fungible, and subject to limited supply. Consequently, the Protocol sparked the emergence of the GHG market. Among greenhouse gases, carbon stands out as the most well-known, and the GHG market is thus commonly known as the *carbon market*. In the subsequent paragraphs, the readers will hopefully get a better understanding of the carbon market industry and how that is related to extensive afforestation projects targeting open grassland ecosystems like the well-known savannahs and prairies but also lesser-known *sholas* in the Western Ghats of peninsular India. A publicly available data set will be used along with published studies to make the readers understand the various aspects of this complex paradigm. The article is for a general audience and thus we will present exploratory data analyses and simple descriptive statistics (counts or means) - in other words *no modelling*.

The focus of the chapter was to cover the various scales of this process thus this article lacks an in-depth explanation of specific ecological and economic processes described. Thus, the readers are urged to explore the literatures cited as well as the database used (see Data Analysis section for citation). The workings of the carbon-offset market, including its currency, governing bodies, and legislative framework, will be initially understood. Attention will then be directed towards the voluntary carbon market. The database as well as relevant literature was used to understand how the carbon currency-based land-use projects are classified and then delve into forestry and land use practices which encompasses all the afforestation/reforestation-based projects globally.

The Currency of the Market

The carbon market operates on credits and offsets. Simply put, a carbon credit is a carbon allowance. With one carbon credit, an entity purchases the right to emit one metric tonne of carbon dioxide or its equivalent in GHGs. A carbon offset, on the other hand, refers to a project or action financed by the entity that avoids, reduces, or removes one metric tonne of CO_2 or the equivalent amount of GHGs from the atmosphere. There are two types of carbon offsets: nature-based and mechanical. Nature-based or natural methods, such as wetlands restoration involve natural processes to offset carbon. Mechanical offsets refer to the development of man-made technologies, such as renewable energy, that lower the amount of carbon emitted, in contrast to traditional, less efficient methods.

The Protocol, and other international frameworks, such as the Doha Amendment (2012), Paris Agreement (2015) (hereafter, referred to as *The Agreement*); and the subsequent annual Conference of the Parties (COPs), highlight the importance of GHG-based emissions goals. It is beyond the scope of this chapter to critically analyse the Kyoto Protocol and other such international frameworks that gave rise to and sustain the mechanisms of the carbon economy (Kim, Tanaka & Matsuoka, 2020). To achieve the goals set up by The Agreement, governments, and international institutions do not work in isolation. Private sector entities, like businesses, civil societies, non-governmental organisations (NGOs), etc. are significant players in carbon markets. Such entities are allowed to purchase carbon credits from governments and other such authorised international bodies. These credits give them the license to emit CO_2. Any additional carbon credits left unused can be traded to other organisations failing to meet their emission targets. Thus, carbon markets function in a way quite similar to traditional economic markets.

Types of Carbon Markets

Currently, there exist two types of carbon markets operational worldwide. First off, there are regulated compliance markets. Colloquially known as the 'cap-and-trade' market, such set-ups are regulated by national, regional, and/or international frameworks or bodies. Currently, there are 30 compliance carbon markets worldwide. Of these 30, there are 3 major government-regulated Emissions Trading Systems (ETS) around the globe:

- European Union ETS: The EU ETS is the world's first international ETS. The market covers all EU states, the European Free Trade Association states (Iceland, Liechtenstein, and Norway), as well as Northern Ireland. In this ETS, private and civil entities open Union Registry accounts to buy carbon allowances from the market, or auctions hosted by the ETS. A provision within the EU ETS permits party states to submit National Implementation Measures, more commonly known as allocation plans, to the ETS committee. Upon approval, the committee grants a certain quantity of free allowances to states contingent that the allowance be used only for industry and heating, *not* for electricity generation. As of 23rd October 2023, one metric tonne of CO_2 was valued at 80.58 EU.
- California Cap-and-Trade Program: In the United States, the state of California has operated an ETS market since 2012. The program, set up under The California Global Warming Solutions Act (2006), authorizes carbon allowances under the aegis of the California Air Resources Board (ARB). Allowances are distributed to various industries and infrastructure-based entities. As of August 3, 2023, the valuation of one metric tonne of CO_2 stood at 36.14 USD. As of 14th December 2023, ARB has issued 256721942 credits. The majority, or 81 percent of these credits, were allocated to forestry projects, while ozone-depleting projects received 10 percent, and mine methane capture and livestock projects received 5 percent and 4 percent, respectively (California Air Resources Board, n.d.).
- China National ETS: Set up on 16th July 2021, the China National ETS (CN ETS) operates on the Shanghai Environment and Energy Exchange. Currently, the ETS covers only the power generation sector but is expected to expand into chemical and petrochemical, building materials and construction, as well as the domestic aviation sectors in the coming years. It is the largest ETS in the world, covering 4 billion metric tonnes of CO_2. In the CN ETS, each carbon credit is priced at approximately 60 CNY.

An Unregulated Operation: Voluntary Carbon Markets

The second market type, the voluntary carbon market (VCM), operates without regulations. Participation in these voluntary setups is optional. These markets operate based on the principle of additionality, meaning they create environmental value beyond the global and national goals established by The Protocol and The Agreement. In such voluntary set-ups, private and civil entities purchase credits and generate offsets on their own accord, in a bid to signal support toward being more eco-friendly and climate-conscious, and to reduce their emissions.

Properties of a Voluntary Credit/Offset Project

- A voluntary offset must cater to the property of additionality i.e., the changes must have been brought about by the measures and would not have happened if no intervention was made (the changes are not neutral).
- Emissions avoidance, reduction, or removal must be measurable and verifiable.
- Voluntary offset projects must generate durable and long-term emissions action for their effort to be considered sustainable.
- Offsets must be supported by legal infrastructure - they must adhere to standards set forth by national governments or international institutions.

Furthermore, VCM projects often boast benefits like prevention of *leakage* (prevention of emissions reduction at a primary location borne at the cost of increasedemissions at a secondary location) and employment generation for residents (such as indigenous tribes or locals that reside close to project locations). Additionally, VCM projects must ensure that credits and offsets are not double counted.

Grassy Biomes

Modern grassy biomes are ecologically distinct from forests (Ratnam et al., 2011). These biomes serve as hosts to numerous biodiversity hotspots worldwide (Noss et al., 2015). For instance, a biodiversity evaluation of the Cerrado savannahs in Brazil established them as a biodiversity hotspot (Myers et al., 2000). These savannahs host a remarkable 161 mammalian species, 837 avian species, 120 reptile species, and 150 amphibian species. Contrary to common belief, the Cerrado savannahs also exhibit floral diversity, sustaining approximately 10,000 plant species. Remarkably, the notable species diversity and richness observed in the Cerrado are not exclusive; grasslands around the world exhibit substantial biodiversity.

Such grassy biomes encompass a diverse range, including but not limited to grasslands such as Pampas, Prairies, Savannahs, and Steppes. Additionally, scrublands and woodlands also encompass biomes distinct from forests (Parr et al., 2014). For instance, woodlands are characterized by a lower tree density than forests, often featuring scattered trees and a more open canopy. In stark contrast to forest vegetation, grassy biomes are primarily colonized by monocotyledonous vegetation. This type of vegetation consists of floral communities composed of graminoids (such as grasses and grass-like flora), forbs, and shrubs. Collectively, this community forms a continuous 'herbaceous' layer along the biome floor. Grassy biomes and other such associated ecosystems (i.e., scrublands and woodlands) are shaped by the high availability of sunlight. This abundance of light fosters the rapid clonal expansion of grasses and grass-like flora, creating highly biodiverse hotspots. The density and spread of such flora are influenced by edaphic and hydrological factors, such as soil porosity and water table depth. Additionally, the increased frequency of naturally occurring fires plays a crucial role in these biomes. These fires act as primary regulators, leading to a high annual turnover and ultimately contributing to a significant degree of species richness.

Data Analyses

Since the early 2000s, a rise in climate consciousness, spurned by global commitments to reduce GHG emissions, has seen the exponential growth of VCM. To acquire a better understanding of the industry of carbon offset projects and their main regulatory agencies, the publicly available dataset, maintained by the University of California Berkeley’s Goldman School of Public Policy, was used (Haya et al., 2023). This dataset is collated from ARB and 4 major project registries globally - American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard (GS), and Verra. The latest available version of the dataset (v9), which is updated till November 2023, was used for analyses in this chapter. All statistical analyses were performed in MS Excel and R studio (ver:2023.12.1-402) (R core team, 2021) using the R package *tidyverse (v1.3.0*; Wickhamet al., 2019*)*.

Findings

Scope of VCMs

Each carbon capture project is of a specific *type* that falls under a broader *scope* such as agriculture, waste management, and forestry and land use. There are nine scopes in total (Figure 1). Forestry & Land Use (FLU) with 1481 projects ranks third in the list after Household & Community (HC) projects (like management of household organic wastes, improved accessibility to clean water, and installation of energy-efficient infrastructure, etc.) and Renewable Energy (RE) projects (see Table 1).

Table 1. Total number of various voluntary carbon offset projects under forestry and land use

Type	Number of Projects
Afforestation/Reforestation	418
Avoided Forest Conversion	16
Avoided Grassland Conversion	32
Improved Forest Management	699
REDD+	238
Sustainable Grassland Management	42
Wetland Restoration	36

Source: Data sourced from the Goldman School of Public Policy's Voluntary Registry Offsets Database (v9).

Within the scope of FLU (Table 1), the highest number of such projects are of the Improved Forest Management (IFM) and Afforestation/Reforestation (AF/RF) types. IFM includes applying practices that increase above and below-ground carbon stocks including reducing timber harvest levels, extending timber harvest rotations, designating reserves, fuel load treatments, enrichment planning and stand irrigation or fertilization. AF/RF involves planting trees and reducing barriers to the growth of natural vegetation in non-urban areas except wetlands. Grasslands receive much less *targeted* attention with only 32 Avoided Grassland

Conversion (AGC) and 42 Sustainable Grassland Management (SGM) projects. Interestingly, projects aimed at Avoided Forest Conversion (AFC) have the fewest numbers, despite the potential of old-growth forests in carbon capture compared to planting new trees in open ecosystems. (see Table 1).

Voluntary Project Registers

80% of all VCM projects are registered with either VCS (3881 projects) or GCS (3117). The other 3 carbon registries (namely ACR, CAR, and ARB) together register 18% of the remaining market. Within the scope of FLU, 51% of the projects have been sanctioned by VCS. GCS is only a minor player with 3% of the projects registered. This stark difference between VCS and GCS highlights how all categories of carbon offset projects may not receive the same attention from each organization (see Table 2 for a comparison between the number of projects registered by VCS and Gold).

Table 2. Number of projects under various scopes of carbon offset projects issued by the 2 major registries - verra and gold standard

Scope	Registered by VCS	Registered by Gold
Agriculture	633	74
Carbon Capture & Storage	7	54
Chemical Processes	19	1928
Forestry & Land Use	765	30
Household & Community	467	888
Industrial & Commercial	219	24
Renewable Energy	1424	119
Transportation	39	--
Waste Management	313	--

Total Carbon Credits Issued

As of 1st November 2023, 1.92 billion carbon credits have been issued. VCS itself has issued 1.22 billion credits. A total of 759 million credits have been issued under the scope of FLU. VCS has issued 539 million of these carbon credits followed by ACR in distant second at 134 million credits issued. GCS, the second largest registry of all carbon offset projects has issued only 5.2 million towards FLU. The readers are directed to Figure 1 to understand the annual patterns of the credit issuances by all organizations except VCS. Verra's approach to credit issuance stands apart from that of the other registries. Unlike them, Verra doesn't issue all credits for a reporting period simultaneously. Instead, it permits project developers to issue credits and pay the corresponding per-credit fee in smaller, incremental batches (Haya et al., 2023). See Figure 1 for a year-wise breakup of the carbon credits issued by the 3 main issuance organizations: ACR, CAR and Gold standard.

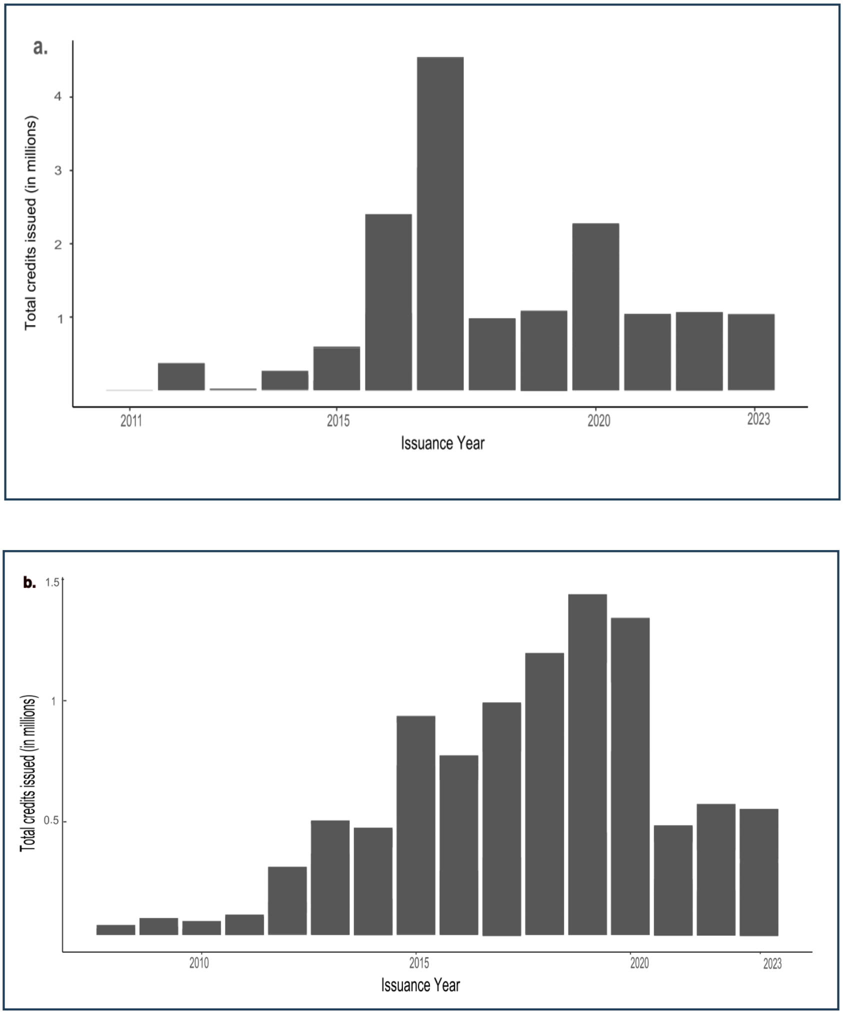
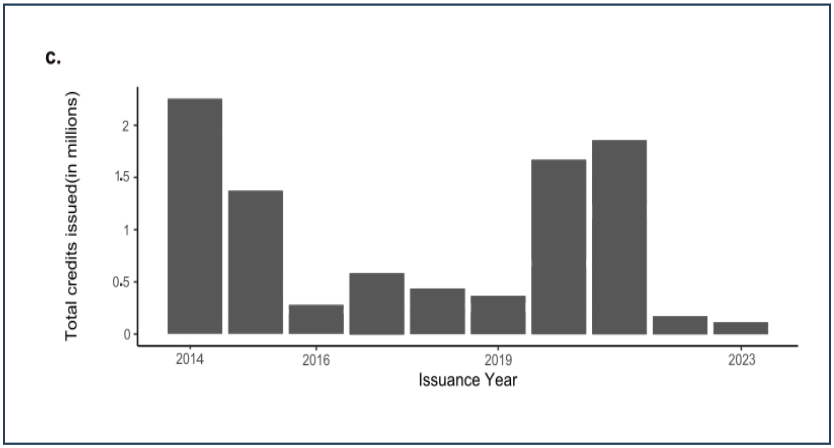


Figure 1. (Continued).



Source: Data sourced from the Goldman School of Public Policy's Voluntary Registry Offsets Database (v9).

Figure 1. Total Carbon Credits Issues by Three Major Organizations Over Years - ACR (American Carbon Registry) (Panel a.), CAR (Climate Action Reserve) (Panel b.) and Gold Standard (Panel c.) Towards Forest and Land Use Projects Including Afforestation/Reforestation, Improved Forest Management Practices and Avoided Conversion of Forest and Grasslands. All currency indicated are in USD.

Table 3. Status of various VCM projects dedicated to protection and management of natural grasslands

Type	Projects Generated	Status of Projects	
Avoided Grassland Conversion	32	Completed	16
		Listed	15
		Registered	1
Sustainable Grassland Management		On Hold	1
		Registered	4
		Registration and verification approval requested	2
		Registration requested	3
		Under development	9
		Under validation	22
		Withdrawn	1

Source: Data sourced from the Goldman School of Public Policy's Voluntary Registry Offsets Database (v9).

The highest percentage of forestry and land use credits fall under the banner of REDD+ (462.5 million credits) and IFM (287.7 million credits). Afforestation/reforestation ranks third in the list and accounts for approximately 59 million carbon credits. 12 million credits have been issued towards sustainable grassland management and only 756 thousand credits have been issued for prevention of grassland. The current status of the projects related to grassland management and protection are presented in Table 3.

Literature Review

Efficacy of the VCM

VCMs present an ambitious call-to-action however often fall short of fulfilling their promises. These markets make use of misguided ecological principles, preaching empty greenwashing at best, and at worst, posing alarming levels of risks to natural and semi-natural ecosystems. An investigative report (Greenfield, 2023) published by the British newspaper The Guardian last year, found that 90% of the carbon offset credits issued by Verra, in rainforests, are "worthless" and represent *phantom credits*. They analysed 87 Verra-approved projects and found that many of the projects were overstating environmental gains (as high as 400% in some cases). A lot of the projects lacked sufficient data in the public domain and only eight out of 29 projects where further analysis was possible showed evidence of meaningful deforestation reductions. Credits from 21 projects had no additional benefits and thus were effectively neutral. These reports highlight the lack of a standardized methodology to quantify the efficacy of carbon-offset projects and their long-term impact on the ecosystem.

Following is detailed discussion on FLU projects and their ecological impacts of these projects on Open Natural Ecosystems (ONEs), such as grasslands, as well as established old-growth forests.

History and Overview of Forestry and Land-use Project

Forestry and Land use carbon offsets are the largest source of nature-based carbon credits. The growth of the VCM thrust *seemingly* simple forestry and land-use cover methods in the spotlight. Methods such as REDD +, IFM, and A/F are often touted as the solutions to help mitigate the climate crisis. For instance, VCM projects often claim A/F as a simple method to aid in abating climate change. The concept, they claim, is an easy one to grasp. With A/F, projects aim to remove or offset a proportion of GHG emissions by planting more trees in previously unforested landscapes or within forested and degraded landscapes. The idea is, to convert millions of acres of '*barren*' and '*degraded*' lands into glorious swathes of forests.

Although codified in international frameworks in the early 2000s, A/F practices gained significant traction earlier in the nineteenth century when large-scale projects were initiated on almost every continent across multiple countries. For instance, in the Prealps of Switzerland, large-scale afforestation of Swiss stone pine (*Pinus cembra L.*) took place in the nineteenth and twentieth centuries (Fragnière et al., 2021). Similarly, in the United States of America, massive afforestation efforts covered approximately 80,000 hectares of land in the South Carolina Coastal plains in the early 1950s. Over half a century, this initiative resulted in an increase in forest cover from 48,714 hectares to 73,824 hectares (Aubrey, Blake & Zarnoch, 2019). Any historical perspective on afforestation (however brief) is incomplete without considering the ramifications of colonization in the Global South. Former colonial outposts in South America, Asia, and Africa experienced extensive afforestation drives aimed at increasing economic productivity rather than enhancing green cover. For instance, Eucalyptus and Pine plantations are scattered across South America, including countries like Argentina, Brazil, Chile, and Uruguay (Fernandes et al., 2016). Similarly, in Asia and Africa, monocultures of economically important floral species were planted to supply timber, pulp, and other economically significant products (Liu, Kuchma & Krutovsky, 2018).

As detailed in prior sections, A/F-based projects account for approximately 6 million carbon offsets. Despite the large amounts of value traded, such projects are often poorly conceived. Generally, projects target barren and degraded lands. Such lands are often viewed as wastelands, providing no ecological value, or in this sense, no ability to sequester carbon (Veldman et al., 2015). Essentially, the lack of trees is viewed as an opportunity to capture carbon. The foundation of such A/F projects is rooted in a flawed understanding of ecosystems in general and mischaracterizes less characteristic ecosystems, such as grasslands and scrublands, as wastelands.

Despite their notable biodiversity, grassy biomes are frequently assigned a low conservation priority. There are 2 major categories of projects focussed on grasslands–

a) Avoided grassland conversion (ACM) and;
b) Sustainable grassland management (SGM).

SGM includes strategies that improve grazing rotation, prevent grazing on degraded land until it regenerates, restore severely degraded pasture through replanting, and lower the frequency of fires through planned burns to boost above- and below-ground carbon stocks. Out of the 1481 forestry and land use projects registered in the VCM, only 32 actively participate in grassland conservation activities, specifically focusing on avoided grassland conversion (Haya et al., 2023) (Table 1). This stark contrast arises from a deficiency in quantifying ecosystem services. Within the Voluntary Carbon Market (VCM), all ecosystems face assessment based solely on one metric: carbon.

The Grassland management projects tabulated (Table 3) above primarily use Verra's VM0026 and VM0042 Methodologies for sustainable grassland management (SGM), and VM0032 Methodology for the adoption of sustainable grasslands through adjustment of fire and grazing. The VM 0032 Methodology is used for managing fire practices, through shifting the timing as well as intensity of the fires to increase soil C inputs. However, the methodology notes that "*Increased fire may be used to shift plant species composition such that net carbon sequestration in soil increases (e.g., conducting a single burn to shift vegetation from shrubs to grasses), but the net increase in SOC must compensate for any losses in woody biomass and increases in methane (CH4) and nitrous oxide (N2O) emissions.*"

There is an increased focus on the ability of a natural ecosystem to sequester C–the only measure that is taken into account, while completely ignoring the unique ecology of grasslands (Aguirre-Gutiérrez, Stevens &Berenguer, 2023) and how changing fire timings (along with suppression of fires during their natural times) can have severe unintended consequences for grassland species In such a carbon-centric framework, the broader spectrum of ecosystem services remains neglected. In the pursuit of enhancing carbon sequestration capacity, grassy biomes, such as the Cerrado savannahs, are disproportionately perceived as opportunities solely for increasing carbon stocks. The Cerrado, for example, has not only faced challenges like forest encroachment but also endured active fire suppression for up to three decades. The absence of comprehensive quantification of ecosystem services, coupled with a carbon-stock-centric approach, has significantly impacted the native ecology of the Cerrado (Abreu et al., 2017).

In 2017, Abreu et al. shed light on a distinctive phenomenon occurring within the Cerrado. Intensive efforts to suppress fires and a rise in forest encroachment resulted in an expansion of tree cover within the tropical savannah. However, this heightened tree cover was accompanied by a decrease in native vegetation, specifically the previously mentioned 'herbaceous' layer. Some studies (Pellegrini et al., 2016; Andika, Anwar & Hendratiti, 2024) (have argued for an increase in biodiversity, by purporting the increase in tree cover, overlooking the actual reduction in native floral species richness. It isn't just flora that suffers; fauna is also adversely affected. Specialist guilds, such as invertebrate communities, especially fail to recover when grasslands are encroached upon by forests. In areas of the Cerrado fully encroached by forests, the diversity of aboveground-foraging ant communities dropped significantly by 86%.

Beyond the Cerrado; savannah, and grassland ecosystems in general exhibit adverse reactions to forest encroachment. Natural grassland vegetation struggles in the low light conditions created by forest canopies. Additionally, floral species face limitations not only in terms of light but also in the absence of fire. Grassland ecosystems possess a unique characteristic - they don't just endure wildfires but thrive with them. In support of the same, Fidelis & Blanco (2014) elucidated that graminoid species demonstrated the highest flowering capacity one year after a fire, while forbs exhibited a greater diversity of flowering species immediately after fires in Brazil's subtropical grasslands.

In contrast to the longstanding practices of A/F, IFM and REDD+ are relatively recent terms, gaining formal recognition as part of the Kyoto Protocol. The scope of the two emerged with a focus on conserving existing forests and addressing issues like degradation and fragmentation.

IFM specifically targets enhancing carbon sequestration, emphasizing sustainable forest management practices. REDD+, while sharing the goal of carbon conservation, goes beyond actively avoiding deforestation and reducing emissions from existing forests. This includes measures such as limiting firewood collection from forests, thereby conserving carbon stocks and mitigating emissions. It's noteworthy that while A/F revolves around establishing new forests (or re-establishing old ones), IFM and REDD+ contribute to broader objectives, encompassing efficient carbon sequestration, biodiversity conservation, and sustainable ecosystem services.

Previous studies have voiced apprehensions regarding IFM and REDD+, expressing concern about the conceptual foundations, implementation strategies, and subsequent consequences. For example, Poudel et al. (2015)

brought attention to a breach of the "*no harm and equitable*" policy pledged by REDD+ protocols in Nepal. Their investigation revealed that attempts to enhance equity by grouping households based on caste, to reduce inter-caste conflicts, paradoxically heightened the probability of intra-caste marginalization.

Another frequently cited limitation of REDD+ pertains to its insufficient attention to wildlife within forest ecosystems. In a literature review (Krause & Nielsen, 2019), various REDD+ initiatives in the Global South were evaluated. The review assessed protocols in place in Colombia, Ecuador, Nigeria, Tanzania, and Indonesia with the aim to determine the extent to which such protocols addressed defaunation and the subsequent cascading ecological repercussions. The review found that while several REDD+ projects at a sub-national level did incorporate mentions of subsistence hunting as a driver of defaunation, such considerations were notably lacking in national-level frameworks. In instances where projects did address subsistence hunting by indigenous or local communities, there was a failure to adequately account for the costs associated with restricting access to forest resources. These costs, including potential impacts on food security for impoverished or indigenous populations in the region, were insufficiently considered. Furthermore, the research underscored a notable inadequacy in monitoring fauna as a significant drawback of REDD+ projects.

Similar to REDD+, IFM protocols are not exempt from criticism. The fundamental drawback of IFM is associated with the issue of over crediting. Specifically, certain IFM methodologies, like those developed by ACR and VCS, neglect to consider losses in soil organic carbon (SOC). This omission is justified by assuming that SOC stocks are transient and, therefore, inconsequential. Consequently, the logistical and financial challenges linked to SOC quantification are deemed unnecessary. By actively excluding SOC stocks from project assessments, IFM protocols frequently overlook the organic carbon lost at and below ground level. Such non-conservative approaches to generating carbon offsets reveal methodologies that are not aligned with the current scope and advances of soil science, indicating a deviation from scientific rigour.

Other project scopes include Avoided Forest Conversion (AFC), Avoided Grassland Conversion (AGC), Sustainable Grassland Management (SGM), and Wetland Restoration (WR). With AFC and AGC, the root of the protocols lies in the principle of avoidance. Unlike A/F, IFM, and REDD+, such protocols do not aim to reduce or restore carbon loss but rather aim to protect existing carbon. Although such protocols require a reduced degree of site preparation and management, they are barely pursued. Worldwide, a measly 48 AFC and AGC projects have been generated. Of these, only 4 have been completed. Despite the low number of projects generated and subsequently completed, studies have been able to illustrate that protocols based on avoidance *can* generate a meaningful loss of emissions and thus contribute to climate change mitigation (Ahlering, Fargione & Parton, 2016).

Discussion

New Forests Are Empty Forests

When Redford (1992) introduced his now seminal findings on empty forests, he identified indigenous hunting in tropical forests as the primary driving force for the depletion of animal populations. While both commercial and indigenous hunting still pose significant threats to the persistence of populated forests, a unique scenario arises when examining deliberate, systematic, and well-funded initiatives that actively contribute to the creation of new (or restored) forests.

In market-based approaches to nature conservation, centred around carbon metric, a seemingly counterintuitive narrative unfolds. For example, in the Cerrado, a combination of forest encroachment and fire suppression in the native landscape led to a consistent annual increase in ecosystem carbon storage. Specifically, in 2015, the mean carbon stocks in the Cerrado were 20.8 Mg ha−1 in open savanna sites and 83.5 Mg ha−1 in forested areas (Abreu et al., 2017). Despite the yearly rise in carbon stocks, the forested areas do not support as many animals as expected. For instance, among the four canids found in the central landscapes of Brazil—namely, the maned wolf, hoary fox, crab-eating fox, and the bush dog—three show a preference for non-forested areas. Studies on niche separation indicate that even when forests are present, canids like the maned wolf and hoary fox predominantly spend their time in Open Natural Ecosystems (ONEs). Notably, the hoary fox, which specialize in predating on termites, become particularly averse to forests due to the collapse of invertebrate guilds accompanying the encroachment of grasslands (de Almeida Jácomo, Silveira & Diniz-Filho, 2004).

The VCM tends to highlight certain landscapes, such as the Cerrado, as success stories due to increased carbon storage resulting from forest encroachment and fire suppression. This emphasis on carbon-centric achievements, while overlooking the loss of biodiversity and ecological integrity in the pursuit of carbon sequestration, creates a paradoxical situation. The very conservation efforts intended to protect forests end up transforming them into 'empty' ecosystems, prioritizing carbon storage over the intricate balance of diverse native species and ecosystems.

Degradations Through Restoration: Ecological Effects of Current Forestry and Land Use Protocol

Forestry initiatives such as A/R protocols are primarily motivated by the overlapping geographic ranges of forests and grasslands. As both biomes can occur in the same location; theoretically, the conversion of a grassland into a forest is feasible (Staver, Archibald & Levin, 2011). However, the mere capacity of a patch to support forests is not a sufficient rationale for transforming an ecosystem from its existing state. The ecological effects of A/R can be classified as follows:

A.) Abiotic effects: Alterations to the physico-chemical properties of various ecosystem components, including soil, water, and geological attributes, constitute abiotic effects. Wu et al. (2019a) elucidated edaphic effects in high-altitude savanna-type grasslands in China that experienced forest encroachment through afforestation efforts. Their research indicated an increase in levels of essential soil minerals such as SOC, calcium (Ca^{2+}), magnesium (Mg^{2+}), and ferric iron (Fe^{3+}). Additionally, an elevation in soil pH was also discerned. Other effects, such as an increase in organic phosphorus (P) in soil have also been observed as a by-product of afforestation of coniferous trees in grasslands.

Ascribing widespread and consistent edaphic effects on a global scale is challenging due to the non-homogeneous nature of soil as an ecological component. Nevertheless, some general inferences can be drawn. For instance, the afforestation of Pinus species in grassland-type ecosystems, both in South America (Uruguay) and Asia (China), led to increased concentrations of soil organic carbon (SOC) along with elevated soil acidification (Gallego et al., 2023; Wu et al., 2019a).

Likewise, A/F exerts substantial influences on the hydrology of native ecosystems. Specifically, A/F activities significantly affect evapotranspiration, a crucial hydrological process wherein both evaporation and transpiration collectively represent the overall water vapor loss from an ecosystem. This combined effect, commonly referred to as evapotranspiration, is frequently observed to increase with afforestation or revegetation, particularly in arid and semi-arid ecosystems (Lu et al., 2018).

Large-scale afforestation projects have a significant impact on the groundwater tables and hydrological cycles in sensitive ecosystems. Such projects increase the evaporation rate through transpiration reducing soil moisture along with decreasing run-off (Trabucco et al., 2008). In turn, this influences local precipitation levels as well as discharge to local water bodies and lakes and can increase the occurrences of droughts in arid areas (Feng et al., 2016). Xiao, Xiao and Sun (2020) provided an in-depth exploration of the hydrological consequences associated with afforestation across various regions in China. Their findings highlighted a notable pattern associating extensive afforestation with a shortage of water resources. Since 1952, A/F has been widespread in Southwestern China. The protocol was intended as a measure to counteract desertification. However, this approach has led to an increase in green cover, accompanied by a concomitant rise in the frequency of drought occurrences. Additionally, the study indicated that the evapotranspiration rate in artificial forests, specifically afforested or newly planted areas, exceeded that of natural or old-growth forests. This elevated evapotranspiration, combined with instances of reduced precipitation, ultimately resulted in situations of water scarcity.

Simulation studies using Regional Hydro-Ecological Simulation System (RHESSys) models (Tague & Band, 2004) have been widely used to compare various theoretical land use management practices. These models use a hierarchical modelling approach to investigate a range of hydrological, climatic, and ecosystem processes associated with a landscape. These tools can also be used as predictive tools for ascertaining the efficacy of various LULC management practices (such as natural revegetation of abandoned agricultural lands, afforestation programs, shrub clearing, etc.) and their long-term effects on the hydrological cycles (Peng, Tague & Jia, 2016). The Pyrenees mountains in the Mediterranean have been the focus of some of these studies as these areas contain large swathes of abandoned farmlands which in some places have been subject to natural process of revegetation or artificial management practices (Khorchani et al., 2022). Their results indicate that an increase in forest cover can decrease the annual streamflow for most of the riverine basins by up to 50% in this arid landscape.

B.) *Biotic effects:* Changes to faunal and floral community composition comprise biotic effects. The biotic consequences caused by forestry and land-use practises are widespread and cascading; spread across trophic levels.

For instance, Príncipe et al. (2015) studied stream ecosystems from Argentina in a series of grassland and pine-afforested ecosystems and quantified the invertebrate Ephemeroptera–Plecoptera–Trichoptera group (EPT) abundance and species richness. The EPT group plays an important role in the decomposition of aquatic leaf litter (Ab Hamid & Rawi, 2017) thus, influencing the energy and nutrient cycle in the ecosystem. Afforested areas showed lower EPT abundance and species richness compared to grasslands thus indicating better water quality in the latter.

The structure of vegetation, light availability, and soil chemical changes affect the richness and abundance of reptiles and amphibians. Pitfall studies in the Pampa grasslands of Brazil found lower herpetofaunal diversity in the afforested lands compared to native grasslands (Saccol, Bolzan & dos Santos, 2017). Similar studies from the Udzunga plateau in Tanzania have found empirical evidence for the local extinction of amphibian populations with smaller assemblages now clustered in small non-pine native grassland refugia (Lawson et al., 2023). A study on the phylogenetic diversity of amphibian species from various human-modified landscapes found a high rate of loss of evolutionary distinct species in pasture lands and agroforestry plantations, two of the major threats for protection of native grassland biomes (Greenberg et al., 2018).

Afforestation-induced changes in the community assemblages of birds have been well-documented from various regions of the world. Open habitat specialists inhabiting native grasslands can be replaced by generalists in plantation forested lands (Jacoboski & Hartz, 2020; Corkery et al., 2020). Studies comparing species assemblages in plantation forests with native grasslands from coastal Brazil found that roughly half of the 40 obligate and facultative grassland species were absent from plantations. These can severely impact rarer species and those with restricted geographic range (Dias et al., 2013). Modelling community composition from large-scale bird datasets from Ireland highlight the threshold values of afforestation land and their implications on bird species richness (Corkery et al., 2020). They found that as forested area approaches 35% of the total land area, there is a shift in the dominant avian community. These shifts result in removal of bird species like rooks, starlings, and swallows from these afforested lands.

Studies from China, which have been a focus of multiple afforestation efforts, highlight their negative effects on mammal communities. Comparison between plantation forests with old-growth and young-growth forests (Wu et al., 2019b), found no difference in the species abundance or richness metrics of small mammals. However, they found evidence of poorer body condition (reduced body mass and increased endoparasitic load) for the mammals from the plantation forests. The true effects of afforestation in shifting mammalian communities can occur over longer time periods as at least in early stages of afforestation there doesn't seem to be any detectable effect on the small mammal assemblages (Johnson et al., 2002).

Conclusion

The rising climate consciousness around the globe and efforts to reduce emissions, forestry, and land use projects have become one of the key strategies adopted by international and national bodies, almost at par with the increased effort to shift to alternate power sources. A/F protocols particularly are viewed as easy fixes to the climate crisis. The aim is simple, to remove or *offset* a proportion of the CO_2 emitted, by planting more trees. With the climate crises only worsening and future projections gloomier than ever, an increased drive to convert millions of acres of "*forestable*" lands into living breathing forests drives A/F. This needs to create forests has led to the misidentification of open habitats — grasslands, open canopy woodlands, savannahs, etc., as ecologically less valuable. Thus, they are viewed as opportunities ripe for forestry.

Our understanding of open ecosystems and the diversity of the flora and fauna that thrive within them is highly nascent. The fundamental problem with afforestation is the notion of transformation. With Afforestation, the aim is to transform "empty space" into dense canopy. In a bid to transform land, a thriving native ecosystem is forcibly changed and modified into another—undoing millions of years of ecological balance in a blink. Such actions have the potential to cause large-scale ecological catastrophes in the near future.

The aim of this chapter was to carefully dissect the historical trajectory of carbon offsets, and the globally agreed upon objectives of voluntary carbon projects that have led to the development of the carbon credit market. Rather than reducing emissions, projects endorsed by the VCM cause significant harm to native ecosystems. These efforts are at best misguided and achieve very little in terms of *reducing* the CO_2 levels in the atmosphere as they are based on a flawed understanding of ecosystems. At their worst, these projects are increasingly being used by corporate entities to *greenwash* their brands and project a sense of false social responsibility towards their customers. They peddle the idea of "carbon neutrality" or "net zero" to appease goals set forth by international frameworks.

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Chapter 4

Understanding the Direct and Indirect Chemical Effects on Biodiversity

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Abstract

This book chapter explores the multifaceted impact of chemicals on biodiversity, exploring various dimensions of habitat alteration, water pollution, air pollution, bioaccumulation, endocrine disruption, and genetic diversity. Focusing on the direct and indirect consequences of chemical interactions with ecosystems, the chapter investigates the profound effects on plant and animal species. Habitat alteration, driven by agricultural chemicals and land use changes, disrupts ecosystems and food webs, leading to a reduction in biodiversity. Water pollution, stemming from industrial discharge and agricultural runoff, poses threats to aquatic environments, causing imbalances and endangering aquatic species. Air pollution, through airborne toxins, contributes to climate change, influencing species behaviour and distribution. Bioaccumulation and biomagnification of persistent organic pollutants (POPs) reveal the intricate dynamics of chemical persistence in the environment, affecting organisms at higher trophic levels. Endocrine-disrupting chemicals (EDCs) interfere with the reproductive and developmental processes of organisms, resulting in population declines and ecosystem imbalances. Mutagenic chemicals induce genetic mutations, diminishing genetic diversity and increasing vulnerability to environmental changes. The chapter also highlights mitigation efforts, emphasizing sustainable agricultural practices, improved waste

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management, regulatory frameworks, and eco-friendly alternatives. International agreements, exemplified by the Stockholm Convention on Persistent Organic Pollutants, underscore the global commitment to addressing the pervasive impact of certain chemicals on both human health and the environment. This comprehensive exploration serves as a valuable resource for researchers, policymakers, and environmentalists working towards sustainable coexistence with the natural world.

Keywords: chemicals, biodiversity, bioaccumulation, pollution, sustainability

Introduction

In an era marked by unprecedented human activities and industrialization, the intricate relationship between chemicals and biodiversity has emerged as a critical area of concern. The impact of chemicals on ecosystems is multifaceted, ranging from habitat alteration to genetic diversity disruption. This book chapter delves into the various dimensions of this complex interplay, unraveling the direct and indirect consequences that chemical interactions inflict on plant and animal species and ultimately on the delicate balance of biodiversity (Shivanna, 2022; Hariram et al., 2023). As human populations burgeon, the demand for agricultural products has intensified, leading to widespread habitat alteration and land use changes. The extensive use of agricultural chemicals, including pesticides and fertilizers, has become synonymous with modern farming practices. These alterations, driven by the relentless expansion of agriculture, disrupt ecosystems and food webs, resulting in a reduction in biodiversity. The chapter embarks on an exploration of the profound consequences of these habitat alterations, revealing the interconnectedness of ecosystems and the vulnerability of various species to such changes. Water pollution, another significant facet of the chemical impact on biodiversity, is often a consequence of industrial discharge and agricultural runoff. The contamination of aquatic environments poses a severe threat to the delicate balance of ecosystems, causing imbalances and endangering aquatic species. The chapter meticulously examines the sources and consequences of water pollution, shedding light on the pervasive influence of chemicals on the health of rivers, lakes, and oceans. It underscores the urgency of addressing water pollution to safeguard not only aquatic life but also the integrity of entire ecosystems (Bashir et al., 2020; Singh et al., 2021).

Air pollution, with its airborne toxins and pollutants, contributes not only to climate change but also influences the behaviour and distribution of various species. The chapter scrutinizes the link between air pollution and biodiversity, unraveling the subtle yet impactful ways in which airborne chemicals alter the dynamics of ecosystems (Manisalidis et al., 2020). From shifts in migration patterns to disruptions in the reproductive cycles of certain species, the consequences of air pollution resonate across the intricate web of life on Earth. The dynamics of chemical persistence in the environment are explored through the phenomena of bioaccumulation and biomagnification of persistent organic pollutants (POPs). The chapter navigates the intricate pathways through which these chemicals permeate ecosystems, affecting organisms at higher trophic levels. The consequences of bioaccumulation extend far beyond individual species, posing threats to entire food chains and ecosystems. Endocrine-disrupting chemicals (EDCs) represent yet another dimension of the chemical impact on biodiversity. These chemicals interfere with the reproductive and developmental processes of organisms, resulting in population declines and ecosystem imbalances (Diamanti-Kandarakis et al., 2009). The chapter scrutinizes the far-reaching implications of EDCs, emphasizing the need for a comprehensive understanding of their effects on both individual species and the broader ecological context.

The impact of mutagenic chemicals on genetic diversity forms a crucial aspect of the chapter's exploration. Genetic mutations induced by certain chemicals diminish the resilience of populations, making them more vulnerable to environmental changes. The intricate dance between mutagenic chemicals and genetic diversity unfolds, emphasizing the importance of preserving the genetic variability that underpins the adaptability of species in the face of evolving environmental challenges (Loewe & Hill, 2010). Amidst these challenges, the chapter highlights mitigation efforts and strategies aimed at promoting sustainable coexistence with the natural world. Sustainable agricultural practices, improved waste management, regulatory frameworks, and the development of eco-friendly alternatives emerge as crucial components of a holistic approach towards mitigating the impact of chemicals on biodiversity. International agreements, such as the Stockholm Convention on Persistent Organic Pollutants, exemplify the global commitment to addressing the pervasive influence of certain chemicals on both human health and the environment (Wang & Praetorius, 2022). In essence, this book chapter serves as a comprehensive exploration of the multifaceted impact of chemicals on biodiversity. By unraveling the intricate threads that connect chemical interactions with ecosystems, it provides a valuable resource for researchers, policymakers, and environmentalists striving towards a harmonious and sustainable coexistence with the natural world.

Habitat Alteration

Habitat alteration, driven primarily by agricultural practices, poses a significant threat to ecosystems worldwide. One major contributor to this issue is the widespread use of pesticides and herbicides. While these chemicals are designed to control pests and unwanted vegetation, they often have unintended consequences on non-target species and the broader environment. Pesticides, such as insecticides and fungicides, are designed to eliminate or reduce the population of specific pests that threaten crops (Tudi et al., 2021). However, these chemicals can have detrimental effects on non-target organisms, including beneficial insects, birds, and aquatic life. For example, neonicotinoid pesticides have been linked to the decline of pollinators like bees, essential for the reproduction of many flowering plants. The disruption of food webs caused by pesticide use can lead to imbalances in ecosystems, with cascading effects on biodiversity (Fairbrother et al., 2014; Latt et al., 2023). Similarly, herbicides, used to control weeds in agricultural fields, can have unintended consequences. These chemicals may not only affect the targeted plant species but also impact surrounding vegetation and the organism's dependent on them. The loss of plant diversity can have repercussions for herbivores and other species that rely on specific plants for food and shelter may be shown in Figure 1.

Deforestation and land use changes are additional drivers of habitat alteration. As agricultural activities expand, forests are often cleared to make way for crops or livestock. This process not only results in the direct loss of habitats but also leads to habitat fragmentation. Fragmentation can isolate populations, making it difficult for species to maintain genetic diversity and adapt to changing environmental conditions. Urbanization further exacerbates the problem by replacing natural habitats with impervious surfaces, disrupting ecosystems and displacing wildlife. Overall, habitat alteration caused by pesticides, herbicides, deforestation, and land use changes poses a serious threat to biodiversity. Conservation efforts must focus on sustainable agricultural practices, reforestation initiatives, and smart land use planning to mitigate the negative impacts of habitat alteration and preserve the delicate balance of ecosystems (Wilson & Lovell, 2016). Only through a holistic approach can we hope to safeguard the diverse array of species that call these habitats home.

Figure 1. Schematic representation of habitat alteration.

Water Pollution

Water pollution caused by the discharge of industrial chemicals and heavy metals poses a significant threat to aquatic ecosystems, with far-reaching consequences for both the environment and human health may be represented by Figure 2. The unchecked release of pollutants into water bodies, such as rivers, lakes, and oceans, has become a pervasive environmental challenge. Industrial activities contribute extensively to water pollution through the release of a myriad of chemicals and heavy metals into aquatic environments (Aziz et al., 2023). These contaminants often stem from manufacturing processes, waste disposal, and improper handling of industrial byproducts. The repercussions of this pollution are multifaceted and can be observed at various levels within the ecosystem. One of the most immediate and visible impacts is the detrimental effect on aquatic species. Fish, invertebrates, and other organisms are particularly vulnerable to the toxic effects of industrial pollutants. Exposure to these chemicals can result in altered reproductive patterns, impaired growth, and even mortality, contributing to a decline in populations. Moreover, the contamination disrupts the delicate balance of aquatic ecosystems, leading to cascading effects on entire food chains (Impellitteri et al., 2023).

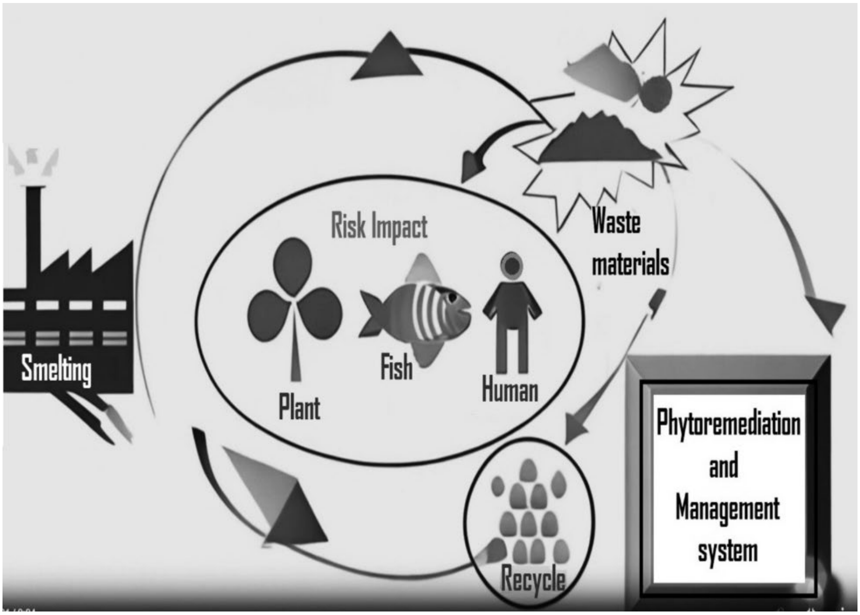

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Figure 2. Water pollution caused by the discharge of industrial chemicals and heavy metals and remediation.

The negative consequences extend beyond individual species to impact biodiversity on a broader scale. As certain species decline or disappear due to pollution, the interconnected web of life in aquatic environments is disrupted. This disruption has a ripple effect, influencing the abundance and distribution of other species. The loss of biodiversity not only compromises the resilience of ecosystems but also diminishes their ability to provide essential services, such as water purification and nutrient cycling. In addition to ecological ramifications, water pollution from industrial chemicals and heavy metals poses a threat to human health. Contaminated water sources can lead to the bioaccumulation of toxins in fish and shellfish, which, when consumed by humans, can result in serious health issues. Addressing this complex issue requires a multifaceted approach, including stricter regulations on industrial discharges, improved waste management practices, and the promotion of sustainable industrial processes (Noman et al., 2022).

Only through concerted efforts can we mitigate the impact of industrial pollutants on water bodies and safeguard the health and diversity of aquatic ecosystems for current and future generations.

Agricultural Runoff

Agricultural runoff represents a formidable threat to the health of water bodies, posing a significant environmental challenge worldwide. The discharge of a myriad of chemicals, including fertilizers and pesticides, into aquatic ecosystems disrupts the delicate equilibrium of nutrients in the water, setting off a chain of ecological repercussions. One of the most pressing issues stemming from agricultural runoff is the proliferation of harmful algal blooms, a phenomenon with far-reaching consequences. These blooms, fueled by an excess of nutrients such as nitrogen and phosphorus, undergo rapid multiplication, forming a dense layer on the water's surface. The consequence is a condition known as hypoxia, wherein oxygen levels in the water plummet (Nwankwegu et al., 2019). This oxygen scarcity proves detrimental to aquatic life, especially fish, which rely on oxygen-rich water for their survival. Consequently, fish kills become a distressingly common outcome, exacerbating the ecological impact of agricultural runoff on water ecosystems. Moreover, harmful algal blooms contribute to a decline in aquatic biodiversity. By outcompeting other organisms for resources and creating inhospitable conditions, these blooms disrupt the natural balance of the ecosystem. The resulting imbalance jeopardizes the overall health and sustainability of aquatic habitats, further emphasizing the urgent need for intervention.

Addressing the adverse effects of agricultural runoff demands a multifaceted approach. First and foremost, the adoption of sustainable farming practices is paramount. Farmers can implement measures such as cover cropping, buffer strips, and rotational grazing to minimize soil erosion and runoff. Additionally, the adoption of precision agriculture techniques, including targeted application of fertilizers and pesticides, can significantly reduce the amount of chemicals entering water bodies. Enforcing stringent regulations is another critical component of mitigating agricultural runoff. Governments and environmental agencies must implement and monitor policies that limit the release of harmful chemicals into water bodies. Such regulations should encompass not only the types and quantities of chemicals used but also the timing and methods of application to minimize environmental impact (Sukenik & Kaplan, 2021). In conclusion, safeguarding water ecosystems from the detrimental effects of agricultural runoff requires a concerted effort from farmers, policymakers, and the broader community. By implementing sustainable farming practices, adopting precision agriculture techniques, and enforcing stringent regulations, we can work towards preserving the integrity of our water ecosystems and ensuring the long-term health and biodiversity they support. It is a collective responsibility to strike a balance between agricultural productivity and environmental conservation for the benefit of current and future generations (Poddar, 2024).

Air Pollution

Air pollution stands as a formidable threat to biodiversity, emanating primarily from the release of airborne toxins originating from industrial activities. These pollutants, encompassing gases and particulate matter, extend their impact beyond direct harm to human health, exerting indirect consequences on ecosystems and wildlife. One significant ramification is their role in contributing to climate change (Manisalidis et al., 2020). The emission of greenhouse gases like carbon dioxide and methane exacerbates the greenhouse effect, fueling global warming. The resultant alterations in atmospheric conditions, influenced by the influx of pollutants, pose multifaceted challenges to ecosystems and biodiversity. The shifts in temperature and precipitation patterns induced by these pollutants have profound effects on habitat suitability, causing consequential changes in species distribution and behaviour. Some species struggle to adapt to the evolving conditions, leading to a decline in biodiversity as ecosystems grapple with the difficulty of maintaining equilibrium among their constituent species. This disruption extends further as the intricate web of interactions within ecosystems is jeopardized, with airborne toxins compromising the health and vitality of various organisms.

Biodiversity, inherently interconnected and interdependent, faces a cascading effect when any element within the ecosystem is disturbed. Hence, mitigating air pollution emerges not only as a necessity for human well-being but also as an imperative for safeguarding the delicate balance of life on Earth. Sustainable practices and stringent environmental regulations play a pivotal role in addressing this pressing issue. By curbing industrial emissions and promoting eco-friendly alternatives, we can alleviate the stress on ecosystems and mitigate the adverse effects of air pollution on biodiversity (Chu & Karr, 2017). The urgency of this matter underscores the need for collective efforts to adopt sustainable practices, invest in clean technologies, and enforce strict environmental policies. Preserving biodiversity is not only a moral obligation but also essential for the resilience and sustainability of our planet. By committing to these measures, we pave the way for a healthier environment, ensuring the preservation of biodiversity for the well-being of current and future generations.

Bioaccumulation and Biomagnification

Persistent Organic Pollutants (POPs) represent a class of chemical substances, encompassing pesticides and industrial pollutants, celebrated for their environmental tenacity. Their resistance to degradation allows them to endure in soil, water, and air over prolonged periods, instigating a cascade of ecological repercussions. The phenomenon of bioaccumulation delineated as the gradual buildup of these pollutants within organisms' tissues over time (Olisah, Adams & Rubidge, 2021), is a critical facet of their impact. As lower trophic level organisms absorb POPs from their surroundings, these chemicals amass in their bodies. The unsettling consequence arises as these contaminated organisms are consumed by predators higher up in the food chain, giving rise to biomagnification. This process accentuates the concentration of POPs at each trophic level, resulting in elevated exposure for animals occupying higher trophic positions. The ramifications of biomagnification are particularly profound for top predators. Animals at higher trophic levels experience magnified exposure to POPs due to the cumulative effect along the food chain. Elevated concentrations of these persistent chemicals in the tissues of these predators can lead to severe health consequences, including reproductive issues and population declines. This has been observed in various ecosystems worldwide, impacting species such as birds of prey, marine mammals, and apex predators (Miller, Hamann & Kroon, 2020).

Beyond posing direct threats to wildlife, the biomagnification of POPs raises concerns about human health. Humans, often positioned at the apex of terrestrial food chains, can inadvertently consume contaminated organisms, resulting in potential health risks and the bioaccumulation of these pollutants within human tissues. Mitigating the impact of POPs necessitates concerted efforts to regulate and reduce their production, usage, and release into the environment. Global initiatives and agreements, exemplified by the Stockholm Convention on Persistent Organic Pollutants, are crucial in addressing the challenges associated with these substances. Such endeavors aim to promote sustainable practices, safeguarding both ecosystems and human well-being. By emphasizing the importance of understanding and mitigating the impact of POPs, these initiatives contribute to a healthier and more sustainable coexistence between humans and the environment.

Endocrine Disruption

Endocrine disruption, triggered by Endocrine-Disrupting Chemicals (EDCs), stands as a critical concern with profound implications for the delicate balance of ecosystems. The endocrine system, a key regulator of physiological processes, including reproduction and development, becomes vulnerable to interference by EDCs. These chemicals possess the capacity to either mimic or block hormones, initiating dysregulation that reverberates through individual organisms and entire ecosystems (Diamanti-Kandarakis et al., 2009). The repercussions of EDC exposure on reproduction and development are severe, manifesting as reproductive abnormalities, diminished fertility, and developmental disorders. These disruptions cascade through ecosystems, contributing to population declines and imperiling the delicate equilibrium of diverse habitats. Species subjected to endocrine disruption face challenges in successfully reproducing, potentially leading to population declines and, in extreme cases, extinction. Human activities emerge as significant culprits in the release of EDCs into the environment (Diamanti-Kandarakis et al., 2009). Industrial chemicals, pesticides, and certain pharmaceuticals constitute common sources, infiltrating water bodies, soil, and air. This pervasive contamination poses a threat to both aquatic and terrestrial organisms. Moreover, EDCs exhibit an alarming ability to bioaccumulate in the food chain, intensifying their impact on higher trophic levels, including humans (Figure 3).

Addressing endocrine disruption necessitates comprehensive strategies encompassing the regulation and monitoring of EDCs. Additionally, efforts should focus on developing alternative, safer chemicals to replace harmful counterparts. Safeguarding ecosystems from the detrimental effects of EDCs emerges as an imperative task to maintain biodiversity and preserve the overall health of our planet (Mnif et al., 2011). As our understanding of endocrine disruption evolves, there is a growing urgency to adopt sustainable practices that minimize the release of EDCs into the environment and mitigate their adverse effects on ecosystems. This involves a collective commitment to responsible industrial practices, informed agricultural methods, and vigilant waste management. By embracing sustainable alternatives and regulatory measures, humanity can play a pivotal role in averting the far-reaching consequences of endocrine disruption and ensuring a healthier coexistence with the natural world.

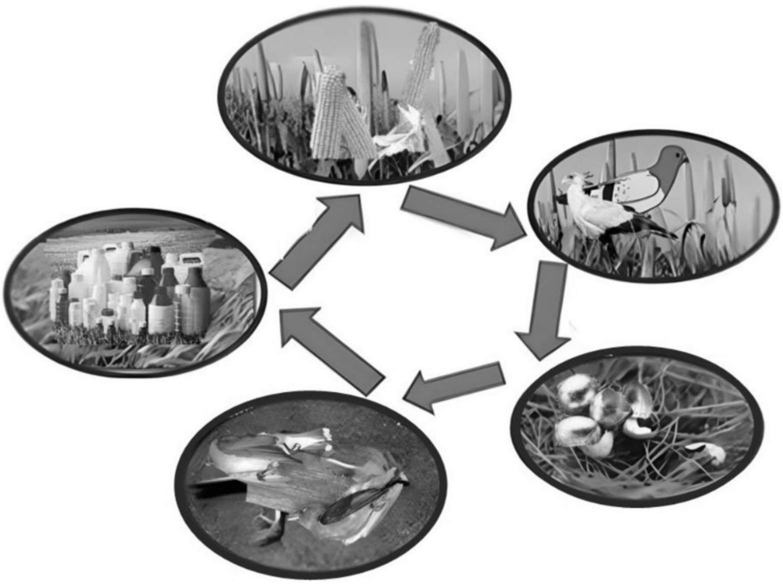

Figure 3. Schematic representation of the effect of pesticides on reproduction and development.

Genetic Diversity

Genetic diversity is a cornerstone of the biological integrity of populations, playing a pivotal role in their adaptability, resilience, and overall survival. One of the significant threats to genetic diversity comes in the form of exposure to mutagenic chemicals. These substances have the capacity to induce mutations in the genetic material of organisms, thereby altering their DNA sequences. This alteration compromises the genetic diversity within a population, posing severe threats to the long-term viability of a species (Sjöqvist & Kremp, 2016). Mutagenic chemicals can emerge from diverse sources, including industrial pollutants, pesticides, and certain drugs. When organisms encounter these chemicals, their DNA may undergo changes such as nucleotide substitutions, insertions, or deletions. These alterations can lead to the creation of new genetic variants, some of which may be advantageous, while others could be detrimental (Figure 4). The consequences of reduced genetic diversity extend far beyond the molecular level. Populations with limited genetic variability struggle to cope with environmental changes, making them more susceptible to threats like diseases, climate fluctuations, or alterations in their habitat (Furlan et al., 2012).

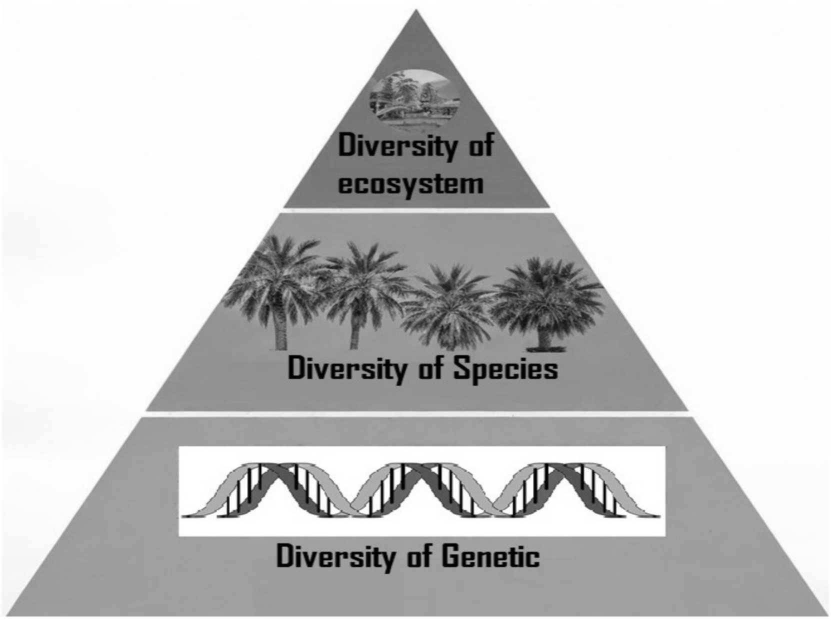

Figure 4. Schematic representation of different diversity.

In addition, the risk of inbreeding becomes a concern in populations with reduced genetic diversity, as individuals may be more closely related. This heightened relatedness increases the probability of expressing harmful recessive traits, further compromising the overall health of the population. Ultimately, a decrease in genetic diversity elevates the vulnerability of a population to extinction, as they become less capable of adapting to changing conditions or combatting emerging threats. This highlights the crucial importance of mitigating exposure to mutagenic chemicals and preserving genetic diversity for the overall health and sustainability of ecosystems (Teixeira & Huber, 2021). Conservation efforts must prioritize strategies to minimize the impact of mutagenic agents. Sustainable agricultural practices, improved waste management, regulatory frameworks for chemical use, and the promotion of eco-friendly alternatives are all essential components of this mitigation effort (Gamage et al., 2023; De, 2019). Sustainable agriculture, for instance, involves practices that maintain or enhance soil fertility, reduce the use of harmful chemicals, and promote biodiversity. Proper waste management ensures that pollutants are disposed of safely, preventing their entry into ecosystems. Regulatory frameworks for chemical use establish guidelines and restrictions to curb the adverse effects of mutagenic substances.

International agreements also play a crucial role in addressing the global impact of harmful chemicals. The Stockholm Convention on Persistent Organic Pollutants is one such example, aiming to regulate and phase out the production and use of certain chemicals that persist in the environment and pose significant risks to human health and ecosystems (Teran, Lamon & Marcomini, 2012). These agreements underscore the need for a collaborative and coordinated approach to protect biodiversity on a global scale. Hence, the preservation of genetic diversity is paramount for the long-term survival of diverse and resilient biological communities. Efforts to mitigate the impact of mutagenic chemicals must be multifaceted, encompassing sustainable practices, effective waste management, regulatory frameworks, and international collaborations. By prioritizing these strategies, we can work towards ensuring the health and sustainability of ecosystems, thereby safeguarding the genetic diversity that underpins the adaptability and resilience of populations worldwide.

Future Aspects

Future aspects of these studies in this field should delve deeper into the evolving landscape of chemical impacts on biodiversity, considering emerging chemicals and their potential consequences. Ongoing studies could explore the synergistic effects of multiple chemicals, as well as the long-term and cumulative impacts of chronic exposure on ecosystems. Advancements in monitoring and analytical technologies can enhance our ability to detect and understand the presence of trace chemicals in the environment. Integrating big data and machine learning approaches may provide more nuanced insights into the complex interactions between chemicals and biodiversity. Furthermore, future research could focus on developing innovative and sustainable solutions to mitigate the adverse effects of chemicals on ecosystems. This may involve exploring alternative agricultural practices, green chemistry initiatives, and the development of eco-friendly substitutes for hazardous chemicals. The interdisciplinary nature of this research calls for increased collaboration between ecologists, chemists, biologists, and policy experts. Future studies should aim to bridge the gap between scientific findings and practical implementation, fostering a more seamless transition from research to actionable policies and conservation practices. As environmental challenges evolve, ongoing adaptation of regulatory frameworks will be essential. Continued international cooperation, as exemplified by existing agreements like the Stockholm Convention, will be crucial in addressing global chemical threats. Future agreements and protocols may need to adapt to emerging challenges and incorporate a more proactive approach to prevent the introduction of potentially harmful chemicals into the environment. Ultimately, the future of research in this field lies in a holistic and dynamic understanding of the multifaceted impacts of chemicals on biodiversity. By combining scientific innovation, policy adaptation, and sustainable practices, we can work towards a future where humanity coexists harmoniously with the natural world, preserving biodiversity for generations to come.

Conclusion

In conclusion, the intricate relationship between chemicals and biodiversity presents a complex and multifaceted challenge that demands urgent attention and concerted efforts from researchers, policymakers, and environmentalists. The exploration of various dimensions, from habitat alteration and water pollution to air pollution, bioaccumulation, endocrine disruption, and genetic diversity disruption, underscores the pervasive impact of chemicals on ecosystems and the delicate balance of life on Earth. Habitat alteration, driven by agricultural practices and land use changes, poses a significant threat to biodiversity, disrupting ecosystems and food webs. Water pollution, originating from industrial discharge and agricultural runoff, jeopardizes aquatic environments and endangers species. Air pollution, with its airborne toxins, contributes to climate change and alters species' behaviour and distribution. Bioaccumulation and biomagnification of persistent organic pollutants (POPs) highlight the persistence of chemicals in the environment, affecting organisms at higher trophic levels. Endocrine-disrupting chemicals (EDCs) interfere with reproductive and developmental processes, contributing to population declines and ecosystem imbalances. Mutagenic chemicals induce genetic mutations, diminishing genetic diversity and increasing vulnerability to environmental changes. Mitigation efforts are crucial to address these challenges. Sustainable agricultural practices, improved waste management, and regulatory frameworks are essential components of a holistic approach. The development and promotion of eco-friendly alternatives play a pivotal role in minimizing the impact of chemicals on biodiversity. International agreements, exemplified by the Stockholm Convention on Persistent Organic Pollutants, signify the global commitment to addressing the pervasive influence of certain chemicals on both human health and the environment. As we navigate the complex web of chemical interactions with ecosystems, it is imperative to prioritize sustainable coexistence with the natural world. By understanding the intricate threads connecting chemical impacts to biodiversity, this comprehensive exploration serves as a valuable resource for guiding future research, shaping effective policies, and fostering a global commitment to preserving the rich tapestry of life on our planet. Through collaborative efforts, we can strive towards a harmonious and sustainable coexistence with the natural world, ensuring the well-being of current and future generations.

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Chapter 5

Public Health Concerns About the Effect of Solid Waste on Soil Pollution

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Abstract

Public health is often faced with soil pollution and the serious problems caused by solid waste. Protection and restoration of soil quality are important measures to maintain ecosystem sustainability, public health, and sustainable economic growth. To understand the complexity of these issues, this chapter aims to increase the reader's understanding and awareness of soil pollution and solid waste issues to support environmental conservation efforts with specific objectives. This paper breaks down some key questions: definitions of soil pollution and solid waste, types of solid waste, sources of solid waste, factors causing solid waste, impacts of solid waste on the environment, and appropriate

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measures for solid waste control and management. Several factors cause solid waste, including changes in consumption patterns, urbanization and population growth, industrialization, disposable materials use, and waste management infrastructure deficiencies. Of course, if solid waste is not prevented and managed properly, it will seriously impact humans and the environment. The impacts include odour, flooding due to clogged drains and sewers, and plastic waste that disturbs aquatic biota. Additionally, organic waste in open landfills creates a good environment for breeding disease-carrying animals (vectors), such as rats, mosquitoes, and flies. It also poses a risk of contaminating water, leading to the development of water-borne diseases. Solid waste management and control can be carried out to avoid the impact caused by the existence of solid waste. Solid waste management includes controlling the amount of waste generated, collection, transportation, processing, and final disposal. These five aspects are essential and must be considered in solid waste management. Besides management, solid waste can also be controlled in several ways, including the Reduce, Reuse, Recycle (3R) method and Waste-to-energy (WtE).

Keywords: public health concern, solid waste, soil pollution, waste-to-energy

Introduction

Soil is a natural system consisting of minerals, organic matter, water, air, and living organisms that interact in a complex manner (Weil & Brady, 2017). According to the Food and Agriculture Organization (FAO), soil is the Earth's surface layer of mineral, organic, and gaseous materials. Soil is the medium for plant growth and provides various ecosystem functions.

Soil pollution is a deepening environmental problem that affects many aspects of life. Soil pollution is influenced by population growth and urbanization (Snelder et al., 2022). Rapid population growth and high urbanization have driven Indonesia's industrial, agricultural, and construction activities. The result of increased population and urbanization is an increase in solid waste production, industrial waste, and significant changes in land use. High waste production that is not matched with proper waste management practices can contribute to soil pollution.

In addition, soil pollution can also impact human health. The impact depends on the type of pollutant, the route of entry into the body, and the vulnerability of the affected population. Some of the impacts of soil pollution on human health include brain and kidney damage from exposure to lead, mercury, cyclodiene etc and the risk of developing cancer from soil pollution. In addition, soil pollution can disrupt plant growth, reduce soil fertility, and damage ecosystems.

We are often faced with the problem of soil pollution and the serious problems caused by solid waste. To understand the complexity of these issues, we need to break down some key questions: definitions of soil pollution and solid waste, types of solid waste, sources of solid waste, factors causing solid waste, impacts of solid waste on the environment, and appropriate measures for solid waste control and management.Protection and restoration of soil quality are important measures to maintain ecosystem sustainability, public health, and sustainable economic growth. Therefore, it is necessary to analyse soil pollution's impact and identify solutions to address this issue.

This chapter aims to increase the reader's understanding and awareness of soil pollution and solid waste issues to support environmental conservation efforts. Some specific objectives are:

1. Define clearly and simply the meaning of soil pollution and solid waste so that various levels of society can understand it.
2. Identify various types of solid waste, including their sources and characteristics, to determine their variations and potential impacts.
3. Present information on the sources of solid waste, including aspects of production, consumption, and human behaviour, to specify the main causes of solid waste problems.
4. Explain the factors that cause solid waste, such as bad habits in waste management and lack of awareness of environmental impacts.
5. Identify the impact of solid waste on the environment, including human health, ecosystem damage, and climate change, to motivate preventive actions.
6. Present solid waste control and management measures, such as recycling, reducing plastic use, and implementing a sustainable waste management system.

Definitions of Soil Pollution and Solid Waste

Soil pollution is when artificial chemicals enter and alter the natural soil environment. According to the U.S. Environmental Protection Agency

(EPA), soil pollution occurs when there are substances in the soil at concentrations that exceed acceptable thresholds or have the potential to cause harm to human health or the environment. Soil pollution is generally caused by leakage of wastewater or industrial chemicals, pesticide use, infiltration of polluted surface water into the sub-surface layer, accidents of vehicles transporting oil, chemicals, or waste, wastewater from landfills, and illegal industrial waste disposal that does not meet established requirements.

According to Government Regulation of the Republic of Indonesia No. 150 of 2000 concerning Control of Soil Damage for Biomass Production, the soil is one of the land components consisting of the top layer of the Earth's crust, containing mineral and organic materials and has physical, chemical, biological properties that support human life and other creatures. However, due to human activities, soil damage is within the established standards.

Soil pollution can occur when hazardous or toxic substances contaminate the soil surface, which can then evaporate, be carried away by rainwater, or seep into the soil. This pollution can cause toxic substances to settle in the soil, potentially impacting humans directly through contact or contaminating groundwater and surrounding air. According to Government Regulation of the Republic of Indonesia No. 150 of 2000, soil damage for biomass production occurs when the basic properties of the soil undergo changes that exceed the established soil damage standards.

According to the Decree of the Minister of Public Works No. 184/KPTS/1990, solid waste refers to waste in solid form, consisting of organic and inorganic elements that have no use value and must be managed properly so as not to cause negative impacts on the environment and to protect investment from damage. According to PP No. 27 of 2020, waste management must still be carried out and must continue to be carried out, as well as separation.

The American Public Works Association (APWA) has classified various types of waste based on their origin, characteristics, and original material composition.

a) "*Garbage*" is the type of waste generated from preparing, processing, and serving food, such as those commonly found in hotels, shops, restaurants, and markets.
b) "*Rubbish*" includes various items such as paper, cartons, wooden boxes, plastics, used textiles, clothing, bed sheets, blankets, leather, rubber, grass, leaves, and garden waste. Non-combustible rubbish

includes cans, tinfoil, soil/mud, stones, ceramics, glass bottles, pottery, and other mineral wastes.

Solid waste in Indonesia is categorized into two main categories, namely wet waste (garbage) and dry waste (rubbish), according to Apriadji (1990), as mentioned by Paksi (2001):

a) Wet waste (*garbage*) is a material that can be easily decomposed by microorganisms when wet and requires an optimal temperature of around 20 to 30oC. Examples include vegetable and food scraps. Examples include vegetable and food scraps.
b) Dry waste *(rubbish*) includes organic and inorganic materials that are not quickly decomposed by microorganisms and, therefore, are difficult to decompose. This type of waste can be further divided into two groups:
    a) Non-rotting and combustible waste, such as paper and wood. This type of waste is suitable for making charcoal briquettes from waste.
    b) Non-rotting and non-combustible waste, such as cans and wires.

Types of Solid Waste

According to Soemirat Slamet (2009), waste can be distinguished by its biological nature so that it receives different management: waste that can decompose, such as food scraps, leaves, garden waste, agriculture, and others; waste in the form of dust; and waste that is hazardous to health, such as waste from industries that contain harmful chemical and physical substances.

According to Noelaka (2008), solid waste can be divided into three types, namely:

Organic Waste

Organic waste is an item that has been unused and discarded by the previous owner but can still be utilized and managed with the correct procedures. It can easily be decomposed through natural processes. Organic waste can be divided into wet and dry. Wet organic waste, such as fruit peels and vegetable scraps, has a high-water content. Meanwhile, dry organic waste is other organic waste with little water, such as paper, wood, tree branches, and dry leaves.

Inorganic Waste

Inorganic waste is waste generated from non-living materials in the form of synthetic products and is the result of the technological process of mining materials. According to Gilbert (1996), inorganic waste generally comes from households, such as plastic bottles, glass bottles, plastic bags, and cans. Inorganic waste can be divided into metal waste and its processed products, plastic waste, paper waste, glass and ceramic waste, and detergent waste. Most inorganic waste has properties that cannot be decomposed by nature or microorganisms (non-biodegradable). Meanwhile, others can only be decomposed in a very long time. Examples of this type of waste at the household level are glass bottles, plastics, cans, and plastic bottles.

Toxic and Hazardous Waste

Toxic Hazardous Waste is waste containing hazardous and/or toxic materials that, due to their nature and/or concentration and/or amount, can directly or indirectly damage, pollute, and endanger the environment. Examples of Toxic and Hazardous Waste are aerosol products, insecticide packaging bottles, batteries, lamps, used ink packaging, and the rest.

Toxic and Hazardous Waste management requires proper handling, such as not mixing organic and inorganic waste. Hazardous waste disposed of directly into the environment has a large and accumulative impact. Given the risks posed by hazardous waste, the government has tried to manage it in a comprehensive, integrated, and sustainable manner.

Sources of Solid Waste

The source of solid waste refers to the origin or place of origin of solid, non-liquid, or gaseous waste. Solid waste can come from various sources, including households, industries, and other sectors.

Here are some explanations of solid waste sources:

1. Residential solid waste is derived from household activities, including individual and group dwellings such as flats or apartments. The main source of solid waste is households, including

plastic packaging, paper, metal, and organic waste (Wilson et al., 2012).

2. Commercial solid waste comes from city centre activities such as offices, shops, restaurants, markets, hotels, motels, and workshops. Although like domestic solid waste, commercial solid waste has a different composition (Bolz, 2019). Solid waste comes from traditional markets and shopping centres, mainly from packaging and food waste (Medina & Waisner, 2011).
3. Institutional solid waste comes from institutional activities such as government centres, schools, prisons, and hospitals. Hospital solid waste is managed separately to prevent chemical contaminants from mixing with other materials. Medical waste, such as syringes and infectious waste, is also a solid waste source that must be managed carefully. (Prüss-Ustün et al., 2017).
4. Solid construction waste comes from construction activities, such as waste from building sites, road repairs, and buildings. Construction and demolition activities generate solid waste, including building scraps, concrete, and other construction materials. (Yang et al., 2019)
5. Public service solid waste comes from public service activities such as street cleaning, recreational areas, sports venues, places of worship, parking lots, parks, and municipal drainage channels. The tourism industry can contribute to an increase in solid waste, especially in popular destinations that generate waste from restaurants, hotels, and tourist activities. (Gössling et al., 2012)
6. Industrial solid waste comes from factory activities, construction, light and heavy industry, chemical installations, and power generation centres. Solid waste from industrial and manufacturing processes, such as e-waste, chemical waste, and production residues, is a significant contributor to the waste problem (Tansel, 2017).
7. Agricultural solid waste comes from agricultural activities such as planting and harvesting. Currently, the disposal of agricultural and livestock solid waste is not fully the waste generator's responsibility, which can cause problems in some areas. Solid waste from the agricultural sector involves crop residues, chemical fertilizers, and packaging of agricultural products (Rigby et al., 2016).

Factors Causing Solid Waste

The *World Health Organization* (WHO) defines solid waste as unwanted material humans generate in their daily activities, usually solid or semi-solid and with no economic value. Identifying the factors that cause solid waste is the first step in developing strategies to reduce waste production and sustainably improve its management.

The following are the factors that cause solid waste:

1. Changes in Consumption Patterns
   Changes in human consumption patterns that lead to more disposable products are often identified as the cause of increased solid waste (Boyle et al., 2001). Addressing the problem of solid waste requires changes in consumption patterns towards more sustainable policies, better recycling, and more durable products. Public awareness about the impact of consumption patterns on solid waste is also very important in reducing the increase in solid waste production.
2. Urbanization and Population Growth
   Population growth and rapid urbanization can increase solid waste production due to the increase in urban population (Hoornweg& Bhada-Tata, 2012). Therefore, actions need to be taken to address solid waste issues, including more efficient waste management, promoting recycling practices, public awareness of waste reduction, and policies supporting more sustainable consumption.
3. Industrialization
   Industrial growth and producing more consumer goods often increase solid waste (Wilson et al., 2006). Construction activities often associated with industrialization can generate construction waste, such as bricks, concrete, and unused wood, which are types of solid waste. Addressing the impact of industrialization on solid waste requires efficient and sustainable waste management efforts. Efficient and sustainable waste management methods include using more environmentally friendly technologies, strict industrial waste management, promotion of recycling, and awareness of good waste management practices within the industry.
4. Use of Disposable Materials
   The use of single-use materials and products, such as plastics, packaging, and electronic items, can increase solid waste

(Subramanian, Sivarajan & Saravanapriya, 2010). Single-use materials are products or packaging designed to be used only once before being discarded, contributing significantly to the solid waste problem. Single-use materials are often more convenient as they do not require maintenance or cleaning after use. The use of disposable materials can encourage consumers to use more disposable products.

5. Lack of Waste Management Infrastructure
   Lack of adequate waste management facilities can lead to irregular waste disposal and accumulation of waste (Kumar et al., 2013). Waste management infrastructure includes various facilities and systems to collect, transport, treat, and manage waste properly. When this infrastructure is inadequate, solid waste is prone to problems.
   The contributing factors of solid waste may vary depending on a country or region's social, economic, and environmental context. Understanding these factors is important in reducing solid waste generation and improving its management. By understanding the causes of solid waste, we can design more effective strategies to deal with it.

The Impact of Waste on the Environment and Health

The production of waste, such as unneeded or unwanted by-products, is an unavoidable consequence of a process (Chen et al., 2020). This production needs more attention, considering the many environmental and human health impacts of waste not processing properly. Improper waste disposal and management causes various types of pollution, namely air, soil, and water (Alam & Ahmade, 2013). Solid Waste Management (SWM) has become a challenge for society and government (Abubakar et al., 2022). Along with economic growth, increasing lifestyles, and daily needs, solid waste management challenges are also getting more difficult.

Solid waste management, which is supposed to reduce the impact of environmental pollution due to waste, also has a negative side contributing to environmental damage.

The following are the impacts of solid waste on the environment and health based on improper waste management (Abubakar et al., 2022):

1. Weak or inadequate solid waste management
   Weak or inadequate solid waste management systems result in littering behaviour in open spaces and waterways. The impact of such behaviour is to increase Green House gas (GHG) emissions, the generation of leachate, and the potential for the spread of diseases from mosquito vectors, such as malaria and dengue haemorrhagic fever, the generation of odours, flooding due to clogged drains and sewers, and plastic waste that disturbs aquatic biota.
2. Irregular waste collection and handling
   Waste that is not properly collected and treated impacts the environment, namely methane gas emissions, bad odours, contamination of soil and water, and breeding of vector animals that transmit diseases to humans. Irregular waste disposal also contributes to marine pollution. Plastic waste in the water becomes a breeding habitat for mosquitoes.
3. Open dumping and landfill
   Improperly regulated landfilling also contributes to methane emission, a major greenhouse gas. Methane and ammonia emissions can cause health hazards such as respiratory diseases. In addition, methane gas is highly flammable, which can cause fire and explosion hazards.
   Organic waste in open dumpsites creates a favourable environment for breeding vectors, such as rats, mosquitoes, and flies. It also poses a risk of contaminating water, leading to the development of water-borne diseases, such as leptospirosis, diarrhoea, and hepatitis A. In addition, a consequence of landfill systems is the generation of leachate. Leachate contains dissolved organic compounds, inorganic contaminants, suspended solids, heavy metals, and other harmful compounds (Afolabi et al., 2022). This leachate can impact the surrounding environment and contaminate groundwater. Leachate can contaminate the community's water sources for drinking and other household needs. This leachate poses a risk to public health due to the hazardous content of leachate (Alam &Ahmade, 2013).
4. Composting
   Composting is a mixture of various materials, such as organic waste, processed into compost for plant needs. Composting involves decomposing organic waste into simple forms naturally with the help of microorganisms, such as bacteria and fungi. However, this

method produces more carbon dioxide emissions than other waste disposal systems. Some literature suggests health hazards from composting, namely nasal congestion, sore throat and dry cough, bronchial asthma, allergic rhinitis, and extrinsic allergic alveolitis (Akmal &Jamil, 2021; Saffron, Giusti& Pheby, 2003).

Solid Waste Management and Control

Solid Waste Management

Japan's UNEP International Environmental Technology Center (IETC) supports waste management systems. It focuses on special waste management. According to PERMEN PU RI No 03/PRT/M/2013 concerning the Implementation of Waste Infrastructure and Facilities in Handling Household Waste and Waste Similar to Household Waste, Chapter III Article 14 states that waste management includes collection, transportation, and final disposal activities, namely:

A. Collection
One of the management efforts is through a collection system to collect waste from individual and communal containers to certain terminals that are carried out directly or indirectly (SNI-19-2554 Year 2002). The act of collecting waste and its source diverted to the Waste Disposal Site (TPS) location. Generally, this process is carried out using wheelbarrows from houses to the TPS location. Several factors can influence waste collection performance, including the type/pattern, frequency, and equipment (Tchobanoglous, 2002).

B. Transportation
In Indonesia, according to the Ministry of Public Works Republik of Indonesia Decree (PERATURAN MENTERI PEKERJAAN UMUM Republik Indonesia) No. 03/PRT/M/2013 concerning the Implementation of Waste Infrastructure and Facilities in Handling Household Waste and Waste of the Same Type of Waste, the pattern of waste transportation can be made based on the waste collection system. Suppose the collection and transportation of waste uses a transfer system (TPS/TPS 3R) or an indirect system. In that case, the transportation process can use a lift container or a fixed container

system (Rizal et al., 2017). The fixed container system can be done mechanically or manually. Mechanical systems use compactor trucks and containers that are compatible with the truck type. The manual system uses labour and containers, which can be waste bins or other types of containers. Transportation is from the waste disposal site (TPS) to the waste processing or final disposal location.

C. Final disposal
Based on Law Number 18 of 2008 concerning Waste Management, the final processing site (TPA) is the last place of waste management. The landfill becomes a place where waste is isolated safely so as not to cause disturbances to the surrounding environment. The technique currently used is open dumping, where waste is placed in a certain location until its capacity is exceeded. This technique has potential negative impacts on the environment. As an alternative, the recommended technique is the use of landfills. It is implemented by creating a new hole to bury the waste.

Solid Waste Control

In order to achieve environmental safety and sustainable development, crucial steps need to be taken. As such, solid waste control measures must be carefully considered and implemented to ensure that waste is properly controlled, reducing negative environmental impacts, especially on soil.

Here are some solid waste controls in dealing with soil pollution:

A. 3R (Reduce, Reuse, Recycle)
Regarding the 3R concept, Sadoko (1993) suggests the following: reducing is an effort to reduce waste at the source of the environment, and it can be done before waste is generated. Reuse is the reuse of materials, so they do not become waste (without the management process). Recycling is the process of recycling useless materials into other useful materials. 3R waste management is a paradigm in prioritizing waste management that focuses on preventing waste generation, minimizing waste by processing usable and biodegradable goods, and implementing environmentally friendly waste disposal.

B. Waste-to-energy (WtE)
   In Waste-to-energy (WtE) technology, solid waste is converted into a usable form of energy through biochemical and thermal processes that facilitate greenhouse gas emission mitigation and power generation (Rigamonti et al., 2016; Johri et al., 2011). Further upgrading of waste to energy generation is required for social and economic viability and environmental friendliness (Scarlat et al., 2015). Gaeta-Bernardi and Parente (2016) reported that Waste-to-energy (WtE) plant conversion can reduce the land requirement for the deposition of waste materials by up to 30 times, reducing CO2 from landfills.
C. Composting
   Compost has beneficial effects on sustainable agricultural production due to its tendency to replenish nutrients in the soil solution with slow release compared to chemical fertilizers. Continuous and unwise use of solid wastes can negatively impact agricultural soils due to their metal toxicity (Lakhdar et al., 2008). Therefore, it is necessary to optimize the dosage of solid waste as well as the type and quality of raw materials for composting. Chemical pollutants from waste include heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls, and Polychlorinated Dibenzo-p-dioxins/polychlorinated Dibenzofurans (PCDD/Fs). Composting can help manage solid waste and increase yields in agricultural, microbial, and crop production. However, the speed and timing of its application require special attention to minimize metal toxicity.
D. Waste sorting
   The role of the community in the 3R-based waste management system (reduce, reuse, recycle) is sorting (Damanhuri & Padmi, 2010). However, sorting activities require government support, as does supervision of recycling activities. Therefore, some households want to avoid sorting waste because they are lazy (32.5%) (Dhokhikah et al., 2015). Sanitation workers play an important role, supervising waste sorting activities among households (Cánovas Creus, Bernstad & Valle, 2015). Sanitation workers can warn households if they do not sort their waste through written or verbal warnings (Sheau-Ting et al., 2016).

Conclusion

Soil pollution is when man-made chemicals enter and alter the natural soil environment. Soil pollution generally occurs due to several reasons, such as leakage of wastewater or chemicals from industries or commercial facilities, pesticide use, infiltration of polluted surface water into the sub-surface layer, incidents of vehicle accidents transporting oil, chemicals, or waste, wastewater coming from landfills, and illegal disposal of industrial waste that does not meet established requirements.

Organic waste is an item that has been unused and discarded by the previous owner but can still be utilizedand managed with the correct procedure. Inorganic waste is generated from non-living materials in synthetic products due to the technological process of mining materials. Meanwhile, Hazardous Toxic Waste (B3) contains hazardous and/or toxic materials that, due to their nature and/or concentration and/or amount, can directly or indirectly damage, pollute, and endanger the environment. The sources of solid waste can come from various sectors, such as residential, commercial, institutional, construction, public services, processing plants, and industry, as well as in the agricultural and livestock sectors.

Several factors cause solid waste, including changes in consumption patterns, urbanization and population growth, industrialization, disposable materials use, and waste management infrastructure deficiencies. Of course, if solid waste is not prevented and managed properly, it will seriously impact humans and the environment. The impacts include odour, flooding due to clogged drains and sewers, and plastic waste that disturbs aquatic biota. Additionally, organic waste in open landfills creates a good environment for breeding disease-carrying animals (vectors), such as rats, mosquitoes, and flies. It also poses a risk of contaminating water, leading to the development of water-borne diseases, such as leptospirosis, diarrhoea, and hepatitis A.

Solid waste management and control can be carried out to avoid the impact caused by the existence of solid waste. Solid waste management includes controlling the amount of waste generated, collection, transportation, processing, and final disposal. These five aspects are essential and must be considered in solid waste management. Besides management, solid waste can also be controlled in several ways, including the Reduce, Reuse, Recycle (3R) method and Waste-to-energy (WtE).

Recommendations

Waste production is inevitable and will continue to increase as the population grows and the needs of daily life increase. However, waste must be handled appropriately not to pollute the surrounding environment and endanger public health. Waste handling and management methods must also be considered. Which one has the least negative impact? After that, each stage of waste handling must be monitored to ensure that the waste is processed properly and does not harm the environment and health. The challenge of handling and managing waste to avoid land pollution requires the awareness of all parties and playing their respective roles in preserving nature and the environment.

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Chapter 6

Bioremediation: A Sustainable Approach to the Mitigation of Salinity-Affected Areas

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Abstract

Salinity poses a significant threat to global food production in the coming decade. Various anthropogenic activities and global warming contribute to increasing salinity levels. Although chemical and physical methods are available for reclaiming saline and sodic soils, bioremediation offers a cost-effective and eco-friendly alternative. Bioremediation utilizes biotic components of the ecosystem, primarily microorganisms and plants, to reduce and reclaim polluted or saline soils. This review discusses the potential of halophilic bacteria and arbuscular mycorrhiza in the remediation of saline soils and their future use in the bioremediation of infertile saline and sodic soils.

Keywords: bioremediation, salinity, sodic soil, halophilic bacteria, arbuscular mycorrhiza

Introduction

An Increase in salinity on farmable lands is a major problem in agriculture. In general, saline soil is divided into two subgroups: sodic soil with high

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carbonate and bicarbonate ions, pH above 8.5, and saline soil with chloride or sulfate ions, pH below 8.5 (Rasool et al., 2013). Salinization in coastal, arid, and semi-arid regions is already a pre-existing problem due to natural processes like the weathering of rocks, seawater intrusion, salt-laden sea winds, and the capillary rise of shallow brackish groundwater. Secondary salinization, on the other hand, occurs through anthropogenic activities such as excessive use of chemical fertilizer and herbicides, resulting in salt precipitation. Globally, more than 77 mha of area is salt-affected and about 43 mha of area is facing secondary salinization. Changes in rainfall patterns and an increase in cyclonic storm frequency in coastal areas due to global warming also contribute to salinization. In the near future, irrigated agricultural lands are at risk of salinization. As urbanization and industrialization in developing countries also restrict the availability of fresh water for irrigation, many places use waste and domestic wastewater for irrigation (Meinzen-Dick & Appasamy, 2002; Zakir, Islam & Hossain, 2016). Along with this, agricultural practices like the removal of cover crops and the avoidance of crop rotation strategies also lead to salinization (Arora, Singh & Singh, 2017).

In the coming years, the salinization of agricultural soil and water will pose an immense threat to food production. The reduction of agricultural land due to rapid urbanization has already aggravated the situation. Recently, this threat has been magnified by increased soil and water salinity. As food scarcity is a leading global problem, it is essential to find ways to reclaim lands affected by salt stress. Managing irrigation methods, mulching, sand mixing, deep ploughing, and treating sodic soils with various calcium salts or gypsum, press mud, and distillery spent wash have been found helpful (Muhammad & Khattak, 2009; Aboelsoud, Engel & Gad, 2020; Yuvaraj et al., 2020). However, from the viewpoint of sustainable development, physical and chemical methods are neither cost-effective nor eco-friendly. In this context, bioremediation can provide a sustainable, eco-friendly technology for the reclamation of sodic soils. Bioremediation utilizes the potential of microorganisms to remediate polluted soils. Plant-microbe interactions, including those with halophilic bacteria and vesicular-arbuscular mycorrhiza (VAM), have gained substantial attention recently for restoring saline soils (Arora et al., 2017). In this chapter, we will discuss the potential of rhizospheric bacteria and arbuscular mycorrhiza for restoring saline soil.

Halophilic Bacteria

Halophilic bacteria are a specific group of bacteria that can tolerate and carry out metabolic functions even in hypersaline conditions (Litchfield, 1998). They belong to the group of extremophiles, which require and tolerate extreme environmental conditions for their growth. Halophiles are mostly found in the primitive phylogenetic group Archaea, with some placed in the phylogenetic group Eukarya. According to Kushner (1988), halophiles can be classified into six broad groups (Table 1). Non-halophiles are bacteria that can thrive when the salt concentration is below 2.5 mol/L. Above this limit, the bacteria cannot perform their metabolic activity. Most bacteria both gram-positive and gram-negative belong to this category, like *Pseudomonas aeruginoa* and *Bacillus* sp. (Sáiz-Jiménez & Laiz, 2000; Sigee, 2005). As the salinity in the environment increases, the bacterial diversity gradually decreases (Le Borgne, Paniagua, & Vazquez-Duhalt, 2008). Halophilic bacteria are also classified depending on their salt tolerance level from mild halophile, moderate halophile, borderline extreme halophile, and extreme halophile (Edbeib, Wahab & Huyop, 2016). Slight halophiles can tolerate 0.2–0.5 M salt levels. *Alkalibacterium thalassium*; *Alkalibacterium gilvum; Erwinia* sp. HAS 6; *Dethiosulfovibrio salsugini; Halomonas zhaodongensis; Roseovarius aquimarinus* (Ishikawa et al., 2009; Díaz-Cárdenas et al*.*, 2010; Li, Jin & Wu, 2010; Jiang et al*.*, 2013; Katayama et al*.*, 2014; Kang et al*.*, 2015) are some examples of them. *Marinobacter piscensi; Spiribacter salinus; Halobacillus sediminis; Halobacillus salicampi; Halomonas heilongjiangensis; Pontibacillus salicampi; Marinobacter shengliensis; Idiomarina aquatica* (Hedi et al*.*, 2015; Jose Leon et al*.*, 2015; Kim et al*.*, 2015; Dou et al*.*, 2015; Lee et al*.*, 2015; Luo et al*.*, 2015) belong to the group of moderately halophiles who can withstand salinity range between 0.5-2.5 M. *Halobacteroides halobius; Halanaerobaculum tunisiense; Halorhodospira halophile; Desulfovibrio retbaens; Halosiccatus urmianus* (Oren, 2002a; Oren, 2002b; Hedi et al*.*, 2009; Mehrshad et al*.*, 2015; Mehrshad et al*.*, 2016) are some representative of borderline extreme halophiles growing in salt concentrations in the 2.5-4.0 M range. Extreme halophiles grow in a high range of salt concentration 4-5.9 M. Most of them belong to the ancient group of Archae. *Halococcus salifodinae; Halobacterium salinaru; Salinibacter ruber; Limimonas halophile; Halanaerobium sehlinense; Sporohalobacter salinus; Lentibacillus kimchii* (Denner et al., 1994; Oren et al*.*, 2002; Antón et al*.*, 2002; Amoozegar et al*.*, 2013; Abdeljabbar et al*.*, 2013; Ben Abdallah et al*.*, 2015; Oh et al*.*, 2016).

Among the non-halophiles some bacteria are present that can tolerate extreme hypersaline conditions, i.e., are viable at a salt concentration of 2.5 M. *Geodermatophilus africanus; Bacillus ligniniphilus; Bacillus pakistanensis; Tamilnaduibacter salinus; Staphylococcus aureus; Anaerosalibacter bizertensi; Methyloligella halotolerans* and *Methyloligella solikamskensi* (Sheehan et al*.,* 1992; Rezgui et al*.,* 2012; Doronina et al*.,* 2013; Montero-Calasanz et al*.,* 2013; Zhu et al*.,* 2014; Roohi et al*.,* 2014; Verma et al*.,* 2015) are some examples of halotolerant (Kusumaningsih et al*.,* 2019).

Both halotolerant and halophilic microorganisms have numerous applications in biotechnology due to their adaptability to extreme environmental conditions. Additionally, they can be used in the restoration of extreme habitats, as they thrive well in such conditions, making them promising candidates for bioremediation.

Table 1. Classification of bacteria depending on their tolerance level

Sl No.	Group	Salt tolerance limit (M)	Reference
1	Non-halophile	<0.2	Edbeib, Wahab & Huyop, 2016
2	Slight halophile	0.2-0.5	
3	Moderate halophile	0.5-2.5	
4	Borderline extreme halophile	2.5-4.0	
5	Extreme halophile	4-5.9	
6	Halo tolerant	Tolerates saline condition	
7	Extreme halotolerant	Viable at 2.5M salt concentration	

Source: Kushner, 1988; Edbeib, Wahab & Huyop, 2016.

Adaptation Mechanisms Useful in a Bioremediation Perspective

Saline soil reclamation using bioremediation techniques leverages the adaptive features of halophiles to tolerate high salinity conditions. Halophilic organisms possess inherent adaptive mechanisms to combat high saline stress. When bacteria are exposed to hypersaline conditions, their main challenge is managing osmotic stress, which can lead to cell shrinkage and loss of cellular structure. To survive in these conditions, halophiles have developed two unique strategies (Figure 1): either producing osmoprotectants or concentrating ions within their cells (Mongodin et al*.,* 2005).

Osmoprotectants: A Key Player in Maintaining Osmotic Balance

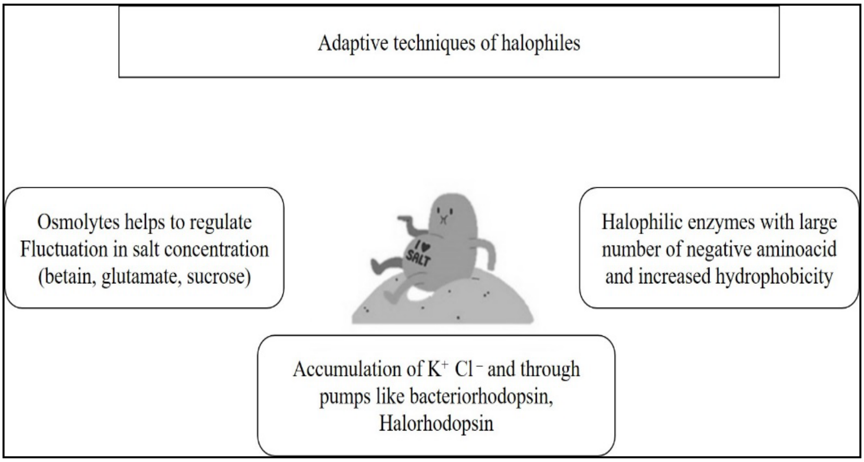
Osmoprotectants are inert organic compounds produced by bacterial cells. These chemicals help halophiles maintain cellular integrity in fluctuating salt concentrations. Bacteria living in moderately saline conditions face the unique challenge of salinity level fluctuations, as saline concentrations can drop to near freshwater levels after rainfall. In these situations, turgor pressure is maintained by producing osmolytes (Mevarech et al., 2000; Saum & Müller, 2008). Osmolytes may be polar and uncharged or negatively charged at physiological pH. Some common osmolytes produced by bacterial cells include glycine betaine, glycerol, proline, glutamate, glycosyl glycerol, hydroxyectoine, sucrose, ectoine, and trehalose. (Galinski & Trüper, 1982; Kuhlmann & Bremer, 2002; Doronina et al*.,* 2003; Desplats et al*.,* 2005; Saum et al*.,* 2006).

Accumulation of Ions Within Cells

In this method, ions are accumulated within the cells of bacteria through pumps present on their cell walls. Among bacteria, halophiles exclusively possess Cl^- pumps to transport ions from the external environment within bacterial cells. Arginine and lysine present in the pumps help in the process (Lanyi, 1990). In an extremely halophilic bacterium *Salinibacter ruber*, Cl^- is incorporated within the cell via a pump named halorhodopsin (Mongodin et al*.,* 2005; Edbeib, Wahab & Huyop, 2016). Halobacteriaceae (extreme halophiles) maintain osmotic balance with the help of proton pump bacteriorodopsin, ATP synthase, and the Na^+/H^+ antiporter. With the help of these pumps, they accumulate K^+ ions within the cell via a uniport mechanism (Edbeib, Wahab & Huyop, 2016).

Presence of Halophilic Enzymes

Traditionally, enzymes which are proteins in nature, have a tendency to denature in high salt concentrations resulting in the loss of their function. As proteins are the key players in metabolic functions in the cell, denaturation of proteins is extremely fatal for bacteria. But halophiles have special haloenzymes, which help them thrive in extreme saline conditions. Two primary features that make them different from the enzymes of non-halophilic bacteria are negative charges and increased hydrophobicity. They also contain a high amount of glutamate and aspartate compared to their non-halophilic counterparts (Ng et al., 2000). Amylase, α amylase, Aldehyde dehydrogenase, Alcohol dehydrogenase, Cyclodextrin glycosyltransferase, Amylopullulanase, Endo-1,4-β-Xylanase, Endo-β-Xylanase, β-Xylanase, β-Xylosidase, Xylanase, Protease CPI, 2-Hydroxy acid dehydrogenase, and DNase are some examples of haloenzymes (Edbeib, Wahab & Huyop, 2016).



Source: Edbeib, Wahab & Huyop, 2016.

Figure 1. Summary of Adaptive Techniques of Halophiles Useful for Bioremediation.

Bioremediation: A Sustainable Way of Reclamation

Bioremediation is a novel, cost-effective, and environment friendly procedure for mitigating polluted areas with the help of microorganisms either by degrading or transforming (Maier, Pepper & Gerba, 2009; Landa-Acuña et al., 2020). Bioremediation using microorganisms is already successfully applied to the mitigation of oil spills, oil-contaminated lands, and heavy metal-contaminated lands and water (Chandra et al., 2013; Hrynkiewicz & Baum, 2014). A Wide variety of bacteria, including members of Eukarya and Archaea, showed potential in bioremediation.

Case Study

Bioremediation of saline and sodic soils using halophilic bacteria is a relatively new area that requires more exploration and attention. Although promising, reports on this topic are not abundant in the literature. Studies have shown that halotolerant and halophilic bacteria are quite efficient in bioremediating saline soils contaminated with oil. *Pseudomonas aeruginosa* and *Alcanivorax* sp. can efficiently remediate both oil contamination and salinity (Dastgheib et al., 2011; Ebadi et al., 2017).

Table 2. Literature reports on bioremediation of saline soil using microorganism

Sl No	Case Study	Bacterial strain	Observation	Reference
1	oil-contaminated saline soil from Iran	*Pseudomonas aeruginosa* consortium of four strains	Capable of degrading crude oil, even in the presence of salinity.	Ebadi et al., 2017
2	Salt affected agricultural land	*Streptomyces californicus; Streptomyces parvulus; Streptomyces coelicolor; Streptomyces griseus*	Produce osmolytes like proline, ectoine, hydroxyectoine, proline, glutamine, alanine to protect cells from salinity stress and making them halotolerant	Killhamt & Firestone, 1984 Bursy et al., 2008 Kol et al., 2010
3	Halophilic bacteria saline soil from coastal Gujarat and sodic soil from Indo-Gangetic plains of Uttar Pradesh	Halophilic bacteria stain CSSRY1 and CSSRO	Halophilic bacteria having plant growth promotion effect helps in bioremediation	Arora et al., 2016
4	Halotolerant bacteria isolated from Pakistan applied to saline fields of Karak district Pakistan	*Pseudomonas* sp., *Thalassobacillus* sp., and *Terribacillus* sp.	Significant reduction in soil salinity	Anees et al., 2020
5	Saline soil from six different site of Jordan	SLR-80 (blend of TRX-80 catalysts and aerobic bacteria)	Remediation of saline soil using bacteria is feasible	Al-Abed et al., 2004
6	Different crude oil contaminated saline soil from Tehran	*Alcanivorax* sp.	Strain Qtet 3 could survive and grow in saline soils with crude oil contamination	Dastgheib et al., 2011

Different species of *Streptomyces* can also remediate salt-affected agricultural lands. They produce various osmoprotectants, such as ectoine, alanine, glutamine, and proline, to survive and grow in these conditions. Among these, proline is found to play the most important role as an osmoprotectant (Killhamt & Firestone 1984; Bursy et al., 2008; Kol et al., 2010). *Pseudomonas* sp., *Thalassobacillus* sp., and *Terribacillus* sp. were reported to reduce salinity from 6.5 to 2 M in salt-affected fields in Shadi Khel, Karak District, Pakistan (Anees et al., 2020). Arora et al., 2016 achieved bioremediation of saline soils from the coastal Gujrat and Indo-Gangetic plains of Uttar Pradesh using a consortium of halophilic bacteria stain CSSRY1 and CSSRO. Similar findings were also observed by Al-Abed et al., 2004 where they found a mixture of aerobic halophilic bacteria with catalyst can reduce salinity in saline fields of Jordan. The reports are listed above in Table 2.

Arbuscular Mycorrhizal Fungi (AMF) : Plant Microbe Interaction

Plant-microbe interactions play a pivotal role in the amelioration of soil salinity, with symbiotic associations between microorganisms and plants being key players. Arbuscular mycorrhizal fungi (AMF) are ubiquitously present in the soil and form symbiotic associations with plants. These obligatory symbiotic fungi, belonging to the fungal group Glomeromycota, are known for their tolerance to salinity. In this symbiotic relationship, plants provide food to the fungi, while the fungi help plants absorb minerals and nutrients through their extra-radical hyphae. The important parts of arbuscular mycorrhiza include arbuscules (fine, tree-like hyphal structures), vesicles, intra-radical hyphae, extra-radical hyphae, and extra-radical auxiliary cells. Among these structures, arbuscules and vesicles are present within the cortical cells of plants and establish direct communication with the plant cells (Smith & Read 2010).

Several studies have shown that arbuscular mycorrhiza promotes plant growth in unfertile soils. Uptake of several essential nutrients can be enhanced with the help of arbuscular mycorrhiza (Mukherjee & Sen, 2021).

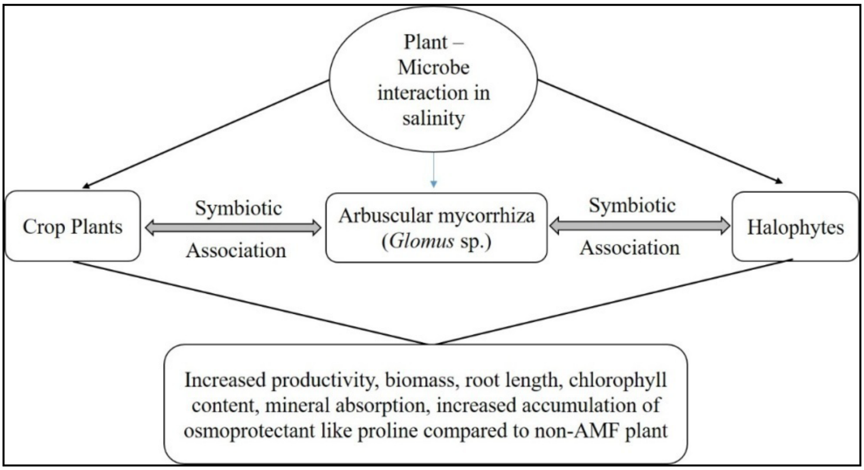
Bioremediation of Saline Soil Using Arbuscular Mycorrhizal Fungi (AMF)

Arbuscular mycorrhiza (AMF) is normally found in saline soil (Aliasgharzadeh et al*.,* 2001), but some study reports have shown that a reduction in the colonization of mycorrhiza due to reduced spore germination. *Glomus* sp. is the most common fungal species that is present ubiquitously in the saline and sodic soils (Landwehr et al*.,* 2002). *Glomus deserticola, G. intraradices, G. mosseae,* and *G. claroideum* are most commonly used species in bio-amelioration process of saline soils. Different literature reports have shown an increase in the biomass of plants in saline soil when inoculated with arbuscular mycorrhiza compared to the control group (Latef & Chaoxing, 2011). Inoculation of different species of *Glomus* has shown an enhancement of salt tolerance in olive plants (Porras-Soriano et al*.,* 2009). Chlorophyll content was also found to be increased in plants in saline conditions when inoculated with mycorrhiza. In saline stress, the absorption of magnesium is reduced, but the application of arbuscular mycorrhiza has been shown to increase the absorption of Mg. (Sheng et al*.,* 2008; Wu et al*.,* 2010). As discussed earlier with osmoprotectants like glycine betaine, proline accumulation is very important to combat saline stress. It has been found that the accumulation of osmoprotectants is increased when plants are inoculated with arbuscular mycorrhiza compared to non-inoculated plants (Duke et al*.,* 1986; Khaled et al*.,* 2003; Sharifi et al*.,* 2007). Similarly, soluble sugar content also increases in inoculated plants. It is expected that high soluble sugar content helps the plant to protect itself from salt stress.

Besides, AMF was found to be closely associated with halophytic plants, who themselves are another key player in the bioremediation of extremely saline soil. Although most of the halophytes do not have any AMF colonization, some of them shows AMF colonization. Salt marsh plants such as *Spartina patens* and *Distichlis spicata*, halophytes like *Aster tripolium; Artemisia maritima; Plantago maritima; Salsola soda*; *Suaeda maritima; Inula crithmoides; Haloxylon aphyllum; Halocnemum strobilaceum; Zygophyllum eurypterum; Peganum harmala,* and *Atriplex nummularia* possess symbiotic association with AMF (Hoefnagels, Broome & Shafer, 1993; Hildebrandt et al*.,* 2001; Landwehr et al*.,* 2002; Asghari et al*.,* 2008; Sonjak et al*.,* 2009). A List of plants is listed in Table 3.

Table 3. List of halophytes with arbuscluar mycorhizal fungi

Sl. No	Name of the plant	Family	Reference
1	*Aster tripolium*	Asteraceae	Hajiboland, 2013
2	*Artemisia maritima, Artemisia caerulescens*		Sonjak et al., 2009
3	*Inula crithmoides*		Sonjak et al., 2009
4	*Plantago maritima, Plantago cornuti,*	Plumbagineaceae	Sonjak et al., 2009
5	*Oenanthe lachenalii*	Apiaceae	Hildebrandt et al., 2001
6	*Salsola soda*	Chenopodiaceae	Sonjak et al., 2009
7	*Salicornia europaea*		Sonjak et al., 2009
8	*Suaeda maritima*		Sonjak et al., 2009, Sengupta & Chaudhuri 1990
9	*Haloxylon aphyllum*		Asghari et al., 2008
10	*Kochia stellaris*		Asghari et al., 2008
11	*Atriplex nummularia*		Asghari et al., 2005
12	*Halocnemum strobilaceum*		Asghari et al., 2008
13	*Seidlitzia rosmarinus,*		Asghari et al., 2008
14	*Matricaria chamomilla*		Füzy et al., 2008
15	*Zygophyllum eurypterum*	Zygophyllaceae	Asghari et al., 2008
16	*Peganum harmala*		



Source: Hajiboland, 2013.

Figure 2. Plant-Mycorrhizal Interaction During Salinity.

Arbuscular mycorrhizal association with halophytes plays a pivotal role in the restoration of extremely saline soils (Figure 2). AMF colonization increases the productivity of halophytes, enabling the restoration of saline areas (Sonjak et al*.,* 2009). It improves nutrient and mineral availability in plants growing in saline soil, improves soil aggregation, and improves antioxidant enzymes like catalase activity, and neutral and alkaline phosphatase in soil (Caravaca et al*.,* 2005; Zhang et al*.,* 2011).

Overview of the Utilisation of Microorganisms in Saline Soil Reclamation

Bioremediation is a low-cost, eco-friendly emerging technique for the cleanup of contaminated sites. The salinization of fertile land due to the overuse of pesticides and fertilizers has resulted in the loss of fertile land, which may lead to food scarcity. The use of microorganisms, primarily bacteria and symbiotic fungi, to reclaim saline and sodic soil is termed haloremediation.

Halophilic bacteria play an important role in the reduction of salinity in soil. They are also classified depending on their salt tolerance level from mild halophile, moderate halophile, borderline extreme halophile, and extreme halophile (Edbeib, Wahab & Huyop, 2016). Halotolerant and halophilic microorganisms can be used in the restoration of salinity-affected agricultural land as they can grow well in extreme saline conditions, resulting in their promising application in the bioremediation of saline soil, i.e., haloremediation. To survive in hypersaline conditions, halophiles have developed two unique strategies: either producing osmoprotectants or concentrating ions within their cells (Mongodin et al*.,* 2005).

Osmoprotectants like glycine betaine, glycerol, proline, glutamate, glycosyl glycerol, Hydroxyectoine, sucrose, ectoine, trehalose plays key role in maintain turgor pressure which helps the microorganism to grow in saline condition. Halophilic bacteria have pumps named halorhodpsin that help in concentrating Cl^- within cells, which helps them to maintain cell functions in sodic soil. Besides this, haloenzymes also help them to thrive in this condition. Amylase, α amylase, Aldehyde dehydrogenase, Alcohol dehydrogenase, Cyclodextrin glycosyltransferase, Amylopullulanase, Endo-1,4-β-Xylanase, Endo-β-Xylanase, β-Xylanase, β-Xylosidase, Xylanase, Protease CPI, 2-Hydroxy acid dehydrogenase, and DNase are some examples of haloenzymes that make the bacteria ready to withstand saline stress. (Edbeib, Wahab & Huyop, 2016).

Although the application of halophilic bacteria in different industrial areas was quite common, its application in remediation in saline soil is a relatively new area of study. Very few reports are available to date. *Alcanivorax* sp, and *Pseudomonas aeruginosa* are reported to grow on oil-contaminated saline soil. They can also efficiently degrade the oil residue on saline soil (Dastgheib et al*.,* 2011; Ebadi et al*.,* 2017). Recently, some studies have reported the successful application of halophilic bacteria to reduce salinity in saline agricultural lands (Arora et al*.,* 2016; Anees et al*.,* 2020). *Pseudomonas* sp., *Thalassobacillus* sp., and *Terribacillus* sp. are some important reported bacterial species that were used successfully in remediating soil salinity (Anees et al*.,* 2020).

Besides halophilic and halotolerant bacteria, another group of microorganisms—arbuscular mycorrhizal fungi—are successfully used in the haloremediation of saline soil. These obligate symbiotic fungi, members of Glomeromycota, form symbiotic associations with halophytes and help reduce soil salinity. Arbuscular mycorrhizal fungi are normally adapted to saline conditions, making them potential candidates for haloremediation. *Glomus* sp. is the most common fungal species present ubiquitously in saline and sodic soils (Landwehr et al*.,* 2002). *Glomus deserticola, G. intraradices, G. mosseae,* and *G. claroideum* are the most used species in bioremediation process of saline soils. *Glomus* sp. can form a symbiotic association with halophytes, resulting in an increase in the accumulation of osmoprotectants like proline. Promotion of chlorophyll level was also observed after inoculation (Duke et al*.,* 1986; Ben-Khaled et al*.,* 2003; Sharifi et al*.,* 2007). Halophytic plants also play a key role in haloremediation. *Atriplex* sp*., Suaeda* sp*., Salsola* sp*., Chenopodium* sp*.,* and *Portulaca* sp. are already reported to be efficient in haloremediation. *Salsola soda* can efficiently remove sodium ions from saline soil without causing any significant damage (Karakas, 2013). *Atriplex nummularia* and *Salicornia europaea* accumulated a high amount of sodium and chloride ion in their bodies (Silva et al*.,* 2016; Morteau, 2016; Rocha de Moura et al*.,* 2019). Inoculation with arbuscular mycorrhizal fungi will enhance the capacity of the plants by promoting their growth. As a result, halophytes with arbuscular mycorrhizal fungi can provide an alternative technology to reduce soil salinity and reclamate salt-affected fertile land.

Future Perspective

Salinization is an emerging problem that will affect food production in the coming years. It is necessary to find cheap, environmentally friendly techniques to improve saline and sodic soils. Bioremediation using microorganisms provides a cost-effective approach to this issue. Halophilic and halotolerant microbes can play a pivotal role due to their natural ability to grow and mineralize Na and Cl ions within their bodies, thereby reducing soil salinity. Halophytes, in symbiotic association with arbuscular mycorrhiza, can also offer an additional mode of bioremediation. The full potential of bioremediation using microorganisms has not yet been extensively explored. This group of microorganisms can provide an excellent alternative for restoring saline and sodic soils compared to existing costly physical and chemical processes. In the future, bioremediation will likely be the best possible alternative, with halophiles dominating the process due to their ability to tolerate and grow in adverse environmental conditions.

Conclusion

Microorganisms play an important role in controlling soil salinity. Native microbes in saline soils are crucial in haloremediation. The close association of arbuscular mycorrhiza with halophytic plants, which naturally grow in saline environments, plays a key role in reducing salinity. These techniques provide more eco-friendly and cost-effective methods compared to traditional chemical and physical methods. Selecting suitable species based on their salinity tolerance enhances the effectiveness of this approach. In the coming era, haloremediation using microbes can play a pivotal role in managing soil salinity and restoring agricultural fields affected by it.

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Chapter 7

Unraveling Ecosystem Dynamics and Managing Risks in the Pursuit of Sustainable Development and Health

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Abstract

To better understand the interconnected processes involved, this study examines the complex relationships among public health, sustainable development, and environmental dynamics. Ecosystems, as integral components of our planet's biosphere, are essential for supporting life and promoting human prosperity. However, human-caused climate change, environmental degradation, and other global changes are putting ecosystem stability and health under unprecedented stress,

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which is having an effect on human societies. This research aims to thoroughly examine the dangers of ecosystem degradation and investigate efficient methods of management that benefit public health and sustainable development. This research takes a multidisciplinary approach by drawing on the fields of sustainable development, public health, and ecological science. Environmental change's effect on ecosystem services, the symbiotic link between healthy ecosystems and human health, and the determination of important risk factors are important areas of study. Ecological restoration, nature-based solutions, and technological integration are some of the developing themes in ecosystem management that this article explores. It emphasises how these trends have the ability to reduce risks and increase resilience. This study gives researchers, practitioners, and policymakers practical insights into the problems caused by ecosystem dynamics by combining case studies with empirical data and theoretical frameworks. The results highlight the need for a public health–protecting, sustainable development–aligned, flexible, and comprehensive strategy for managing ecosystems. The ultimate goal of this research is to promote a sense of shared ecological stewardship by informing decision-making based on evidence. This study aims to contribute to a future where development can coexist harmoniously with ecosystem and community health by understanding ecosystem dynamics and outlining appropriate risk management measures. It also seeks to make a lasting impact.

Keywords: ecosystem dynamics, sustainable development, risk management, public health, interdisciplinary approach

Introduction

A critical point has been reached, and the delicate balance of the ecosystems that make up our world is on the verge of experiencing a change that has never been seen before. The intricate interactions that take place between natural systems and human activities have created the conditions for a hazardous future that will be characterised by huge challenges and opportunities that have never been seen before (Soltysova & Modrak, 2020). The objective of this chapter is to disentangle the complex web of ecosystem dynamics while simultaneously drawing attention to the critical importance of risk management in the context of our efforts to achieve sustainable development and improve public health as shown in Figure 1. In spite of the fact that the contemporary era has been witness to a period of incredible developments, this progress has been achieved at a significant expense. As a result of human activity, the ecosystems that are responsible for maintaining life on Earth have come under increasing pressure (Terán-Yépez et al., 2020). Climate change, the destruction of habitats, pollution, and the unrelenting exploitation of natural resources have all contributed to the occurrence of disruptions that have reverberated throughout communities and landscapes simultaneously (Reynolds et al., 2008).

These difficulties are rooted in the complex and varied processes of ecosystems, which must be taken into consideration. There is a delicate balance that exists between these interwoven networks of life, which include flora, fauna, soil, water, and climatic systems. This equilibrium is what allows life to continue existence. The perturbations that occur in a single component can set off cascading effects that spread throughout ecosystems, so influencing the well-being of humans, as well as the biodiversity and stability of the environment. The repercussions of ecosystem disruptions reach far beyond the realm of environmental issues; they are inextricably intertwined with the socio-economic systems and the health of humans. Disruptions in ecosystems represent major dangers, including the exacerbation of inequality and the threat to the basic foundations of sustainable development. An increased vulnerability to illnesses and limited access to key resources are two of the concerns that are posed by biodiversity loss.

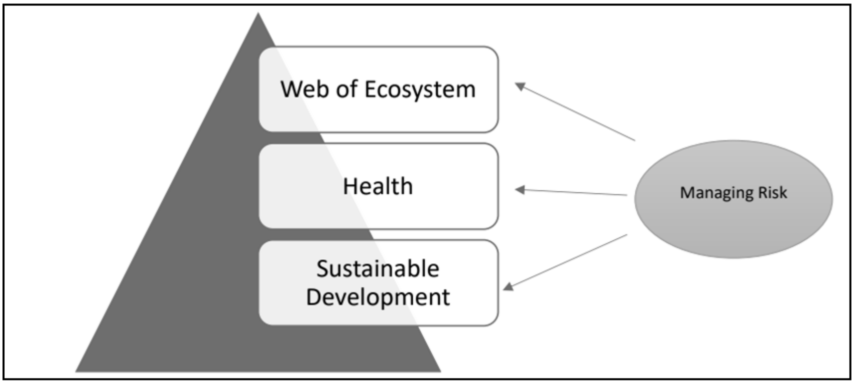

Figure 1. Ecosystem Dynamics Paradigm.

Background of the Study

The contemporary world is confronted with a complex interaction between the dynamics of ecosystems, the development of sustainable practices, and the concern for public health (Saebi et al., 2019). A complex network of biological, physical, and chemical components that interact with one another in a variety of ways is what we refer to as an ecosystem. These delicate balances have been thrown off by human activities, such as industrialization and urbanisation, which have resulted in far-reaching effects for the environment, society, and health.

These disruptions are exemplified by problems such as climate change, the loss of biodiversity, deforestation, pollution, and the destruction of habitats. It is possible for a single change in an ecosystem to set off a chain reaction, which can influence the stability of the environment, the availability of food, the incidence of diseases, and the socioeconomic disparities.

Significance

Ecosystem

Connections Between Human Health and the Sustainability of Ecosystems It is essential to have a solid understanding of the linkages that exist between human health and ecosystem health (Shepherd &Patzelt, 2022). Ecosystems fulfil fundamental functions, such as the provision of clean air, water, and food, which have a direct influence on the well-being of humans. It is possible for disruptions in ecosystems to result in the appearance of diseases, to exacerbate existing health disparities, and to put livelihoods in jeopardy.

The Sustainable Development Goals (SDGs): This subject is relevant to the accomplishment of the Sustainable Development Goals set forth by the United Nations. (Punla et al., 2022). One of the most important aspects of accomplishing these objectives is striking a balance between economic growth, environmental sustainability, and societal well-being. To achieve long-term sustainable growth, it is essential to have an efficient management system in place for ecological risks.

Important Implications for Policy and Management: In order to effectively address these difficulties, diverse methods are required (Pearce, Ricciardi & Zardini, 2017). It includes interventions in public policy, the development of novel technology, involvement with the community, and international collaboration. It is essential to have robust strategies for the preservation of ecosystems, restoration of ecosystems, and risk reduction.

Implications for the World: The dynamics of ecosystems and the impact they have on health and development are concerns that affect the entire world. What occurs in one region of the world frequently has repercussions in other regions of the world. Therefore, in order to effectively address these difficulties, it is vital to engage in collaborative activities and to share responsibilities.

Resilience and Future Preparedness: Societies can create resilience to future challenges by first gaining an understanding of the dynamics of ecosystems and then controlling the risks that are connected with those ecosystems (Umali et al., 2023). As a result of this information, proactive efforts can be taken to anticipate, avert, or minimise possible catastrophes, so contributing to the development of a future that is more sustainable and healthier. Figure 2 shows the framework of sustainaibility to resilience the future challenges.

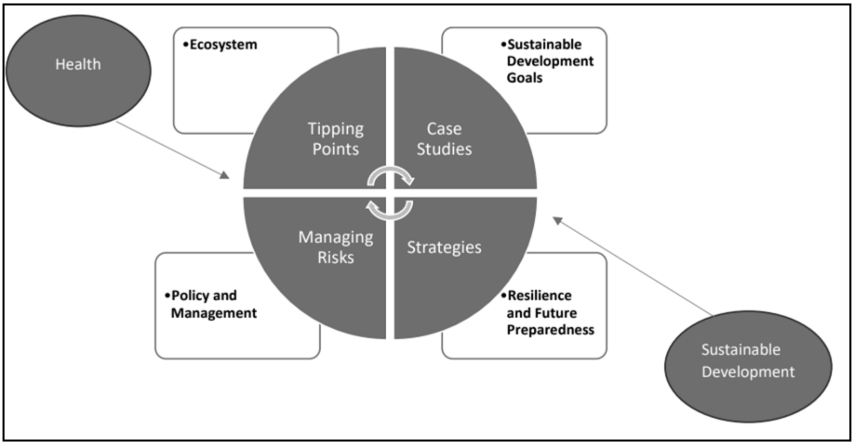

Figure 2. Sustainability Framework.

Collaborating across disciplines, conducting research, and having a comprehensive understanding of how ecosystems function is all necessary for successfully navigating this complexity. In order to encourage a healthy coexistence between nature and civilization, it is necessary to find innovative solutions that strike a balance between the demands of humans and the preservation of the human environment. This field is not only intellectually engaging, but it is also of essential relevance for the future of humanity and the world as a whole.

Objectives

Through this chapter, we will attempt to delve into the complexities of ecosystem dynamics, shed light on the dangers that are posed by disturbances, and suggest solutions that can be used to negotiate these obstacles (Kousky, 2016). By addressing specific objectives, such as analyzing ecosystem stressors, assessing health impacts, proposing integrative solutions, exploring exemplary models, and preparing for future risks, our goal is to provide a comprehensive understanding of this crucial intersection of ecosystems, sustainable development, and health, as well as insights that can be put into action.

1. Comprehensive Understanding:
   - Explore Ecosystem Dynamics: Dive into the complexities of ecosystem functions, interdependencies, and the impact of human activities on these sensitive systems. This will provide you with a comprehensive understanding of ecosystem dynamics.
   - Examine the Drivers of Change: Identify and analyse the primary drivers that undermine the stability of ecosystems, such as climate change, pollution, deforestation, and urbanisation.
2. Assessing Risks and Impacts:
   - Risk Assessment: Evaluate the risks associated with ecosystem disruptions on human health, socio-economic systems, and global sustainability (Gao et al., 2020). It is important to evaluate the risks connected with ecosystem disruptions.
   - Implications for Health: Conduct research into the direct and indirect effects that ecological imbalances have on human health, including the spread of diseases and the lack of stability in food supplies (Shepherd & Patzelt, 2022).
3. Strategies for Sustainable Development:
   - It is important to integrate health and the environment while developing strategies for sustainable development. In order to accomplish the objectives of sustainable development, you

should suggest certain ways for coordinating the activities of health promotion and environmental conservation (Zhang et al., 2020).
- Make suggestions for policy frameworks and actions that can be used to manage ecosystem threats while simultaneously supporting economic development and collective well-being.

4. Interdisciplinary Approaches:
    - Interdisciplinary approaches, include research that is conducted across disciplines: Bringing attention to the significance of collaboration between different fields, such as ecology, public health, economics, and policy-making, is particularly important (Baquiran et al., 2023).
    - Presenting innovative technology and methods for minimising risks and restoring ecosystems is an important part of the innovative solutions solution.
5. Examples of Best Practices and Case Studies:
    - By presenting case studies from a variety of places, you can demonstrate the worldwide importance of ecosystem risk management and the many different approaches that can be taken (Dagar et al., 2022).
    - Identification of successful examples of ecosystem management and risk reduction, with an emphasis on lessons learned and models that can be replicated, is one of the best practices.
6. Prospective Courses of Activities and Obstacles:
    - Prepare for Potential Dangers in the Future: Discuss the issues that may arise in the future as a result of the continual changes in the environment and the activities of humans (Dwivedi et al., 2022).
    - Recommendations for Action: In order to address new dangers, it is important to provide recommendations for future study, the implementation of policies, and community engagement.

In the context of environmental preservation (Pan et al., 2022), each objective seeks to contribute to a more thorough understanding of the dynamics of ecosystems, to highlight the relevance of effectively managing associated risks, and to provide methods that can be implemented to promote sustainable development and health within the context of environmental preservation.

Understanding Tipping Boundaries in Ecosystems

To have a complete understanding of the sensitive thresholds beyond which these complex systems experience changes that cannot be reversed, it is essential to have a firm grasp on the tipping borders that exist within ecosystems (Umali et al., 2023). The term "tipping boundaries" refers to key areas in ecosystems where relatively minor changes can cause dramatic and frequently sudden transformations in the functioning of ecosystems. While these thresholds differ from species to ecosystem, they serve to define limitations for issues such as the loss of biodiversity, climate change, and the deterioration of habitat. It is possible that crossing these thresholds could result in cascading effects, which will have an influence on ecological stability, the survival of species, and the provision of essential ecosystem services. Interdisciplinary approaches are utilised by researchers in order to find and designate these tipping points. These approaches involve the integration of ecological, climatological, and socio-economic data. The recognition and observance of these boundaries are essential components of sustainable management, serving as a guide for the formulation of policies and practices that intend to prevent the crossing of these crucial thresholds. By gaining an understanding of these tipping thresholds, we are able to get insights that are particularly important for the protection of ecosystems, the reduction of hazards, and the promotion of a harmonious balance between the activities of humans and the resilience of natural systems.

Definition and Conceptual Framework

Tipping Point: In the context of ecosystems, the term "tipping point" refers to a crucial threshold or boundary that is the point at which a very minor alteration or disturbance can result in major and frequently irreversible shifts in the current state or behaviour of an ecological system (McPherson et al., 2023). When this threshold is crossed, it can set off a chain reaction of rapid and sometimes unexpected changes that result in a change in the ecosystem's stability, function, or composition.

Conceptual Framework

1. Threshold Dynamics:
   The concept of threshold dynamics refers to the relationship between stability and instability. Ecosystems demonstrate resilience within specific bounds (Bhati, 2021). As soon as these boundaries are crossed, the system is able to make the transition to a different state, shifting from a stable one to an unstable one.
   Responses that are nonlinear tipping points frequently entail nonlinear responses, which are situations in which very minor changes can have disproportionately huge consequences, resulting in sudden shifts.
2. The Influencing Factors That Drive Tipping Points:
   Destruction of biodiversity: Decreases in biodiversity can reduce the resilience of ecosystems, making them more likely to reach tipping points.
   Alterations in climatic patterns: This can drive ecosystems towards tipping points, which can have an effect on temperature, precipitation, and extreme weather events. This phenomenon is caused by climate change (Dwivedi et al., 2022).
   Habitat fragmentation and degradation: Changes in land use and habitat degradation that are caused by humans have the potential to push ecosystems beyond the bounds that they have reached.
3. Identifying and Monitoring Tipping Points:
   The process of determining and keeping track of tipping points, including indicators and signals: By gaining an understanding of the indicators and early warning signs that precede tipping points, it is possible to more effectively identify and monitor these events (Kumar et al., 2023).
   Modelling and data analysis: The utilisation of mathematical models, simulations, and data analysis is a resource that assists in the prediction of potential tipping points.
4. Management Strategies and Implications for the Situation:
   Once tipping points have been crossed, it may be difficult or even impossible to return to the prior state. This is referred to as irreversibility (McPherson et al., 2023).
   Adaptive management strategies that include adaptive management, conservation initiatives, restoration, and policy interventions are

undertaken with the intention of preventing or mitigating the effects of tipping points.

5. Capacity for Resilience- Restoration:
   Building Resilience: Increasing the resilience of ecosystems by preserving biodiversity, lowering the impact of stressors, and restoring habitats that have been degraded can be an effective way to avert tipping points.
   Restoration Efforts: Restoring ecosystems after they have crossed tipping points requires restoring both the functionality of the ecosystem and the diversity of the organisms that live within it.
6. An Approach That Is Holistic and has A Global Perspective:
   Connections between things: The recognition of the interconnection of ecosystems on a global scale, as well as the recognition that tipping points in one region can have cascading impacts in other regions.
   Strategies Through Collaboration: In order to address tipping moments, it is necessary to engage in collaborative initiatives that span several disciplines, stakeholders, and international borders.

Historical Cases of Tipping Points

As with any complex system, ecosystems are interdependent and vulnerable to tipping points, where seemingly little changes can have far-reaching and sometimes permanent consequences (Terán-Yépez et al., 2020). Some examples of ecological tipping points in the past are as follows:

- Coral bleaching, in which corals shed the symbiotic algae that live in their tissues, can occur at any point in time due to the sensitivity of coral reef ecosystems to changes in sea temperature. When corals are under too much stress, widespread bleaching events will occur; this is the tipping point (Papagiannidis et al., 2022). Coral bleaching episodes have been observed in many parts of the world, and they have a negative effect on the coral reef ecosystems' health and biodiversity.
- The Amazon rainforest is currently experiencing destruction as a result of human activities like logging, farming, and building infrastructure. Here, the threshold beyond which the rainforest may undergo a transition to a more open, savannah-like ecology called

the tipping point (Pearce, Ricciardi & Zardini, 2017). Severe ramifications for global climate regulation and biodiversity might ensue if the Amazon is pushed beyond this tipping point by ongoing deforestation and climate change.

- Sea ice in the Arctic is melting as a result of climate change, a phenomenon that has been going on for some time. At the essential minimum extent, the ice could begin to melt at a faster rate and alter the dynamics of the ecosystem (Muñoz et al., 2018). This is the tipping point. Sea ice is essential to the survival of many animals, including polar bears, seals, and others.
- One good example of a tipping moment is the 1990s reintroduction of grey wolves to Yellowstone National Park (Markman et al., 2019). The introduction of wolves into an ecosystem set off a chain reaction that altered elk behaviour, which affected plant life and eventually led to a return to ecological equilibrium.
- The collapse of fisheries can occur at any point in time due to overfishing, which occurs when fish stocks are exploited beyond sustainable levels (Singh &Sharma, 2022). When fishing pressure surpasses fish populations' reproductive and replenishment capabilities, a tipping point is typically reached. The early 1990s cod fisheries collapse off the Newfoundland coast is one historical example.
- The Great Plains Dust Bowl of the 1930s: This disaster occurred in the United States's Great Plains due to unsustainable farming methods and a prolonged drought. The ecosystem was degraded and had extensive environmental and social repercussions when soil erosion, wind, and a lack of vegetation combined to produce large dust storms. This was the tipping point (Kousky, 2016).

Sustainable practices and conservation efforts are crucial in preventing or mitigating tipping points, as these situations demonstrate how ecosystems are vulnerable to both natural and human-induced changes.

Implications for Sustainable Development

Sustainable growth is greatly affected by our inability to understand and control ecosystem tipping points (Liu et al., 2023). Recognising the intricate equilibrium within ecosystems is crucial as mankind navigates the intricacies of environmental concerns. Promoting resilience in these ecosystems is crucial for sustainable development as it helps to avert irreversible changes that could jeopardise biodiversity and essential services (Singhal, 2020). Ecosystem health and adaptation depend on conservation initiatives including preserving natural habitats and adopting sustainable land use practices. A major component of sustainable development is action to adapt to and mitigate the effects of climate change, with an emphasis on lowering emissions of greenhouse gases and protecting ecosystems that are crucial to this process. In order to keep ecosystems from reaching critical points, it is equally important to promote activities like sustainable agriculture, responsible water resource management, and marine conservation. To ensure sustainable development, it is crucial to integrate local communities, protect indigenous knowledge, and promote global cooperation through good policies and governance. The future of ecosystem preservation and restoration depends on education and awareness initiatives, which help bring people together in favour of these causes. This will ensure that human well-being and environmental health are in harmony in the years to come.

Risk Identification in Ecosystems

To effectively manage and conserve ecosystems, it is essential to identify and comprehend threats (Khedhiri, 2022; Valdez & Nunag, 2023). The first step in creating plans to lessen or avoid damage to ecosystems is to identify the risks that these systems face. Important components of ecosystem risk assessment are as follows:

- Ecosystems are in danger due to human activities like deforestation, urbanisation, and infrastructure development, which modify and fragment natural environments (Shepherd & Patzelt, 2022). Conservation activities can be better prioritised and sustainable land-use plans can be better guided if regions at danger of habitat loss can be identified.
- When non-native species are introduced to an environment, they can cause changes in the dynamics of that system by either outcompeting or predating local species (Asio, Sardina & Olaguir, 2023). It is critical to detect invasive species and track their movement if we want to stop them from harming local biodiversity.

- Temperature increases, changed precipitation patterns, and more intense weather events are just a few of the ways in which ecosystems are threatened by climate change (Soltysova & Modrak, 2020). Conservation efforts and adaptation tactics can be better guided by vulnerability assessments and an awareness of possible consequences on habitats and species.
- Overfishing, logging, and poaching are examples of unsustainable resource harvesting practices that can lead to population decline and upset ecological equilibrium. Sustainable resource management strategies can be put into place after places and species at danger of overexploitation have been identified (Saebi et al., 2019).
- The spread of disease has the potential to wreak havoc on ecosystems and animal populations (Al Dhaheri et al., 2021). Developing measures to avoid or manage outbreaks and protect vulnerable species requires an understanding of disease transmission patterns and the identification of possible vectors.
- The destruction of natural habitats to make way for farms or cities is one example of how land use change can disrupt ecosystems in a domino effect (Reynolds et al., 2008). Conservation priorities and sustainable development plans can be better informed by identifying places experiencing fast land use changes.
- Species extinctions and population decreases are examples of changes in biodiversity that must be tracked in order to pinpoint vulnerable regions. Services like pollination and water purification are threatened when ecosystems lose biodiversity (Papagiannidiset al., 2022).
- Ecosystems are susceptible to calamities like hurricanes, floods, and wildfires. In order to lessen the environmental toll of disasters, it is necessary to first pinpoint which regions are most vulnerable to certain types of natural disasters (Pearce, Ricciardi & Zardini, 2017).
- As human populations grow, there is a greater risk of interactions with animals, which can have devastating effects on both species. To better safeguard human livelihoods and biodiversity, it is important to identify hotspots where human and wildlife conflicts are likely to occur (Dwivedi et al., 2022).
- Acidification of the seas: Marine ecosystems are impacted by acidification, which is caused by the seas absorbing more carbon

dioxide. In order to pinpoint vulnerable locations and put solutions in place to tackle this worldwide problem, it is essential to monitor pH levels and learn about the effects on marine life (Markmanet al., 2019).

Ecosystem risk assessment must take into account a wide range of variables, from specific human actions to more systemic environmental shifts. When we have this information, we can build conservation and management plans that will help ecosystems be healthier and more resilient.

Intervention Strategies for Sustainable Development

In order to achieve sustainable development, intervention techniques must incorporate an all-encompassing approach that tackles the interrelated problems of environmental degradation, social inequality, and economic instability (Pingol &Hipona, 2022). In order to alleviate the effects of climate change and reduce reliance on fossil fuels, one of the key pillars of these policies is the shift to renewable energy sources for energy production, such as solar and wind power. Sustainable urban planning is crucial, with the primary goal of developing environmentally friendly communities that are equipped with public transit that is efficient, green infrastructure, and buildings that are energy efficient. The adoption of techniques that are part of a circular economy helps to reduce waste and increases resource efficiency. The conservation and restoration of ecosystems are extremely important in the process of preserving biodiversity and ensuring that natural systems remain in a state of structural equilibrium (Pazaitis, Kostakis & Bauwens, 2017). To ensure that development is in line with the requirements of local communities and takes into account the cultural contexts in which they live, efforts are being made to empower local people through inclusive decision-making procedures and educational activities. A more equal and just society can be achieved through the implementation of programmes that alleviate poverty, the provision of clean water and sanitation, and the adoption of socially responsible business practices (Valdez & Nunag, 2023). Supporting technological innovation and the transfer of that innovation, in conjunction with robust regulatory regulations, helps to encourage the adoption of environmentally responsible practices across all sectors of the economy. It is of the utmost importance to engage in global collaboration and partnerships, since it is widely acknowledged that numerous difficulties affect multiple countries and need for collective solutions. Furthermore, the acceleration of progress towards a future in which economic prosperity, social well-being, and environmental health can live happily is facilitated by the allocation of financial resources towards green investments and sustainable projects. By putting these intervention techniques into action, sustainable development is transformed into a goal that is both attainable and attainable, so ensuring a future that is both resilient and balanced for people and the earth.

Policy and Governance Interventions

It is essential to implement policy and governance reforms in order to lead societies in the direction of sustainable sustainability. Effective policymaking requires the formulation and execution of laws and regulations that give priority to the preservation of the environment, the promotion of social fairness, and the maintenance of economic stability (Zhang et al., 2020). The formulation of legislation that encourages sustainable behaviours, such as emission reduction objectives, incentives for renewable energy, and conservation measures, is a significant responsibility that falls on the shoulders of governments. Robust governance frameworks guarantee that rules are executed, thereby making individuals and businesses accountable for the impact they have on the environment and society. In addition, policies that promote socially responsible land use, urban planning, and the management of natural resources all contribute to the conservation of ecosystems. Having decision-making processes that are inclusive and engaging the community are both vital components of effective governance (Nishant, Kennedy & Corbett, 2020). These components help to develop transparency and ensure that a variety of opinions are taken into consideration. The importance of international cooperation cannot be overstated because environmental problems frequently transcend national boundaries. The establishment of global agreements and initiatives that address concerns such as climate change and the loss of biodiversity can be the result of multilateral efforts that involve collaborative efforts among governments. In the end, good policy and governance interventions lay the groundwork for a future that is both sustainable and resilient, directing societies towards development that is both responsible and equitable (McPherson et al., 2023).

Ecological Restoration and Conservation Practices

When it comes to preserving biodiversity, restoring ecosystems that have been degraded, and promoting environmental sustainability as a whole, ecological restoration and conservation methods are essential components (Grover et al., 2020). In the context of ecological restoration, the process of actively repairing ecosystems that have been harmed or degraded is undertaken with the intention of improving the ecosystems' health, functionality, and resilience. On the other hand, conservation methods are centred on the protection of existing ecosystems and the species those ecosystems contain. At the same time, both are essential to the process of preserving the equilibrium of natural habitats.

The establishment and administration of protected places, such as national parks, wildlife reserves, and marine sanctuaries, are included in the scope of conservation practices. These regions provide as safe havens for a wide variety of plant and animal species, so contributing to the preservation of their habitats and preventing the loss of biodiversity. In addition, conservation efforts include the restoration of habitats within protected areas as well as the development of measures to combat illegal poaching, logging, and other activities that pose a harm to ecosystems (Dev et al., 2020).

In addition to providing protection, ecological restoration involves actively rehabilitating ecosystems that have been destroyed. Reforestation initiatives, which aim to restore tree cover, wetland restoration projects, which aim to enhance water quality and offer habitat, and reintroduction programmes for endangered species are all examples of what this may include (Clemente, 2023). Participation from the community is essential in both the conservation and restoration processes. When local people are involved in conservation initiatives, it helps to cultivate a sense of stewardship and ensures that actions are in line with the requirements and understanding of individuals who live in and around the ecosystems.

Educating people and improving their awareness are also essential components of these activities (Gupta & Khan, 2023). It is important for the general public to have an awareness of the significance of ecosystem services, the value of biodiversity, and the significance of conservation and restoration activities in order to contribute to long-term sustainability. The culture of environmental stewardship is fostered, and appropriate behaviours are encouraged as a result of this act.

In a nutshell, ecological restoration and conservation methods are needed in order to lessen the negative effects that human activities have on ecosystems and to foster a more sustainable cohabitation with the natural world (Liu et al., 2023). Not only is it possible to preserve and repair ecosystems via the implementation of these principles, but it is also possible to establish a harmonious relationship between human cultures and the many habitats that they inhabit.

Integrating Health and Well-Being into Ecosystem Management

Incorporating health and well-being considerations into ecosystem management is a method that takes a holistic perspective that acknowledges the interdependence between human health and the health of ecosystems (Kumar et al., 2023). In this integration, it is acknowledged that healthy ecosystems contribute to the well-being of human populations, and that, on the other hand, human activities have a substantial influence on the state of ecosystems. The following are some of the most important strategies for successfully incorporating health and well-being into the management of ecosystems:

The Relationship Between Ecosystem Services and Human Health

It is important to acknowledge and quantify the ecosystem services that contribute to human health in a direct or indirect manner (Clemente, 2023). These services include the provision of clean air and water, the regulation of diseases, the provision of food, and the benefits to culture and recreation. Gaining an understanding of these connections enables one to prioritise measures related to ecosystem management that have a favourable influence on public health.

One Health Approach

This acknowledges the interconnection of human health, animal health, and environmental health. Consider adopting this method. When it comes to addressing health issues that arise at the intersection of humans, animals, and ecosystems, this strategy places an emphasis on collaborative efforts between ecologists, individuals working in the medical field, and other stakeholders.

Conservation and Biodiversity

It is important to protect and restore biodiversity because it plays a significant role in ensuring the resilience of ecosystems and offers a variety of health benefits. In many cases, diverse ecosystems play a role in the regulation of diseases. This is because different species have the ability to function as buffers against the spread of infections.

The Relationship Between Green Spaces and Mental Health

For the purpose of improving mental health, it is important to create and preserve green spaces in both urban and rural regions. Researchers have shown a correlation between having access to natural and green settings and lower levels of stress, enhanced mental health, and increased levels of physical exercise (Al Dhaheri et al., 2021).

Sustainable Agriculture That Guarantees Food Security

Facilitate the implementation of sustainable agricultural techniques that take into account the ecological well-being as well as the nutritional well-being of communities (Kumar et al., 2023). Approaches that are agroecological put an emphasis on the health of the soil, limit the number of chemical inputs, and contribute to the production of food that is both diverse and healthy.

Water Resource Management

Ensure that sustainable water resource management methods are implemented, with a focus on both the health of ecosystems and the availability of clean water for human populations (Clemente, 2023; Lee et al., 2007). The prevention of diseases that are transmitted through water and the promotion of overall health are both dependent on the protection of watersheds and the maintenance of water quality.

Adaptation to Climate Change and the Resilience of Health

In order to address possible health implications, such as increased heat stress, altered disease vectors, and extreme weather events, (Gao et al., 2020) it is important to incorporate measures for adapting to climate change into plans for managing ecosystems. The development of resilient ecosystems can make a contribution to the health resilience of communities.

Participation of local communities in decision-making processes pertaining to ecosystem management is the eighth step in the community engagement and empowerment process (Shepherd & Patzelt, 2022). By empowering communities, we can develop a feeling of ownership, ensuring that interventions are culturally relevant, and guarantee that they are aligned with the health needs of the local community.

Raising Awareness and Educating People

Through the implementation of educational programmes, raise knowledge about the interdependence between ecosystems and human health. The likelihood of communities supporting ecosystem management measures that enhance both environmental sustainability and public health is increased when such communities are properly informed (Dwivedi et al., 2022).

Research and Monitoring

To gain a deeper understanding of the connections between the health of ecosystems and the well-being of humans, research should be conducted. It is important to put in place monitoring systems in order to evaluate the effects that changes in ecosystems have on the health of the community and to alter management plans accordingly.

Policy Integration

Developing and implementing policies that incorporate health and well-being factors into ecosystem management is the eleventh step in the policy integration process (Khedhiri, 2022). At the policy level, it is vital for there to be coordination between the environmental, health, and other related sectors in order to achieve something that is complete.

By incorporating health and well-being into ecosystem management, there is the potential to build settings that are more resilient, sustainable, and beneficial to people's health. The approach that is being taken is consistent with the more comprehensive idea of sustainable development, which places an emphasis on the interconnected objectives of preserving the environment, promoting social well-being, and producing economic prosperity (Markman et al., 2019).

Intersecting Dimensions of Ecosystem Health and Human Well-Being

Taking a holistic approach to sustainable development is essential because the crossing dimensions of ecosystem health and human well-being indicate a complex and mutually influential relationship (Muñozet al., 2018). This relationship highlights the need of taking a holistic approach. Human well-being is strongly influenced by the health of ecosystems since ecosystems provide individuals with critical services such as clean water, food, and the regulation of diseases. It is the complicated web of biodiversity that exists within ecosystems that contributes to the resilience of both natural environments and human societies. Diverse ecosystems provide a multitude of benefits, ranging from the provision of medicinal supplies to the provision of cultural information and recreational opportunities. (Yadav et al., 2021). The interconnectedness is amplified as a result of climate change, which is mostly caused by human activity. This has an impact on ecosystems and makes communities more vulnerable to both direct and indirect health concerns. Human health is directly impacted by the quality of water resources, which is controlled by the state of the ecosystems that are found in aquatic environments. A significant contribution to the maintenance of food security and nutrition is made by agricultural systems, which are highly reliant on the services provided by ecosystems. As a reflection of the state of the ecosystems in the surrounding area, urban green spaces have an effect on mental well-being. In light of the fact that vulnerable populations frequently bear the brunt of environmental degradation, which in turn exacerbates health disparities, the relationship extends to social justice and equity. Recognising and negotiating these crossing dimensions demands efforts that are collaborative and interdisciplinary. It is also necessary to acknowledge that the health of ecosystems is inextricably linked to the well-being of human societies. In order to cultivate resilience and harmony between ecosystems and communities, it is vital to take a holistic and well-balanced approach to sustainable development. This approach should place an emphasis on the integration of environmental conservation, social fairness, and economic prosperity.

Risk Management Strategies in the Pursuit of Sustainable Development and Health

The pursuit of sustainable development and health necessitates the implementation of efficient risk management solutions in order to successfully negotiate the in169
tricacies of environmental, social, and economic concerns (Punla et al., 2022). Some of the most important risk management solutions that incorporate these elements are as follows:

1. Interdisciplinary and Integrated Planning for Sustainable Development:
   Plan for sustainable development that takes into account environmental, social, and economic concerns, and make sure that your plans are comprehensive and integrated (Saebi et al., 2019). In order to accomplish this, it is necessary to identify potential risks and vulnerabilities, create clear goals, and devise adaptive tactics that encourage resilience across a variety of sectors.
2. Early Warning Systems:
   Put in place early warning systems for potential threats to the environment and to human health. Monitoring indicators such as the quality of the air and water, the prevalence of diseases, and the patterns of climate can provide early information, which enables proactive responses and the prevention of possible disasters (Shepherd & Patzelt, 2022).
3. Adaptation to Climate Change:
   Create and put into action solutions that will allow you to adjust to the conditions that are caused by climate change (McPherson et al., 2023). This includes the planning of infrastructure that takes into account shifting patterns of climate, the management of water

resources to address extreme weather events, and public health programmes that anticipate shifts in disease patterns.

4. Methodologies that are based on Ecosystems:
   Encourage the use of risk management strategies that are ecosystem-based. The provision of essential services by healthy ecosystems, such as the provision of clean air, water, and food security, contributes to the preservation of the environment as well as to the improvement of public health (Kumar et al., 2023). The protection and restoration of ecosystems provide an increased level of resistance to a variety of threats.
5. Public Health Preparedness:
   It is important to strengthen public health systems and disaster readiness, as stated in the fifth point (Zhang et al., 2020). This includes making investments in healthcare infrastructure, providing training to healthcare personnel, and building response plans in order to efficiently meet health crises such as pandemics and disease outbreaks.
6. Participation of the Community and the Development of Capabilities:
   The local communities should be involved in the processes of risk management, and their capacity to respond to difficulties should be strengthened (Baquiran et al., 2023). Communities that are empowered are better able to recognise hazards, take measures to minimise them, and adjust to them, which contributes to the establishment of sustainable practices and improved health outcomes.
7. Diversification of Resources:
   Diversify both the resources and the supply chains in order to lessen reliance on resources that are either susceptible or limited (Terán-Yépezet al., 2020). Through the establishment of a more solid and adaptable economic base, this method helps to reduce the impact of disruptions, improves resilience, and contributes to the implementation of sustainable development.
8. Safety Nets for Social Interactions:
   The establishment of social safety nets and support networks is necessary in order to reduce the impact of economic and social risks on groups that are specifically vulnerable. As a means of fostering equity and well-being, these safety nets may consist of social

welfare programmes, unemployment benefits, and access to healthcare services.

9. Technological Innovation:
   The ninth recommendation is to make use of technical innovation in order to effectively control risks (Valdez & Nunag, 2023). Artificial intelligence, remote sensing, and data analytics are examples of advanced technologies that have the potential to improve early detection, monitoring, and reaction capabilities, so contributing to an overall improvement in resilience.
10. Integration of Policies and Governance:
    Incorporate risk management concerns into the policies and governance structures that are in place. The coordination of efforts between various levels of government and sectors ensures a unified and efficient response to threats, which in turn promotes sustainable development and safeguards public health (Singh, A., & Sharma, N. C. 2022).
11. Education and Knowledge:
    Encourage education and knowledge of the dangers that are often connected with practices that are not sustainable, as well as the impact that these practices have on both health and the environment (Agarwal et al., 2019). The likelihood of populations adopting sustainable behaviours and contributing to risk reduction is increased when those populations are informed and aware.
12. International Collaboration:
    Foster international collaboration to address global risks (Gupta & Khan, 2023). When it comes to ensuring sustainable development and protecting global health, there are a number of difficulties that call for coordinated responses and joint efforts across borders. Some examples of these challenges are pandemics and climate change.

Through the implementation of these risk management measures, societies have the ability to work towards a future that is more sustainable and resilient, one that places equal importance on the well-being of humans and the health of the planet. In order to arrive at solutions that are both comprehensive and long-lasting, it is essential to take into account environmental, social, and economic factors (Baquiran et al., 2023).

Future Directions and Challenges

There are a number of developing trends that are expected to have a significant impact on the future of ecosystem management. These trends are a reflection of the rising recognition of the complicated links that exist between environmental sustainability, human progress, and global concerns. As attempts to repair damaged ecosystems and reintroduce native species connect with the urge to conserve biodiversity and promote ecosystem resilience, it is anticipated that the rising emphasis on ecological restoration and rewilding programmes will gain momentum. This is because natural habitats are becoming increasingly important. At a time when there is a growing emphasis on green infrastructure and sustainable land management, nature-based solutions that take into account the inherent value of ecosystems are positioned to play a crucial role in the mitigation and adaptation of climate change (Al Dhaheri et al., 2021). The integration of technology, which includes developments in artificial intelligence and remote sensing, presents interesting options for the improvement of ecosystem monitoring and decision-making that is driven by data (McPherson et al., 2023). Despite this, there are still obstacles to overcome, such as the requirement for interdisciplinary teamwork and the necessity for fair access to technology. In addition, the incorporation of indigenous knowledge and community-based conservation initiatives is becoming increasingly popular. This movement highlights the significance of local engagement and the maintenance of traditional ecological expertise. As these trends continue to develop, there are still obstacles to overcome in terms of gaining sufficient money, navigating the complexities of policy, and tackling the varied nature of environmental problems. The problem of striking a balance between ecological integrity and socio-economic factors is an ongoing one that calls for the implementation of adaptive techniques and the participation of a wide range of stakeholders in joint efforts (Liu et al., 2023). The future of ecosystem management lies on the incorporation of innovative techniques, sustainable practices, and inclusive governance in order to cultivate resilience and guarantee the coexistence of human societies and ecosystems that are prospering.

Summary of Key Findings

Discovering key insights at the nexus of ecological sustainability, human well-being, and global concerns can be accomplished through the investigation of emerging patterns in ecosystem management (Clemente, 2023). The most important findings highlight the growing importance of ecological restoration, rewilding, and nature-based solutions as essential techniques for preserving biodiversity and improving the resilience of ecosystems. Despite the fact that there are still obstacles associated with fair access, technological breakthroughs, particularly in the areas of remote sensing and artificial intelligence, present potential tools for effective monitoring and decision-making. It is widely acknowledged that the incorporation of indigenous knowledge and community-based techniques is of utmost importance, highlighting the importance of local participation and the maintenance of traditional ecological understanding. In addition to gaining funds, managing complex legislation, and striking a balance between ecological integrity and socio-economic issues, persistent problems include the following. When it comes to addressing the diverse character of environmental concerns, interdisciplinary collaboration emerges as an essential component, underlining the significance of inclusiveness and adaptive tactics. The provision of equitable access to technology, resources, and benefits, in conjunction with the requirement for inclusive governance, continues to be an essential component of effective ecosystem management. To summarise, the findings highlight the importance of adopting a strategy that is holistic, inventive, and collaborative in order to successfully negotiate the complex relationships that exist between ecosystems, human societies, and global concerns. This will ensure that a sustainable coexistence may be achieved in the distant future.

Conclusion

In conclusion, the investigation of developing tendencies in ecosystem management reveals a dynamic environment that is characterised by the intersection of ecological sustainability, human well-being, and global issues (Depoux et al., 2020). The dedication to preserving biodiversity and enhancing the resilience of ecosystems is highlighted by the emphasis placed on ecological restoration and rewilding. Solutions that are based on nature, in conjunction with technical improvements, offer viable options for addressing climate change and supporting sustainable land management (Sheikh, 2021). The incorporation of indigenous knowledge and community-based conservation strategies brings to light the significance of local participation and the maintenance of ecological information that has been passed down through generations.

However, the path towards ecosystem management that is both successful and efficient is not devoid of obstacles. Persistent challenges include securing sufficient finance, negotiating complex policy environments, and striking a careful balance between ecological integrity and socio-economic considerations. These are all very difficult challenges to overcome. There are a number of core themes that emerge in the quest of good ecosystem management. These themes include equitable access to technology, resources, and benefits, as well as the requirement for inclusive governance.

It is becoming increasingly clear that inter-disciplinary collaboration is a crucial factor in successfully navigating the complex relationships that exist between ecosystems, human societies, and global concerns. In order to effectively handle the complex nature of environmental problems, it is necessary to bring together a wide range of stakeholders and to implement methods that are flexible (Dwivedi et al., 2022). The requirement for a strategy that is both comprehensive and all-encompassing is of the utmost importance in order to guarantee that the coexistence of flourishing ecosystems and human societies will continue to be robust in the face of changing environmental dynamics.

The findings highlight the significance of innovation, teamwork, and environmentally responsible behaviours as we go forward through this process. The management of ecosystems needs to be tackled with a forward-thinking perspective, one that acknowledges and embraces the complexities of our linked reality. We are laying the groundwork for a future in which environmental sustainability and human well-being can coexist in a healthy manner by incorporating emerging trends, capitalising on technical breakthroughs, and showing respect for the wisdom of local communities. When it comes to protecting the well-being of our planet for future generations, the journey that lies ahead requires a constant dedication, the ability to adapt, and everyone taking responsibility for the situation.

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Chapter 8

The Global Health Crisis: Addressing the Interconnected Challenges at Present

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Abstract

This chapter explores the interconnectedness of sustainable development, global health, and emerging infectious diseases. It argues that sustainable development, which balances environmental, economic, and social aspects, is key to building healthy and equitable societies. Particularly in healthcare, sustainable development offers a transformative approach, promoting resilient and accessible healthcare systems. It goes beyond immediate health outcomes, examining the delicate balance between environmental, social, and economic factors. Sustainable healthcare focuses on optimizing resources, minimizing environmental impact, and promoting community well-being for present and future generations. Furthermore, the chapter explores the rise of emerging infectious diseases, fuelled by factors like climate change, globalization, and deforestation. The COVID-19 pandemic highlights the vulnerability of global health systems and the need for proactive, collaborative efforts to prevent, detect, and respond to such threats. Through analysis and case studies, the chapter emphasizes the importance of global collaboration, strengthened healthcare systems, and robust preventative measures to navigate the challenges of infectious diseases in the interconnected world. Ultimately, it offers

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insights and strategies for navigating these complexities, paving the way for a healthier and more sustainable future.

Keywords: interconnectedness, sustainable development, global health, emerging infectious diseases, collaborative efforts

Introduction

Sustainable development encompasses fostering growth of a community or a society that fulfils its present needs while safeguarding the capacity of future generations to fulfil their own. This forms the basis of a just and fair society. It stands at the crossroads of environmental, economic, health and social dimensions. At its core, sustainable development embodies an approach to growth and advancement that strives to harmonize diverse and at times conflicting needs, all while maintaining a keen awareness of the environmental, social, and economic constraints confronting in the society.

In the contemporary landscape of healthcare, sustainable development emerges as a transformative paradigm. It is not merely a concept but a vital ethos guiding the evolution of healthcare systems. It is no longer a peripheral concern but a cardinal principle guiding the trajectory of healthcare systems. Today's healthcare discourse has transitioned from singular preoccupations with immediate health outcomes to a nuanced understanding of the intertwined threads of environmental, social, and economic factors that influence wellbeing.

Sustainable healthcare, thus, embodies a commitment to optimize resource utilisation, mitigate environmental impact, and foster communal well-being. It champions the ideal of providing high-quality care while simultaneously safeguarding the thriving of future generations. By embracing innovation, harnessing the power of technology, and fostering collaborative global initiatives, healthcare is poised to evolve into a resilient, equitable, and environmentally cognizant domain, paving the way for a healthier world for generations to come.

Today, the focus extends beyond immediate health outcomes to the delicate balance between environmental, social, and economic dimensions. Sustainable healthcare seeks to optimize resource use, minimize ecological footprints, and enhance community well-being. It's a commitment to delivering quality care without compromising the ability of future generations to thrive. Through innovation, technology integration, and collaborative global efforts, healthcare is evolving into a resilient, equitable, and environmentally conscious domain, ensuring a healthier world for generations to come.

The pursuit of universal good health has emerged as a widely recognized global objective, underscored by significant advancements in life expectancy over the last century. However, despite these gains, disparities in health persist between affluent and disadvantaged populations. Moreover, the trajectory of future health outcomes is increasingly intertwined with the evolving dynamics of globalization.

Traditionally viewed primarily through an economic lens, globalization is now understood as a multifaceted phenomenon, influenced by a diverse array of factors and events that are rapidly reshaping in this society.

In this chapter, we delve into the critical intersection of sustainable development with health and well-being, emphasizing the urgent need to address the global health crisis. The interconnected challenges we face today demand comprehensive and collaborative strategies to tip the boundaries towards a healthier and more sustainable future.

Emerging Infectious Diseases

The world has witnessed a concerning surge in emerging infectious diseases, exacerbated by factors like climate change, globalization, and deforestation. The COVID-19 pandemic starkly underlines the fragility of global health systems and highlights the necessity for a proactive, cooperative approach to prevent, detect, and respond to such hazards.

In a global security report commissioned by the Secretary-General of the United Nations (UN) and developed by a high-level panel, infectious diseases were identified among a concise list of threats that demand immediate and sustained attention, both now and in the foreseeable future. The report emphasizes that these threats transcend national borders and necessitate concerted action at the global, regional, and national levels, as no single state, regardless of its power, can shield itself entirely from their impact.

Globalization has changed how infectious diseases appear, spread, and are handled. Because countries are more connected through increased trading, traveling, and communicating, germs can move across borders faster. One big impact is how quickly diseases can travel from one part of the world to another. Airplanes and global trade make it easy for germs to spread fast, which makes it hard to control them (Frenk, Gómez-Dantés & Knaul, 2011; Lim et al., 2021).

For example, in 1347, the Black Death started in Central Asia and spread to Europe, where it killed a lot of people. During that time, people in Venice came up with the idea of quarantine, where they would keep ships separate for 40 days to stop the spread of disease.

The conquest of the Aztec and Inca empires in the sixteenth century shows how diseases like smallpox and measles were unintentionally spread to people who had never been exposed to them before. This led to a situation where the indigenous populations in the Caribbean and Brazil were almost wiped out. To compensate for the loss, slaves were brought from West Africa, which brought diseases like malaria and yellow fever to the Americas, causing more problems. Columbus might have even brought a disease called syphilis from the Americas to Europe (Beaglehole & Yach, 2003).

Another example is the cholera pandemic in 1829, which started in Asia, went through Egypt, North Africa, Russia, and Europe, and eventually reached the eastern coast of the United States three years later.

In the twentieth century, the flu pandemic of 1918, often called the Spanish flu, caused about 50 million deaths worldwide, which was five times more deaths than those caused by World War I.

In recent years, we've seen many new diseases spread from animals to humans, like HIV, the 1918 flu, the Middle East respiratory syndrome, and COVID-19. For a new disease to become a problem for humans, a few things need to happen: people need to come into contact with the animals carrying the disease, the disease needs to develop the ability to spread from person to person, and it needs to spread beyond where it first appeared.

Changes happening globally have made each of these steps more likely. People are moving into areas where animals live, which increases the chances of contact between humans and animals. More people, more farms, and more land being used for farming mean we're encroaching on animal habitats, which can lead to more diseases spreading. Also, certain activities like hunting wild animals or having both wild and domestic animals in close contact can increase the risk of diseases jumping from animals to humans. For example, the Nipah virus, found in bats, caused a serious outbreak in Malaysia in 1999, mostly affecting pig farmers.

Globalization has also transformed the way information about infectious diseases is disseminated. The rapid sharing of data and experiences enables faster response times, facilitating the global community's ability to collaborate on prevention and containment strategies. However, the same interconnectedness can also contribute to misinformation, complicating efforts to disseminate accurate public health information (Huynen, Martens & Hilderink, 2005).

In summary, globalization has intensified the impact of infectious diseases by facilitating their rapid spread, amplifying risks for vulnerable populations, and altering the dynamics of information dissemination. Effective global collaboration, strengthened healthcare systems, and robust preventive measures are imperative to navigate the challenges posed by infectious diseases in interconnected world (Baker et al., 2022).

Non-Communicable Diseases (NCDs)

While infectious diseases continue to be a worry, another challenge arises from non-communicable diseases (NCDs). These are long-lasting health issues like heart disease, diabetes, and mental health disorders, which are becoming more common and adding pressure on healthcare systems worldwide. This highlights the need to rethink healthcare priorities, focusing more on prevention and overall well-being.

Globalization plays a big role in the rise of NCDs because it directly affects the risks to populations and indirectly affects national economies and healthcare systems. For instance, the tobacco and alcohol industries, with their global production and marketing, pose significant challenges for policymakers and public health workers. Dealing with this requires a wide range of policies from both government and non-governmental organizations. However, the resources and capacity needed for this response are often lacking, and governments need to step up accordingly.

It's crucial to understand why non-communicable diseases (NCDs) are becoming more common in certain populations. These diseases, like high blood pressure, diabetes, high cholesterol, and obesity, can be caused by a variety of factors including fast urbanization, unhealthy diets, the spread of sedentary lifestyles due to globalization, and aging populations. In essence, NCDs are often the result of the individual and collective choices, behaviours, cultural practices, where we live, genetic makeup, public policies, market influences, and other factors.

Urbanization, a key component of globalization, has given rise to environments that promote unhealthy behaviours. Diets high in processed foods, sedentary work routines, and limited access to recreational spaces contribute to the escalating burden of NCDs, particularly in urban areas .

The global marketing of unhealthy products is another facet of globalization impacting NCDs. Multinational corporations promote the consumption of sugary beverages, fast food, and tobacco across borders, contributing to the rise in conditions such as obesity, diabetes, and cardiovascular diseases.

Globalization has also influenced healthcare systems' ability to address NCDs. While some regions may experience improved healthcare access and better management of NCDs, others may face challenges due to disparities in resources and infrastructure.

To tackle non-communicable diseases (NCDs), the focus should be on preventing them from occurring in the first place. This includes promoting healthy habits like eating well and exercising, creating healthier urban environments to prevent conditions like obesity, high blood pressure, diabetes, and cancer, and ensuring early detection and treatment through screenings for diseases like diabetes, high blood pressure, and cancer. Laws that promote public health, such as taxes on unhealthy foods in some countries like the USA, also play a role in improving access to vaccinations, screenings, and treatments.

The factors that contribute to NCDs, like tobacco and alcohol use, lack of physical activity, and unhealthy diets, are closely linked to social, cultural, political, and environmental influences.

By addressing these factors that can be changed, we can reduce the burden of NCDs. However, many urban planning decisions, policies, and implementations have contributed to the rise in NCDs like injuries, high blood pressure, diabetes, high cholesterol, and obesity.

To effectively control NCDs, collaboration is needed among engineers, policymakers, environmental experts, and health professionals such as yoga instructors, meditation coaches, and nutritionists. This collaboration should focus on identifying, communicating, and reducing the risks associated with NCDs. Unfortunately, such efforts are often lacking on the ground due to various reasons.

To prevent non-communicable diseases (NCDs), it's important to encourage healthy habits such as practicing yoga, meditation, and regular exercise. It's also crucial to avoid risky behaviours like consuming unhealthy foods high in calories, fast foods, sugary drinks, and foods with preservatives. These actions can help prevent conditions like obesity, stress, high blood pressure, diabetes, and cancer.

In conclusion, globalization plays a pivotal role in the rise of non-communicable diseases by fostering interconnected risk factors and influencing lifestyles on a global scale. Addressing the NCD pandemic requires collaborative efforts on an international level, encompassing policy interventions, public health initiatives, and the promotion of healthy, sustainable lifestyles worldwide (Bhattacharya et al., 2020).

The Environmental Impact on Health

Environmental degradation and pollution significantly impact public health. Air and water pollution, deforestation, and climate change not only exacerbate existing health conditions but also contribute to the emergence of new diseases. Addressing these environmental challenges is paramount for achieving sustainable development goals and promoting a healthier global population.

While we're aware of the health effects of pollution and environmental changes, we don't pay as much attention to how healthcare itself impacts the environment. When we evaluate healthcare, we usually focus on its direct effects on health and its costs. But healthcare also has an environmental footprint, meaning it contributes to pollution of the air, water, and soil, which can harm health in unintended ways.

Healthcare is a big part of many economies and job markets. In countries that are members of the Organisation for Economic Co-operation and Development, about 9% of the total money earned (GDP) is spent on healthcare. As investment in healthcare grows worldwide, we need to understand how the environmental impact of healthcare affects health. Often, the people who are harmed by this environmental impact live far from those who benefit from the healthcare provided. So, it's important for doctors and other leaders in the healthcare sector to measure, watch, and deal with the environmental impact of healthcare, both practically and ethically.

In 2016, around 24% of all deaths worldwide were caused by environmental factors. These include things like air pollution, access to clean water and sanitation, rising temperatures leading to heat waves and extreme weather, and exposure to harmful chemicals. To figure out how much disease is caused by these environmental factors, we need to know how much people are exposed to them and how these exposures affect people's health.

Understanding how much disease and ill health can be attributed to modifiable environmental risks can contribute to identifying opportunities for prevention and should add impetus to global efforts to encourage sound preventive measures through available policies, strategies, interventions, technologies and knowledge.

The globalization of supply chains often involves the production and transportation of goods over long distances, contributing to increased carbon emissions and air pollution. These environmental stressors are associated with a higher prevalence of respiratory diseases, cardiovascular problems, and other health issues.

Additionally, deforestation and habitat destruction, often linked to globalization-driven activities, can lead to the emergence of zoonotic diseases as ecosystems are disrupted, bringing humans into closer contact with wildlife.

While globalization has facilitated the dissemination of knowledge and resources, it has also intensified the challenges posed by environmental degradation to global health. Addressing these issues necessitates international collaboration, sustainable practices, and policies that prioritize both human well-being and environmental conservation. As we navigate an interconnected world, acknowledging and mitigating the environmental impact on health becomes imperative for the holistic development and health of current and future generations (Lenzen et al., 2020).

Social Determinants to Health

Social determinants, including income inequality, education, and access to healthcare, play a crucial role in shaping health outcomes. As we strive for sustainability, it is imperative to address these underlying factors to ensure that health and well-being are equitable across diverse populations.

Globalization, the interconnectedness of nations through economic, cultural, and technological exchanges, has profound implications for social determinants of health (SDH). While it has brought about positive changes such as improved access to information and healthcare innovations, it has also exacerbated social inequalities, influencing the SDH on a global scale.

Economic globalization, characterized by increased trade and investment, has led to income inequality within and between nations. This economic disparity directly affects the social determinants of health, as individuals with limited resources face barriers to education, employment, and healthcare access.

The WHO Global Commission on the Social Determinants of Health (CSDH) found that unfairness in society is causing widespread harm. They pointed out that differences in where people are born, live, work, and grow old, driven by inequalities in power, money, and resources, lead to differences in health (World Health Organization).

There are three big problems facing global health: ongoing financial issues, worsening environmental problems, and quickly growing gaps in income and wealth within and between countries. When leaders talk about these problems, they often suggest solutions similar to those recommended by the 2008 WHO Commission on Social Determinants of Health (CSDH). However, the actual decisions made by policymakers often go against the evidence and recommendations of the Commission's final report. If we don't take steps to better control financial systems, set rules for big international companies, or make sure that trade and investment agreements prioritize development goals and human rights, health inequalities around the world will only get worse.

On a more positive note, there's a growing idea to implement global taxes. But the real challenge for global health will be whether governments are willing to make choices at home and abroad that help redistribute income, regulate the economy, and protect the rights of their citizens.

Technological globalization, marked by the rapid dissemination of information, has the potential to bridge knowledge gaps and improve health outcomes. However, it also accentuates existing disparities in access to technology, perpetuating inequalities in education and health information.

Globalization underscores the importance of addressing social determinants collectively. Policies promoting equitable economic development, cultural diversity, and universal access to technology and education are essential to mitigate the negative impact of globalization on social determinants of health and foster a more inclusive and healthier global society (Donkin et al., 2018; Hayudanti et al., 2022).

Advances in Global Health Governance

Strengthening International Collaboration

The global health crisis underscores the need for strengthened international collaboration. Initiatives like the World Health Organization's Global Action Plan for Healthy Lives and Well-being provide a framework for coordinated efforts to address health challenges at a global scale. Building on these foundations, nations must work together to share resources, expertise, and technology.

Technological Innovations in Healthcare

Advances in technology offer unprecedented opportunities to enhance healthcare delivery. Telemedicine, artificial intelligence, and data analytics can improve disease surveillance, diagnosis, and treatment outcomes. Integrating these innovations into healthcare systems contributes not only to better health outcomes but also to the overall sustainability of healthcare infrastructure.

Applications in Sustainable Development

A holistic approach to sustainable development recognizes health as a catalyst for thriving communities. Investments in healthcare infrastructure, education, and poverty alleviation contribute not only to better health outcomes but also to resilient and sustainable societies. By integrating health considerations into development strategies, we can create lasting positive impacts on both individuals and communities.

Achieving sustainable development requires policy coherence across sectors. Health considerations should be mainstreamed into policies related to environment, economy, and social welfare. This integrated approach ensures that efforts aimed at sustainable development contribute to improved health outcomes and vice versa (Labonté, 2012; Higuchi, 2021).

Conclusion

As the world becomes more connected and complicated, people's health is seen as the result of many factors like the environment, society, culture, money, and institutions. So, it's like a big picture that shows how healthy the natural world and society are in the long term.

There's a growing agreement that globalization is really complex. It's not just about trade or culture; it's about how different aspects of technology, culture, money, society, and the environment all interact with each other on local, national, and global levels. This definition of globalization talks about how different countries and cultures become more connected and how this affects many parts of life.

Given the global health crisis, the idea of sustainable development is closely linked to how well people all over the world are doing. To tackle the big challenges we face, we need to change how we think about health, sustainability, and development. By working together internationally, using new technology, and making sure health is a big part of the plans, we can make the world healthier and more sustainable. This chapter is a call for everyone involved in different areas to come together and work towards a better future for everyone.

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Chapter 9

Analyzing Cardiovascular Risk Factors in the Monitoring of Heart Disease: Leveraging Machine Learning Tools

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Abstract

This chapter analyses the driving factors behind cardiovascular diseases using appropriate machine learning tools. A dataset of 918 individuals based on the presence or absence of heart disease along with the values of 11 concomitant variables has been used. The aim of this paper is to classify observations based on the values of the covariates and also to evaluate their significance in affecting the target variable. For that, various machine learning tools have been employed. Finally, all these tools have been compared in light of their ability to explain the data at hand.

Keywords: cardiovascular diseases (CVD), logistic regression, lasso regression, k-nearest neighbor classifier, support vector machine classifier; random forest classifier

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Introduction

Cardiovascular diseases (CVD) are one of the leading causes of mortality in the Indian subcontinent (Kumar and Sinha, 2020). Cardiovascular complexities such as ischemic heart disease and cerebrovascular complexities such as stroke claim 17.7 million lives per year, making up to 60% of all deaths. In 2016 alone, CVDs accounted for 28·1% of total deaths and 14·1% of total disability-adjusted life years (DALYs) in India as compared with 15·2% and 6·9%, respectively, in 1990, making it clear that there has been a huge jump in the numbers (Ruhil, 2018). Moreover, CVD is prominently hitting people from the Indian subcontinent a decade earlier than those from western origin, affecting them in their most productive years, i.e., the Middle Ages (Prabhakaran, Jeemon and Roy, 2016). It has been observed that the fatality rate is also pretty high in low-income communities as compared to middle- or high-income groups. This is a matter of high concern in a country like India, where most of the people belong to low-income groups. Another concern is that most cardiac arrests happen in the homes of patients, and sufficient time is not left for proper treatment in the hospital. Some of them had not even been diagnosed with the presence of CVD at all before the event. This makes it one of the most difficult epidemiological diseases to monitor, with an inherently huge possibility of underestimation.

Heart disease is a very generic term, which means the heart is not working normally. A person with any kind of heart disease may or may not have any physical symptoms. It is, therefore, absolutely essential to understand and recognize the various indicative factors that may eventually lead to the conclusion that a person has CVD. The most common types of heart issues may be broadly classified into coronary artery diseases (CAD) or ischemic heart disease and arrhythmia (Although arrhythmia may or may not be a result of the presence of CAD in the first place). CAD normally occurs when plaque accumulates on the arterial walls as a result of high cholesterol and triglyceride levels in the blood. The arteries become narrow and obstruct blood flow to the heart. Sometimes, a clot can also do the same thing. If blood vessels connected to the heart become very narrow or somehow blood vessels are blocked partially or completely, then blood cannot flow through them, which is less than normal. As a result, the heart muscles are unable to work in their normal capacity, causing them to gradually grow weak. Prolonged pressure of this kind on the heart may finally result in myocardial infarction (heart attack) and stroke. (Ghosh & Sen, 2021; Kumar, Umashankar & Poddar, 2020).

The risk factors include a plethora of socio-economic and biological aspects and their interactive effects. A very important job is to determine the indicative and causative factors for the onset of CVD in people, eventually leading to a deterioration of their current condition. The World Health Organization (WHO) has established a set of modifiable and non-modifiable CVD risk factors (CVRFs) (Kaptoge et al., 2019), addressing mainly myocardial infarction (heart attack) and stroke. Modifiable CVRFs are those that individuals have more control over. These involve behavioural factors like physical activity, diet, alcohol, and tobacco consumption that may evolve over time with an individual's choice and resolve. Non-modifiable factors are those over which individuals have no control. These comprise of factors like genetic makeup, age, sex, and ethnicity.

The main two objectives of this study are, therefore, a comparison between various classification or regression procedures and to determine the regressors that are most critical to drawing meaningful inferences about the response variable, which is the presence or absence of heart disease. For this, the machine learning toolkit was used.

Machine Learning Basics

To motivate the understanding of the mentioned problem, a very generic model has been considered here,

$$Y = f(X) + \varepsilon \tag{1}$$

where $X = \left(X_1, X_2, \dots, X_p\right)$ are the set of p predictors that will help in the observation/prediction of the quantitative or qualitative response variable Y. The ϵ is the random (random variable) error term that is independent of X and has zero mean. Essentially machine learning refers to a set of procedures for estimating f. There are basically two broad reasons why one wants to identify or estimate f - prediction and inference. For the purpose of prediction, one can in general use the idea of

$$\hat{Y} = \widehat{f(X)} \tag{2}$$

wherein a predicted response $\hat{Y}$ is evaluated using an estimated $\widehat{f(X)}$ since the error terms average out to zero in the long run assumption of estimation procedures. Here note that $\widehat{f(.)}$ is treated as a black box, knowing whose exact functional form is not that necessary. On the other hand, when inference is the aim, it is required to find out the exact relationship that Y has with the regressor set $X = (X_1, X_2, \ldots, X_p)$ so that comprehensive conclusions about the effect that each regressor has on the response variable can be made and also to determine the most important driving forces behind the behaviour of the response variable (James et al., 2013). The next important question is how one may estimate f. There are many parametric and non-parametric methods to do so. All of these estimation procedures are based on the concept of minimization of the error component in the model. Hence to summarize, the primary aim is to estimate f in such a way to minimize the error term such that an appropriate predicted value may be achieved.

It is to be noted that there is no single super-powerful model that is appropriate for all kinds of data. Some models may perform better for a certain kind of data, and some models may not perform as well. For that, assessing the model's accuracy is a key factor. Of course, the model's accuracy increases drastically with an increase in the number of predictor variables involved. However, it also means that model complexity has also increased, and according to the principle of parsimony, a good tradeoff between model accuracy and model complexity is to be kept in mind for the most optimum results.

Models with quantitative responses are generally classified as regression problems, and those with qualitative responses become classification problems. However, the differences are not always clearly demarcated. For example, generalized linear models are regression problems of which both linear regression models and the logistic regression model are particular forms. However, linear regression models, estimated with the help of the method of least squares, are the most widely used regression problems for quantitative response data. On the other hand, logistic regression models deal with qualitative data with usually two response classes. Hence, it is typically a classification problem and is treated as such. Then there are methods, such as nearest neighbours that can successfully deal with qualitative as well as quantitative responses.

Most Important Models and Tools

LASSO

LASSO is a regression technique with the primary aim of shrinkage and variable (or feature) selection. The process introduces a specified upper bound to the sum of the absolute values of the parameters. This causes the regression coefficients of the less important regressors to shrink towards zero. This very much eases the process of variable selection as it helps identify the most significant predictors for the response variable. Thus, the process compacts the model into a simpler and more meaningful form, even reducing prediction errors to a great extent. In other words, LASSO removes redundant variables from the model.

The method uses $L_1 = \sum_j^p |\beta_j|$ as a penalty term. Here β_j's are regressor coefficients. It penalized the factor towards least square or as maximum likelihood estimation. It consists of tuning constant λ_L which is multiplied with the penalty term i.e., the sum of absolute numbers as the parameter of interest β. The tuning constant is the penalizing factor which helps to decide how many predictors would make it to the final list. The formula becomes$\lambda_L \sum_j^p |\beta_j|$. If $(j = 0,1, \dots, p)$ then the LASSO penalized function, say, L_{LASSO} becomes

$$L_{LASSO} = logL - \lambda_L \sum_j^p |\beta_j| \tag{3}$$

Final results and inferences are quite sensitive to the variation in λ. Thus, it must be carefully determined (Tibshirani, 1996).

Logistic Regression

Simple or multiple linear regressions is based on the assumption of a linear dependence relation between the response variable and the explanatory variables, with a normality assumption for the error terms and also the conditional distribution. However, when the response variable takes dichotomous values only, this normality assumption cannot hold, nor can the simple (or multiple) linear model be appropriate. In this case, logistic regression is most appropriate (Montgomery, Peck and Vining, 2021). In fact, the conditional distribution of is binomial.

In logistic regression, the log of odds to have a linear dependence structure with the explanatory variables has been taken (or covariates). The regression coefficients can be estimated using a variety of methods, such as the Iteratively Reweighted Least Squares Method, Maximum Likelihood Estimator etc.

K-Nearest Neighbour Classifier

KNN (k-nearest neighbors) classifier is a type of non-parametric machine learning algorithm that is effective in solving regression or classification problems. It is particularly useful in cases where the underlying relationships between the features and the target variable are non-linear or complex.

The basic algorithm can be summarized as follows:

First, the distance between the new data point and each training example is calculated using a distance metric such as Euclidean distance, $(x, y) = \sqrt{\sum_{i=1}^{n}(y_i - x_i)^2}$.Even Manhattan distance and Minkowski distance can be used here. Then, the set of k training examples with the smallest distances to the new data point are identified and named say N_0. It then calculates the conditional probability for class j as the fraction of points in N_0 whose response value equals j, $P(Y = j|X = x_0) = \frac{1}{k}\sum_{i\in N_0} I(y_i = j)$. Finally, the algorithm classifies the test observation x_0 to the class with the highest probability.

The choice of k determines the flexibility of the KNN model. A small k value results in a more flexible model that can fit the training data more closely, but it may not generalize well to new data. On the other hand, a large k value results in a less flexible model that is less likely to overfit the training data, but it may not capture the underlying patterns in the data (James et al., 2013). However, it may not perform well on high-dimensional data or in cases where the feature space is sparse. For regression, the response variable should be a continuous variable and for classification, the response variable should be a categorical variable.

Support Vector Machine

The Support Vector Classifier is a machine learning tool which can be used as a solution to both regression and classification problems mainly to separate two different classes by a hyperplane. But there might be cases where this hyperplane may not be able to separate two classes perfectly especially when the decision boundary is non-linear. One good solution to the ensuing problem is to extend the feature space by taking some quadratic or cubic function of the predictor variables.

The Support Vector Machine does this kind of extension through a specific way i.e., by using kernels. A kernel $K(x_i, x_i{}')$ in a very general sense of the term refers to as a function that quantifies the similarity between two points x_i and x_i'. They can be of different types for example the linear kernel $\sum_{j=1}^{p} x_{ij}x_{i'j}$, polynomial kernel $\left(1 + \sum_{j=1}^{p} x_{ij}x_{i'j}\right)^d$, radial kernel $\exp\left(-\gamma \sum_{j=1}^{p}\left(x_{ij} - x_{i'j}\right)^2\right)$ etc.

Like all other tools, it has its own set of advantages and disadvantages. It can be a bit inefficient in the case of large datasets, especially those that are noisy. It can also be quite sensitive to the choice of kernel. However, in cases where the feature space is large or the decision boundary is non-linear, this may be very useful (James et al., 2013).

Random Forest

Random Forest is a machine learning algorithm proposed first by Breiman, (2001). It is used for both regression and classification tasks. It is a type of ensemble learning method that merges multiple decision trees for better accuracy and robustness of the predictions. In this algorithm, each of those decision trees is trained on a subset of the data which is chosen by the random sampling method from the given dataset and a random subset of the features, which helps to reduce the overfitting problem and improve the generalization ability of the model. For regression work, the response variable should be a continuous variable and for classification work, the response variable should be a categorical variable (Amalia, Said & Nambiar, 2024).

Random Forest can work with a huge number of features and work well with both numerical and categorical data. They are less susceptible to overfitting compared to any other decision tree-based models, as the algorithm trains multiple decision trees on random subsets of the data and features. They can give information on how valuable each feature is in the prediction.

However, too much time is taken to train them, which may not be cost-efficient in some cases, especially when high-volume data is being dealt with. This tool may not be ideal to use when there is an imbalance in the dataset or a high number of insignificant features in the dataset. The main challenge is to interpret the result of the random forest model as it combines the results of multiple decision trees.

Analysis of the Results

For a numerical illustration of the discussed models, a data set on heart disease has been used here, made available by Kaggle (n.d.). It consists of the data of 918 individuals on the presence or absence of heart disease, along with the values of 11 covariates, namely age, sex, chest pain type (TA: Typical Angina, ATA: atypical angina, NAP: non-anginal pain, ASY: asymptomatic), resting blood pressure, cholesterol, fasting blood sugar, resting ECG (electrocardiogram), old peak and ST slope (whether or not there is an elevation in the ST segment of the ECG). The aim of this analysis is to evaluate the effect of these covariates on the presence or absence of the disease. It has been treated both as a regression and classification problem using the models discussed in the introduction and Machine Learning Methods (Rosdiana & Cahyati, 2019; Pranata et al*.,* 2023).

Determination of the Covariate Set Using LASSO

The Lasso regression has been applied here and it has been found that ‘Resting ECG’ is the covariate that is not as significant in affecting the presence or absence of heart disease. Hence, this feature was removed, and a new model was formed. After that, all the algorithms namely, the logistic regression, KNN, SVM and Random Forest have been run for both the complete and the reduced feature space.

Logistic Regression

The logistic regression model is fitted for the data at hand. Since the response variable is dichotomous, this is the most ideal situation for this kind of modelling. However, after an initial analysis of the data, a few outliers were detected and removed. Recommendations from Montgomery, Peck and Vining (2021) were used while identifying the said observations as outliers.

Then logistic regression is carried out for the complete feature space and the LASSO reduced one. The parameter estimates are provided for the one with LASSO reduced feature space, although not a very significant effect is seen in their values due to the application of LASSO. The covariate estimates are given in Table 1.

K-Nearest Neighbour Classifier

The entire data has been split into training and testing subsets in the ratio 7:3, as is commonly suggested in the literature (James et al., 2013, for example). As before, the KNN classifier is run for the entire feature space and the reduced one after running the LASSO. The confusion matrices, as well as the run times for each model, have been noted for the purpose of comparison. Different values of K are chosen, and the accuracy is noted every time.

Additionally in the classification models, the confusion matrix helps evaluate some very important indices namely, accuracy, precision, recall and F_1 score. Here accuracy measures how close the predicted values are with the true values (accuracy $=\frac{TP+TN}{TP+TN+FP+FN}$) (TP: True Positive, FP: False Positive, TN: True negative, FN: False Negative), precision is the amount of actual positive labels from all of the labels that are classified in the model as positive (precision$=\frac{TP}{TP+FP}$), recall measures the number of positive labels in the model that has been correctly classified as positive (recall $=\frac{TP}{TP+FN}$) and F_1 score is a balance between precision and recall as they have an inversely proportional relationship (F_1 Score $= 2 \times \frac{precision \times recall}{precision+recall}$). All these have been calculated for both models, that is before and after application of Lasso Regression Technique. Tables 2 and 3 provide the various precision estimates for the KNN models before and after the application of LASSO.

Table 1. Various estimates in the logistic regression model

Coefficients	Intercept	Age	Sex	chest pain type	resting BS	cholesterol	fasting BS	Resting ECG	Maximum HR	Exercise Angina	old peak	ST slope
Estimates	6.722356	0.023334	1.640727	0.650490	0.008507	0.005140	0.118289	0.078877	0.010495	1.187794	0.299003	.779695

Table 2. Important measures for KNN classification model before applying LASSO

KNN algorithm with different values of k	Accuracy	Precision	Recall	F_1 score
When k = 1	0.9737	0.9787	0.9650	0.9728
When k = 3	0.9967	0.9929	≈1	0.9964
When k = 5	0.9868	0.9716	≈1	0.9856
When k = 7	0.9769	0.9503	≈1	0.9745
When k = 15	0.9737	0.9433	≈1	0.9708
When k = 19	0.9737	0.9433	≈1	0.9708

Table 3. Important measures for KNN classification model after applying LASSO

KNN algorithm with different values of k	Accuracy	Precision	Recall	F_1 score
When k = 1	0.9789	0.9669	0.9865	0.9766
When k = 3	0.9789	0.9735	0.9800	0.9767
When k = 5	0.9819	0.9735	0.9866	0.9800
When k = 7	0.9729	0.9603	0.9797	0.9699
When k = 15	0.9699	0.9470	0.9862	0.9662
When k = 19	0.9609	0.9271	0.9859	0.9556

Support Vector Machine

As before, the data has been split into training and testing subsets for application in the algorithm. A RBF kernel has been used in the process. The RBF Kernel is defined as

$$f(x_1, x_2) = e^{\frac{||x_1 - x_2||^2}{2\sigma^2}}$$

where σ^2 is variance and hyperparameter. A larger value of σ results in a narrower kernel and a more complex decision boundary. A smaller value of σ results in a wider kernel and a smoother decision boundary.

The RBF kernel is a popular choice because it is a universal kernel, meaning that it can approximate any continuous function to an arbitrary degree of accuracy. This makes it very versatile and useful for a wide range of applications. Figure 1 represents the count plot for 'heart disease'.

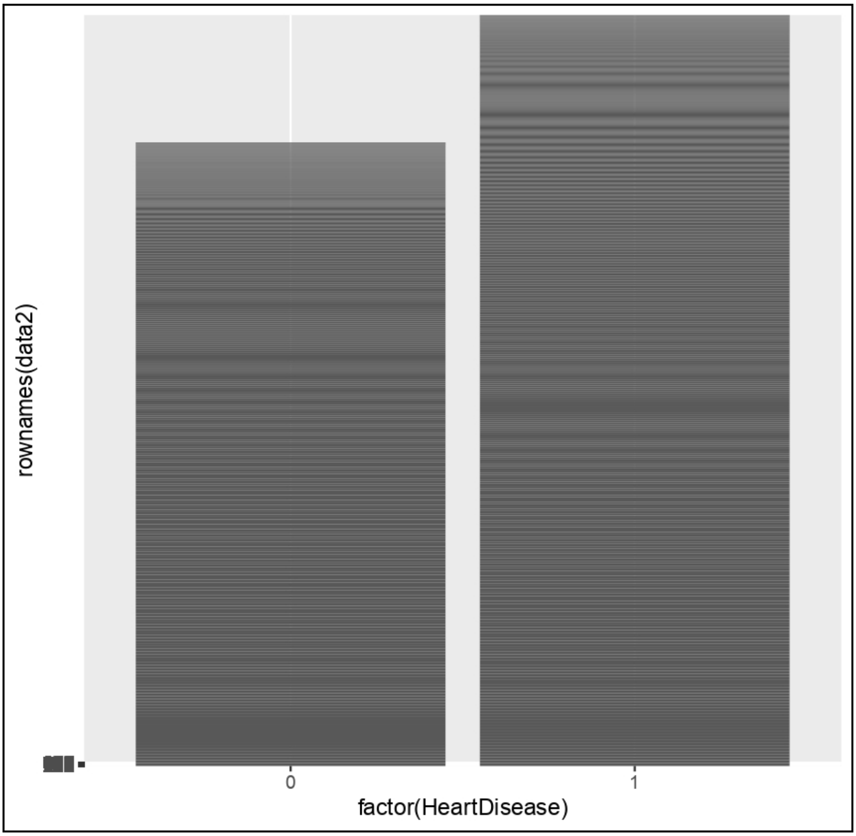

Figure 1. Count Plot for "Heart Disease" Column (Target Variable Column).

Random Forest

In Random Forest classifiers, the data is also split into training and testing subsets, and the algorithm is run for both the complete model and the LASSO reduced model. A comparison of the end results can be seen in Table 3. The error against the number of trees is plotted here, and it can be seen in Figure 2 that the error rate is stabilized with an increasing number of trees. Although the graph for the complete model has been provided, a very similar trend can be seen even for the Lasso-reduced model as well.

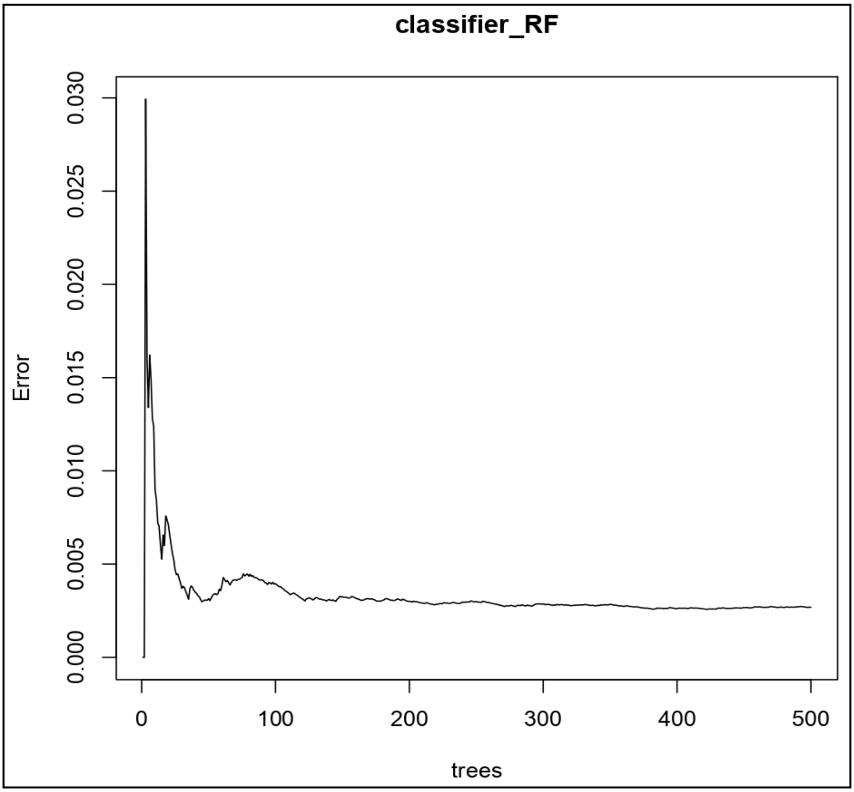

Figure 2. Stabilization of Error with the Increase in the Number of Trees.

Model Comparison

For the purpose of model comparison, the quantities ‘accuracy’, ‘precision’, ‘recall’ and ‘F1 score’ have been calculated for both the complete and LASSO reduced feature spaces as defined in the section K Nearest Neighbour Classifier. Further on, receiver operating characteristic (ROC) curves have been plotted for each model.

To calculate ‘accuracy’, ‘precision’, ‘recall’ and ‘F1 score’ for all of the models before and after Lasso Regression technique, ‘Confusion Matrix’ has been calculated first using ‘Caret’ package in R. Except that, ‘table ()’ function in R can be also used which also helps to provide a categorical representation of data with the names of variables in a form of table.

Moreover, for K-Nearest Neighborhood Model 'misClassError' is used here which has provided mean for all those data values where predicted values are not similar with actual values. And 'Accuracy' has been obtained from this formula: '1 - misClassError'. The corresponding results are given in Table 4.

Table 4. Important measures for classification models

Type of algorithm	Accuracy	Precision	Recall	F_1 score
Logistic Regression	0.8493	0.8668	0.8529	0.8598
SVM before Lasso Regression	0.9967	≈1	0.9929	0.9964
SVM after Lasso Regression	0.9970	≈1	0.9937	0.9968
RF before Lasso Regression	≈1	≈1	≈1	≈1
RF after Lasso Regression	≈1	≈1	≈1	≈1

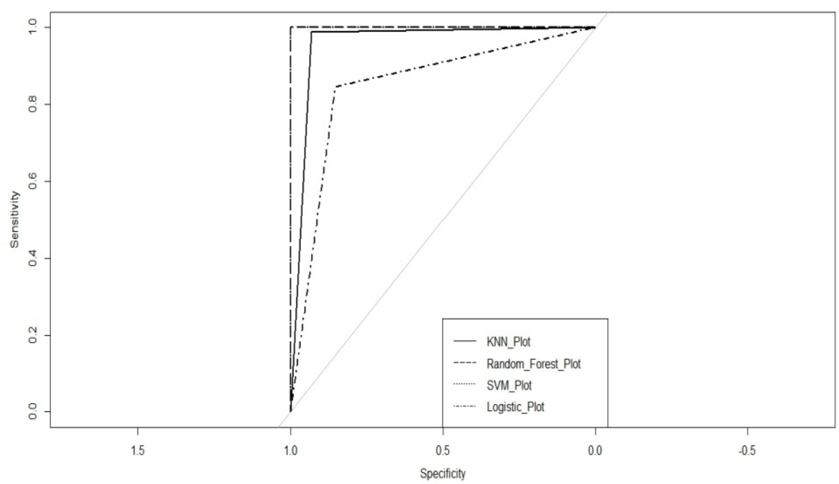

Figure 3. ROC Curves for the Different Algorithms.

To construct ROC Curve using R programming, 'pROC' package has been opted here so that Area Under the Curve can be calculated and using that ROC Curves for different models can be plotted successfully. Note that the Area Under the Curve helps to determine which model is best among the four models that have been plotted so that a proper comparison can be established. From Figure 3 it is apparent that AUC for Random Forest Classifier > (AUC for Support Vector Machine, Logistic Regression, KNN

Classifier) thus, the Random Forest Classifier model is better than the other three models.

Table 5. Important packages of R programming to execute mentioned classification models and LASSO regression technique

Type of models	Useful packages
KNN Classifier	e1071, caTools, class
Random Forest Classifier	randomForest
SVM Classifier	e1071
Lasso Regression	glmnet

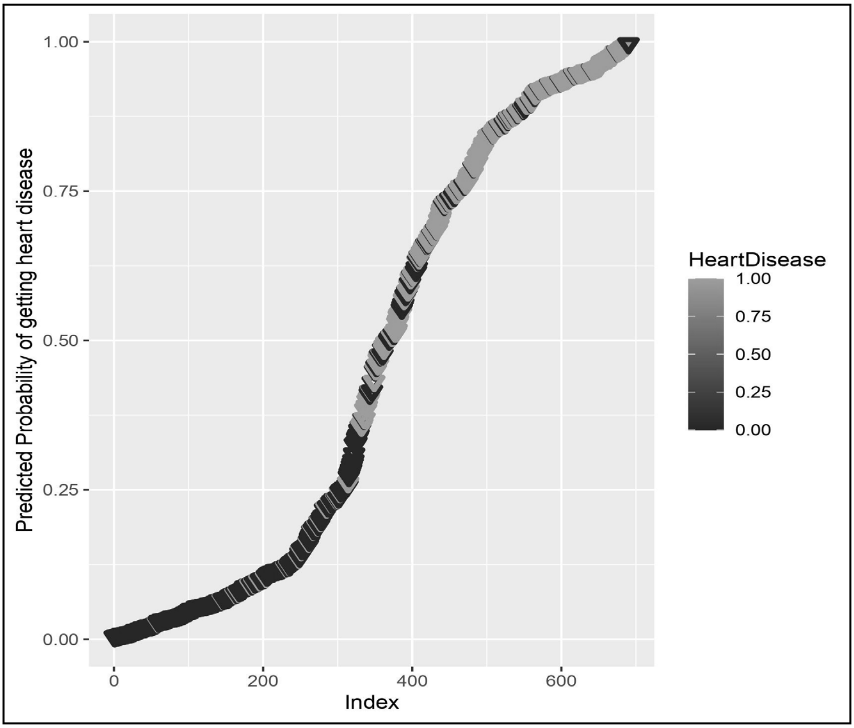

Figure 4. Sigmoid Curve.

Figure 4 is the visual presentation of Sigmoid Curve based on Predicted Values of target variable (Here, it is Heart Disease). Due to this, the first probabilities of having heart disease and having a normal healthy heart have been found out. After that, this sigmoid curve is plotted using ‘ggplot2’ and ‘GGally’ packages. Note that, both the endeavors to compare have given way to the same conclusion that Random Forest is the best classifier model for the data at hand, closely followed by the SVM model. However, the difference between the two is quite marginal. Table 5 represents the various packages that have been used in the analysis.

Feature Selection

Since after the model selection procedure, conclusively RF is the most optimal model for considered dataset. Feature selection process has been performed for the same. Feature selection for random forest classifiers can be done automatically through 'Variable Importance Package' in R. Using this package, Variable Importance Plots can be constructed so that it can be determined which feature is most effective while predicting target variable. The results of the feature selection procedure are provided in Figure 5.

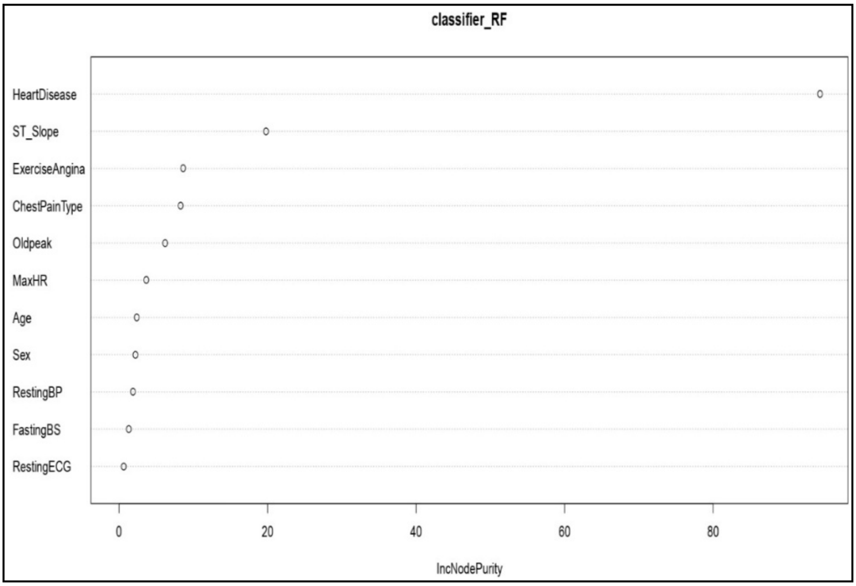

Figure 5. Selection for Random Forest Model.

Conclusion

This analysis suggests that ST Slope is the most important covariate, followed by Chest Pain Type, Exercise Angina, Old peak, Max heart rate and Age which is very close to what is stated in medical literature as well (Surawicz et al., 2009). ST segment elevation in the ECG is believed to represent a 'current of injury' from damaged heart cells. The threshold values of ST-segment elevation of 0.25 mV are considered normal for a male aged 40 years, and that for a female is 0.15 mV by some sources. However, the general heart condition also depends on a variety of other factors, which explains the other factors that have been found useful in this study. The future direction of work can be to investigate the interplay of factors, that is, to model the interaction effects. That can give us some very insightful results.

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Chapter 10

Vector-Borne and Waterborne Diseases

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Abstract

This chapter examines the potential effects of vector-borne and waterborne illnesses on human health. Rapid urbanization has caused an imbalance in environmental factors and led to a shift in the habitats of several vectors and bacteria. This has been proven to disperse many diseases to various parts around the globe. Numerous factors contribute to the spread of vector-borne diseases, such as climate change, urbanization, host immunity, pathogen invasion patterns, and many extrinsic and intrinsic factors. Dengue and malaria have been reported on many continents worldwide as the highest reported incidence and mortality-causing vector-borne diseases. Many countries, such as those in Southeast Asia, America, and African countries, have reported the resurgence of these infections. There are numerous documented cases of outbreaks occurring after flooding, contaminating subsurface water sources. Globally, waterborne illnesses remain the primary cause of morbidity and mortality among people. Waterborne disease-causing bacteria pose the world's most serious public health problem. Although waterborne illnesses present a significant hazard to public health worldwide, they are uncommon in modern nations due to advanced sewage disposal, water distribution, and purification systems.

Keywords: transmission, vector-borne and water borne disease, urbanization

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Introduction

Vector borne disesases have been reported to be the major public health concern in many countries throughout the world. The disease is not directly transmissible to humans, instead it spreads when favourable conditions arise for the transmission of infections, animal hosts, vectors, and susceptible populations of people (Savić et al*.,* 2014). In the past, vector-borne illnesses like trypanosomiasis, leishmaniasis, filariasis, yellow fever, plague, filariasis, louse-borne typhus, and malaria caused more illness and deaths in humans throughout the 17th through the early 20th century (Gubler, 1998). Over the past 20 years, it has been reported that several vector brone diseases have spread to new areas and an equal number of endemic diseases has rise in occurance (Harvell et al*.,* 2002). Recently, in the years 2014–2016, people from Liberia, Guinea and Sierra Leone were ravaged by the largest Ebola outbreak ever recorded, followed by the Zika Virus outbreak in Southeast Asia and Latin America (Aylward et al., 2014) Previous studies have indicated that vector borne human infectious diseases such as dengue and malaria and yellow fever pose a wider range of distribution. There seems to be a correlation between vector brone diseases and climate change factors. Anthropogenic greenhouse gas emissions are causing the Earth to warm rapidly, with significant long-term effects for vector-borne disease prevention and control. It is unevitable that the climate affects many facets of nature and thus causing global warming, and it is reported that the average global temperature is likely to increase in the next 80 years by 1 to 3.5°C on average (Lovett, 1997). Among the vector borne disease, Malaria has the highest percentage of incidence, with 249 million cases in 2022 compared to 244 million cases in 2021. Researchers reported an estimated mortality rate of 608 000 worldwide in 2022, compared to 610 000 in the previous year.

Since the local climate and weather closely influence their exposure pathways, the hydrologic cycle intensification may affect waterborne infections (Semenza & Ko, 2023). However, different infections have varying environmental and climatic transmission drivers. Large-scale outbreaks of waterborne diseases that cause gastrointestinal sickness have been linked to a number of different agents, including norovirus, hepatitis A virus, Giardia, Campylobacter, E. Coli, Salmonella, and Shigella (Neil et al., 2023; Hossain, Ali & Islam, 2021). Certain diseases, like Vibrio and Salmonella, have the ability to reproduce outside of their host, but other pathogens, including Campylobacter, Cryptosporidium, and Norovirus, are not active outside of their host (Semenza & Ko, 2023). Bacterial diarhoeal infections, specifically salmonellosis and campylobacteriosis, are more common during warm summer months (Yun et al., 2016). This is because pathogens reproduce more successfully at higher temperatures. Climate-sensitive waterborne diseases follow a specific seasonal pattern (Yun et al., 2016). The most well-known illnesses linked to waterborne epidemics worldwide are cholera, typhoid fever, meningitis, encephalitis, dysentery, hepatitis, legionellosis, pulmonary sickness, poliomyelitis, leptospirosis, giardiasis, and salmonellosis (Andrade et al., 2018; Murphy et al., 2014).

Vectors and Transmission Dynamics and Urbanization

The term "transmission dynamics" refers to a variety of variables that affect how efficiently a population's genetic material spreads over time and geographical topography. These variables include travel, host immunity, fundamental reproduction number, and human conduct. The transmission of the disease, vector, host (humans and other animals acting as reservoirs), and additional environmental variables determines the dynamics of transmission (Eder et al., 2018). Variability in the daily, seasonal, or annual climate can lead to adaptability of vectors and pathogens, as well as changes or expansions in their geographic ranges. Depending on host immunity, pathogen evolution, and vector-host interaction, these changes may change the incidence of disease.

Vectors are the primary transmission mode for infectious vector-borne diseases, such as mosquitoes, ticks, fleas, sandflies, and lice. These vectors rely on environmental changes for their internal temperature regulation, precisely known as ectothermic. For instance, mosquitoes require the presence of optimum humidity and water bodies for the development of the larval stage, which directly correlates with the spread of diseases such as dengue and malaria. Many vector-borne illnesses, such as Zika, chikungunya, dengue, and malaria, primarily affect humans, while other vector-borne diseases have a more intricate mechanism involving both humans and non-human hosts. For instance, a wide range of bird species serves as reservoir hosts, exhibiting varying degrees of competence, while other animals such as mammals and humans serve as dead-end hosts. The vectorial capacity is often increased by high breeding output under suitable conditions and the high capability to invade the ecologically imbalanced environment, mainly in peridomestic habitats where humans and domestic animals are present (Swei et al., 2020; Paunikar & Kulkarni, 2020).

There is a widespread resurgence of vector borne disease in urbanized areas. Numerous studies have indicated the the modifications in the environment can destroy the habitats, host and predators which alters the population dynamics, host seeking behaviours, ovipositiona nd the vector population. This indirectly encourages the host to seeks for a new breeding habitat and new blood feeding sources (Vieira et al., 2020). Local transmission characteristics are influenced by a multitude of parameters, such as host density and demography, ecological circumstances for the vector (such as vegetation, temperature, rainfall, and breeding sites), vector abundance, and financial resources (such as bed nets and window screens) (Bousema et al., 2010). Rapid urbanization and deforestation have a direct and indirect impact on the transmission patterns of the vector borne diseases.

Another factor which has been reported to increase the incidence of VBD is the formation of natural disasters due to significant climate changes (Wilke et al., 2019). The formation of hurricanes and storms are able to disperse the vectors to new breeding sites and establish a new habitat (Colón-González et al., 2021). The rapid urbanization and the correlation between climate change, cause the expansion of vector population in different areas cause the increased risk for pathogen transmission to humans (Ogden & Lindsay, 2016).

Dengue

Dengue has the highest prevalence and vector that can spread in urban and peri urban areas. Dengue fever can be found mainly in the tropical and subtropical regions and approximately a third of the human population is affected by this disease. The dengue fever is caused by blood sucking female Aedes mosquito *Aedes aegypti* and *Aedes albopictus* and the causative agents is any four types of dengue serotypes DENVs 1-4 flavivirus from the family Flaviviridae A DENV infection can cause a range of clinical states, from moderate, asymptomatic dengue fever (DF) to severe, potentially fatal dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS) (Murphy & Whitehead, 2011).

The *Aedes* mosquito has an 8–10-day life cycle at room temperature, depending on how often it feeds. There are two stages to it: the aquatic phase (larvae, pupae) and the terrestrial phase (eggs, adults). The DENV is mainly transmitted to humans via the bite of an infected female mosquito via horizontal transfer. Through this process, the mosquito becomes infected when the blood from the viremic host enters the body of the vector. The interval of time between a susceptible mosquito ingesting contaminated blood and the presence of infectious virus particles in its salivary secretions is known as the extrinsic incubation period (EIP). After this incubation period, the mosquito is able to transmit the virus to a new human host (Thaís & Flavia Barreto dos, 2017). Some arboviruses can spread from an infected male or female parent to their progeny during oviposition or within the ovary. This occurrence is referred to as vertical transmission (Lequime et al., 2016).

Malaria

The female blood-sucking Anopheles mosquito transmits the malaria parasite. The mosquito inhabits in the stagnant water streams, ponds and lakes during its beginning stages (Foster & Walker, 2002). The transmission of malaria is influenced by increased human and vector exposure, temperature and humidity. This adaptation may induce a shift in the duration of the life cycle or the effectiveness of the biting. It is reported that there was notably greater incidence of malaria worldwide in 2022 after the pandemic (Covid 19).

Malaria is an infection caused by Plasmodium species. The Plasmodium species that infect humans are P. falciparum, P. vivax, P. ovale, P. malariae, and P. knowlesi. The pathophysiology of malaria infection begins with a mosquito feeding on an infected person with malaria and ingesting blood containing gametocytes. Within a week or two, infective sporozoites are produced and can be transmitted to other human hosts, reaching the hepatocytes in the liver. Tissue schizonts are produced, and each schizont produces abundant merozoites, which enter the bloodstream once the hepatocytes rupture. These merozoites further transform into trophozoites upon invading red blood cells. Finally, the trophozoites transform into gametocytes, and sexual reproduction takes place in the mosquito's gut. The parasites grow into oocysts, producing infectious sporozoites that travel to the salivary glands. Malaria is characterized by mild to severe symptoms, including malarial paroxysm caused by the hemolysis of red blood cells, and it may progress to hepatomegaly and splenomegaly. (Nureye & Assefa, 2020).

Lympathic Filariasis

Around the globe, lymphatic filariasis (LF) is one of the most prevalent illnesses spread by mosquitoes. The transmission of LF is by mosquito bite exposure. Human LF is caused by three parasites: *Wuchereria bancrofti*, *Brugia malayi*, and *Brugia timori*. These parasites are spread by exposure to vector mosquitoes such as Culex, Aedes, and Anopheles. Over 90% of illnesses worldwide are caused by *W. bancrofti*, with *B. malayi* primarily contributing to the spread of the disease (Tyagi, 2018). Once the parasites gain access to humans, the lymphatic veins and nodes in the body are blocked by these parasites. This obstruction results in the accumulation of fluids in the tissues, which can produce massive swelling known as "lymphedema." Due to the worms' extended lifespan and the way the infection builds up over time, LF infection becomes chronic. Many people may be infected without realising it, however after a protracted infection; some people may experience severe chronic symptoms like lymphoedema and hydrocele (Chakraborty et al., 2013).

When a mosquito bites a human and ingests the microfilariae along with the blood, the extrinsic life cycle begins. The microfilariae pass through the mosquito's intestinal wall and enter the thoracic muscles, where they become maturedinto first-stage larvae (L1). The larvae in the L1 stage grow and evolve into the more active L2 stage after 5-7 days, and by 10-11 days, they become the infective stage larvae (L3). Most infectious larvae (L3) migrate to the mosquito's proboscis after they reach maturity, where they prepare to infect another person (Al-tameemi & Kabakli, 2019 and Goel et al., 2016).

Zika

The positive-stranded RNA virus known as Zika virus (ZIKV), which is spread by mosquitoes and belongs to the Flaviviridae family (genus Flavivirus), has generated an unprecedented widespread outbreak in the Americas. In the past, ZIKV invaded the Caribbean, Central America, and South America in 2015, then moved to Africa and Asia to the Pacific Islands in the late 2000s and early 2010s. It finally made its way to North America in 2016. The major transmission vector for ZIKV have been identifiied as Aedes aegypti and Aedes albopictus mosquito which is the same causative vector for dengue and malaria. ZIKV infection has been connected to an increasing number of severe neurological disorders, such as Guillain-Barré syndrome and microenchepaly in childens, even though it typically only results in a mild symptoms or no symptoms at all.

The Guillian Barre syndrome is the syndrome where the immune system attacks the peripehral nervous system and causes severe neurological impairment and finally even death. The ZIKV associated Guillian Barre syndrome was first detected in the year 2014 and also obrserved in the Americas in year 2015 and 2016. Apart from that, congenital and postnatal microenchepaly has been reported as the clinical manifestation of ZIKV. Thedecrease in the number of neurons created during neurogenesis isthe origin of primary microcephaly, a decrease in the number of dendritic processes and synaptic connections isthe cause of secondary microcephaly which causes the infant head to be smaller than normal due to improper development of the brain (Tang, 2016).

Cholera

Despite decades of efforts to eradicate it, cholera remains a global menace to public health (Caplan et al., 2020). In the 19th century, cholera was a major worldwide health problem that mostly originated in the Indian subcontinent and frequently spread to European cities in the form of widespread epidemics (Tulchinsky, 2018).According to statistics, there are millions of new cases of cholera each year in 69 endemic countries, and the disease may be responsible for up to 143,000 deaths annually (Ali et al., 2015).According to the World Health Organization (WHO), cholera is non-discriminatory, affecting or killing both children and adults within hours of symptoms appearing after consuming contaminated food or water (Azman et al., 2013).

Vibrio cholerae, is a waterborne pathogen most vulnerable to and prevalent during extreme weather events (Cann et al., 2013 and Funari et al., 2012). These weather patterns accelerate the transfer of *Vibrio cholerae* and other germs from feces to drinking water and food systems (Harris et al., 2008). About 80% of infections in poorer countries are caused by poor sanitation and contaminated drinking water (Halvorson et al., 2011).

Typhoid Fever

The World Health Organization (WHO) reports that there are 11–20 million typhoid cases worldwide, with a yearly fatality rate of 128,000–161,000 (Salman et al., 2022). The spread of typhoid diseases among the population is caused by inadequate sanitary infrastructure, a high rate of open defecation, and contaminated water sources (Mejia et al., 2020). Typhoid fever is an enteric fever that is distinguished by systemic disease with abdominal pain with fever (Salman et al., 2022).

Salmonella typhi causes enteric fever, while other serotypes, *Salmonella paratyphi* (A, B, C), induce similar symptoms but with less clinically severe disease (Salman et al., 2022). *S. Typhi* is frequently linked to a protracted fever that can reach temperatures of 103–104°F (39–40°C) (Salman et al., 2022). Further signs and symptoms include a headache, a cough, intense exhaustion, constipation, appetite loss, and diarhoea (which develops later in the infection) (Crump, 2019). Salmonella is primarily found in places with overpopulation, social unrest, and inadequate sanitation. It is spread through the fecal-oral route and can also be contracted through undercooked food, polluted water, and the feet of infected people (Gu et al., 2020). Numerous factors, including as the infectious species, pathogenicity, host immunity, and infectious dosage, influence the pathogenesis of typhoid fever (Salman et al., 2022).

Leptospirosis

Leptospirosis is a major zoonotic bacterial disease that mostly affects resource-poor populations and causes severe morbidity and mortality (Rajapakse, 2022). The bacteria Leptospira is the source of leptospirosis, a blood infection that can affect humans, dogs, rats, and numerous other domesticated and wild animals (Chacko et al., 2021). Almost all mammals can be leptospirosis carriers, harboring and shedding the organisms from the proximal tubules of the kidneys (Haake & Levett, 2015). Despite the fact that numerous wild and domestic animals can serve as reservoir hosts, the brown rat (Rattus norvegicus) is the most common source of human illnesses (Haake & Levett, 2015).

Leptospira, a spirochete that causes infection, is typically exposed through tainted fresh water. Infection occurs as a result of direct or indirect contact with infected reservoir host animals, which contain the pathogen in their renal tubules and shed harmful leptospires in their urine (Haake & Levett, 2015). Although the majority of infections have no symptoms, some can cause anything from a nonspecific, mild feverish illness that goes away on its own to fulminant respiratory and renal failure that has a high death rate (Rajapakse, 2022).

Conclusion

Viruses are a key cause of human waterborne and water-related diseases. The rapid resurgence of vector-borne and waterborne diseases highlights the importance of understanding the factors that influence transmission. This understanding could help eradicate and prevent further spread of these diseases. Vector-borne and waterborne diseases have affected people worldwide. Understanding the pathogenesis and etiological aspects of these diseases would be very beneficial in gaining in-depth insight into their nature, reservoirs, and transmission dynamics, which is important for early prediction, prevention, and eradication of the diseases.

Disclaimer

None.

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Chapter11

Use of the Biopsychosocial Model in Diabetes Self-Management

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Abstract

Diabetes Mellitus has emerged as one of the leading non-communicable life-threatening chronic diseases. It is not only a life-threatening disease but also has costly complications and reduces life expectancy. The global prevalence and incidence of diabetes mellitus has reached pandemic proportions of 9% (463 million adults) in 2019. Diabetic Research and clinical practice reported that 41,600 new cases of type 2 diabetes mellitus were diagnosed among children and adolescents in 2021 worldwide. The prevalence rate of diabetes mellitus among adults (20-79 years) has more than tripled in 2021 since the 1st edition in 2000 and will rise to 12.5%, 11.5%, and 10.9%, respectively by 2045. The highest estimated number of new cases was seen in China, India, and the United States of America. Presently, diabetes patients need to adopt a healthy behavioural lifestyle to manage glycaemic illnesses, stay active, and reduce complications. The application of the biopsychosocial model helps to reduce physical health problems, reduce

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conflict, establish good communication, and ensure quality of life. To overcome these conflicts in practice, self-control-environment is essential. Biopsychosocial model use may need inter-disciplinary self-control for effective self-management, which bridges cognition and emotion through a series of self-management processes. The aim of writing this book chapter is to guide people to control hyperglycemia using the biopsychosocial model.

Keywords: diabetes mellitus, type-1 DM, type-2 DM, self-management

Introduction

Diabetes Mellitus is an auto-immune, chronic life-threatening disease, characterized by hyperglycemia, that occurs when insulin generation is insufficient, or generated insulin cannot be utilized in the body (Egan & Dinneen, 2019). It is estimated that 537 million adults throughout the world between the ages of 20 to 79 years (10.5% of this range of the adult population), and 643 million people will have diabetes mellitus by the year 2030, and it will increase to 783 million by the year 2045 (Kumar et al., 2024). The most alarming facts reported that more than half a billion people; men, women, and children in every country, will be living with Diabetes by the year 2025 (Halsey, 2023). The International Diabetes Federation (IDF), 10th edition, revealed that the incidence of diabetes mellitus has been significantly increasing for at least 20 years in South-East Asia (SEA) nations (Kumar et al., 2024). The current incidence rate of diabetes has emerged as one of the most common warning non-communicable diseases causing life-threatening, disabling, costly complications, psychological impact, and reduced life expectancy (Sun et al., 2022). A prolonged sedentary lifestyle, processed food consumption, and physical inactivity lead to metabolic disorders and ultimately there is insufficient insulin generation, or the generated insulin cannot be utilized in the body, resulting in a chronic metabolic disorder (Kumar et al., 2024). Diabetes can be classified as Type-1 (auto-immune β cell destruction leading to absolute insulin deficiency), Type-2(due to progressive loss of adequate β cell insulin secretion), Gestational (diabetes diagnosed at the 2nd or 3rd trimester of pregnancy), and Specific due to other causes like; neonatal or maturity-onset, cystic fibrosis or pancreatitis, drug or chemical induced (Davies et al., 2022). Type 2 Diabetes Mellitus is due to independent Insulin resistance or inadequate insulin secretion, the commonest form of chronic disabling disease, and accounts for near about 95% of cases in most populations globally (Ma & Tong, 2024). The prevalence rate of diabetes mellitus among adults (20-79 years) has more than tripled in 2021 since the 1st edition in 2000 and the incidence of diabetes in the World, Southeast Asia, and India was 10.5%, 8.8%, and 9.6%, respectively, throughout 2021 and will rise to 12.5%, 11.5%, and 10.9%, respectively by the year 2045(Kumar et al., 2024).

In this global alarming scenario of people living with diabetes, the use of the biopsychosocial model in healthcare is very effective both as aconceptdevelopment and self-management of diabetes. Here biology refers to the influences and interplay of anatomy, physiology, nutrition, epidemiology, and genetics. Psychology refers to the influences of thought, emotions, feelings, and behaviours. Sociology refers to how the individual can manage his or her health problems using social support like self, family, friends, and other agencies to stay healthy. (Beyer & Boazak, 2021).

According to IDF, the rate of increasing incidents of diabetes is due to associated factors of obesity, unhealthy eating habits, a sedentary lifestyle, a knowledge deficit, and a lack of self-care management. The International Diabetes Federation (IDF) is regularly updated about evidence-based practices for controlling and managing diabetes and guides the use of health promotional biopsychosocial models for good glycemic control and better survival in daily life (IDF, 2021).

The prevalence of type 2 diabetes in adolescents and young adults is dramatically increasing with major predisposing risk factors such as obesity, family history, and sedentary lifestyle (Lascar et al*.*, 2018). Obesity is a chronic, and relapsing disease with numerous metabolic, physical, and psychosocial complications leading to premature death and disability as well as a costly disease affecting more than 415 million people worldwide. Pediatric T2DM is more progressive than its adult-onset counterpart and Projections from the SEARCH study estimate 84,000 youths aged 10 to 19 years will have T2DM by the year 2050 (Burmeister, Delgado & Virga, 2021). Over 90% of T2Diabetes Mellitus cases are reported in low and middle-income countries due to the adoption of the Western lifestyle and urbanization, among other influences (Zwane et al., 2023). Many studies show utilizing self-care management using the biopsychosocial model facilitates patients in clinical judgment following the best routine care at all stages and establishing a positive correlation between T2DM self-care management and unhealthy lifestyle (McCrossan et al*.*, 2022).

The use of this type of model in diabetes self-management is now an essential supportive element for all people with diabetes. The ADA

(American Diabetes Association) and Education Specialists in diabetic care strongly advocate for the use biopsychological model to improve quality outcomes. Different studies have proven its benefits while reducing hospitalizations and healthcare costs in controlling hyperglycaemia, lower HbA1c, and ensuring the quality of life (Davis et al., 2022).

To manage current health problems of diabetes, only medications are not effective, the other non-pharmacological treatment modality is also better effect to control imbalanced glycaemic index. The biopsychosocial model is a non-pharmacological treatment modality that helps diabetes patients, their family members, and caregivers to understand their role in a comprehensive manner and how they should adjust or educate about lifestyle modification to have a better quality of life (McCrossan et al., 2022).

The Biopsychosocial Model in Diabetes Self-Management

The father of the Biopsychosocial Model, George Libman Engel was born on 10th December 1913 and expired on 26th November 1999, an American internist andpsychiatrist. He is well-known for his formulation of the biopsychosocial model, a general theory of illness and healing. He spent his golden time and focused on his career at the University of Rochester Medical Center in Rochester, New York. He introduced his concept in 1977, that one's illness factor is associated with biological, social, and psychological factors.

His concepts are explained in the model:

- Bio means physiological pathology.
- Psycho means thoughts emotions and behaviours, current coping.
- Social means socio-economical or socio-environmental adjustment

So, he explained that one's chronic illness can be managed by utilizing three factors through self-engagement and self-activities (Lynch, 2020).

Goals of Application of the Model for Self-Management

- To identify the psycho-social needs of the person with a family.

- To provide participants with the knowledge and skills to enhance the psychological well-being of people with diabetes
- To ensure good behavioural approaches, motivational techniques, goal setting, and emotional support in self-management education.

About Self-Management

Diabetes is one of the most life-threatening chronic diseases affecting an estimated 537 million adults in the whole world between the age group 20 to 79 (10.5% of all adults in this age range) and it is expected that by 2030, it will increase from 643 million to million 783 by 2045. So, self-management has an important role in managing glycemic index (Kumar et al., 2024). American Diabetes Association reported that engagement in daily self-care and self-management activities will lower the Hb A1C (Glycosylated hemoglobin) by at least 0.6%, with no side effects. More than 10 hours of self-management activities can reduce greater A1C reductions (Chrvala, Sherr & Lipman, 2016). Glucose monitoring with type 2 diabetes requires regular self-care management following a healthy and nutritious diet, physical activity, and ongoing medical care to lower HbA1c. Self-management protocol ensures knowledge enhancement, self-efficacy, and self-regulation motivation. It can be short-term goals or long-term goals following healthy behavioural approaches (Lee & La., 2024).

The alarming prevalence and incidence rate of diabetes induces diabetes self-management, which is a process of self-consciousness and the practice of healthy habits with regular glycemic monitoring. Self-management modalities are cost-effective, feasible, and affordable but challenging as they need self-confidence. Different study reports revealed strong evidence between glycaemic control and self-management which are cost-effective, decrease hospital readmissions, and ensure the quality of life (Adu et al., 2024).

Self can be defined by two distinct perspectives, social behaviourism, and communication of both conscious and unconscious layers, and is informed by observations of others (IDF, 2021).

Self-management is a conscious and psychologically healthy practice organized by concepts. Figure 1 describes how one can focus on self-management, considering the self as an object, to achieve the goal (IDF, 2021). As per the ADA (American Diabetes Association), self-care is person-centered care, that considers an individual's total involvement in controlling co-morbidities and hyperglycaemia in a respectful way based on their engagement in self-care with preferences, needs, and values (Fadli et al., 2024).

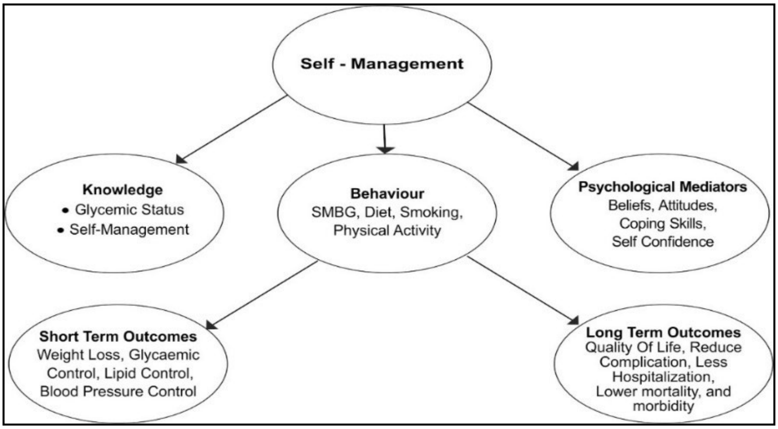

Figure 1. Diabetes Self-Management with Good Glycaemic Outcome.

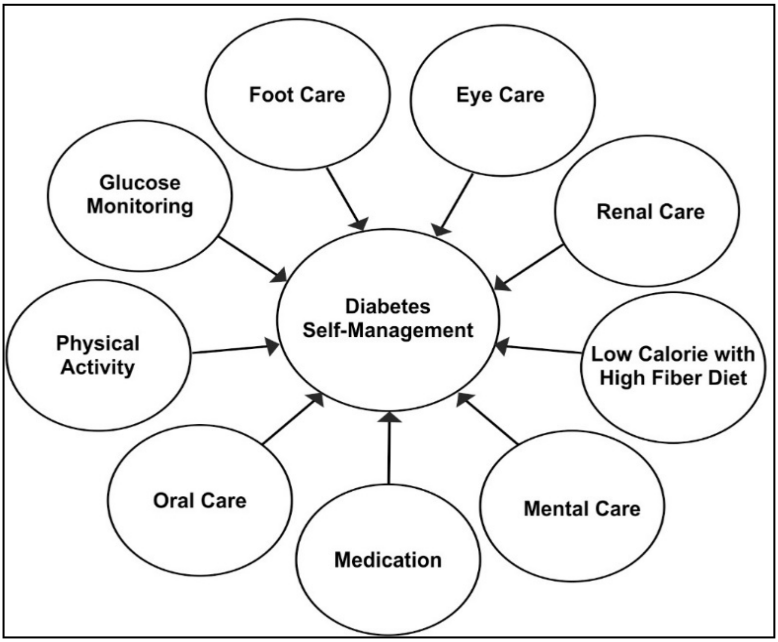

Figure 2. Diabetes Self-Management Component.

Self-Efficacy

Staying physically inactive with sedentary behaviour is a global issue (Tcymbal et al., 2020). Numerous studies have highlighted the importance of physical activity (PA) in the general population (Bennasar-Veny et al., 2023). Adopting health-promoting behavioural approaches is widely accepted as an evidence-based practice (Nisar et al., 2024). Figure 2 explains how one's self-efficacy can manage diabetes using self-management components.

Self-efficacy is the second component of the stages of the biopsychosocial model. It determines how confident a person is, and how can make the proposed change, or engage in the desired behaviour. Self-efficacy can be assessed by asking a behaviour on a scale of 1 to 10 (where 10 is very confident and 1 is not at all confident). Confidence increases as the person moves through stages. Physical activity (PA) has become a key pillar of healthy lifestyles. Physical activity has been considered a foundation of diabetic management. Many research studies have shown that Physical activity is very effective in lowering disabilities and controlling clinical parameters such as glycosylated hemoglobin (Gallardo-Gómez et al., 2024).

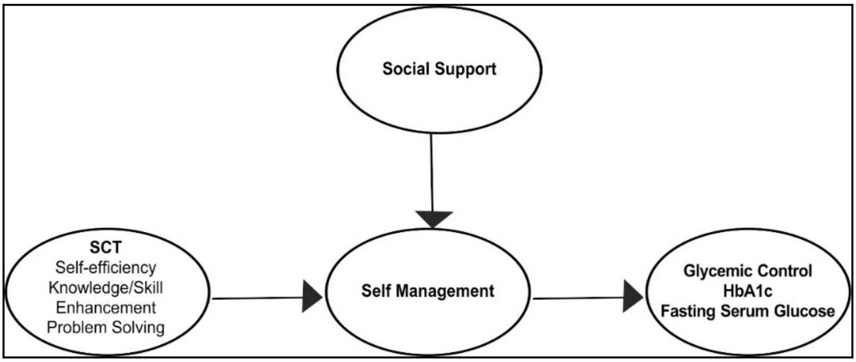

Figure 3. Self-Support Toward Glycaemic Control.

Application of the Transtheoretical Model in Diabetes Self-Management

The significant incidence and prevalence of Type 2 diabetes mellitus and its life-threatening co-morbidities induced the use of different biopsychosocial models in managing complications. Figure 3 explains that the Transtheoretical model is a client-friendly model developed to assess an individual's readiness to act on new healthier behaviour through a process of changes (Miezah et al., 2024). Practically, the Transtheoretical model (TTM) is the type of model which have suggested behavioural changes among the public (Arafat, Mohamed Ibrahim & Awaisu, 2016). This model is composed of four components such as - stages of change, efficacy, decisional balance, and processes of change. Thismodel is used to explain the health benefits of behaviours including cessation of smoking, weight reduction, avoiding intake of a high-fat diet, delinquent behaviours of adolescents, safe sex, mammography examination, etc (Honda et al., 2020). A sedentary lifestyle, intake of junk food, and physical inactivity are present global issues (Liu et al., 2018). The Transtheoretical Model incorporates among the people with diabetes both cognitive and behavioural strategies to control hyperglycemia (Hawks et al., 2023).

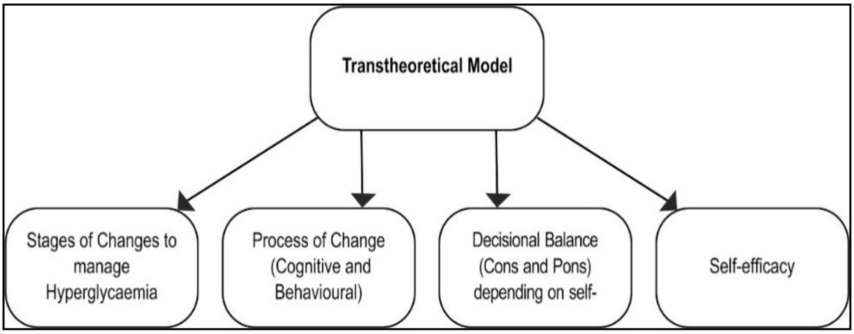

Figure 4. Application of the Transtheoretical Model in Self-Management.

Application of the Transtheoretical Model in Self-Management, as described in Figure 4, is a dynamictheory-based model that is applied to changes in health behaviours. In the first stages of change, one applies cognitive, affective, and evaluative processes to understand the changes of improvement. Modernization of societies, urbanization, Industrialization, and an increasingly mechanical lifestyle have led to an increased prevalence of chronic diseases such as obesity, heart disease, diabetes, etc. Transtheoretical Model consists of four components: stage of change (pre-contemplation, contemplation, preparation, action, and maintenance), which explains thoughts and behaviours regarding how the public must change their behaviour; and adopt the process of change with self-efficacy. This model helps to analyse their self-confidence and how long they will be able to resist the desire to change and take decisional balance to achieve a positive goal (Hashemzadeh et al., 2019).

Pre-contemplation- When an individual says, “I won’t make that change now or in the next 6 months.”

- *Contemplation*- When individuals say, “I will think about it” or “I might make the changes in the next 6 months.”
- *Preparation*- When individuals say OK, “I will do that, but I need to get ready first, or maybe within a month I will be able to start.”
- *Action*- When they are actively carrying out the new behaviour at the target level. For example- if they plan to walk, can walk three times a week.
- *Maintenance*- When an individual has been engaged in the new behaviour for at least six months and this is becoming a second change of lifestyle, and it is challenging. Health education and health awareness for self-management among the public have been recognized as key factors associated with quality clinical outcomes. The Transtheoretical model use (TTM) has long been considered useful and beneficial through a series of stages for better conceptualization in the process of intentional behavioural changes (Tseng et al., 2017).

Decisional Balance

The 3rd component of the model is decisional balance. If a person sees more reasons to make a change than reasons not to do so, they are probably ready. Ask people to write down or verbally list all the reasons they think a change would be a good thing and all the reasons why it would not be a good thing to determine the decisional balance. The role of a person or health care provider is to try to build up the positive side of the equation. Self-motivation is a core component of diabetes management because it allows people to adhere to clinical recommendations (Hsu et al., 2021).

Process of Change

The change processes are the interventions that help people to make a change. The processes are used at different stages and if used at the correct stage they can be useful to help a person move forward. The application of the model helps the individual in motivation and increases self-efficacy (Miezah et al., 2024).

There are 10 processes.

- Consciousness-raising
- Dramatic relief
- Supportive relationships
- Self-re-evaluation
- Environmental re-evaluation
- Self-liberation
- Social liberation
- Stimulus control
- Counter conditioning
- Reinforcement management

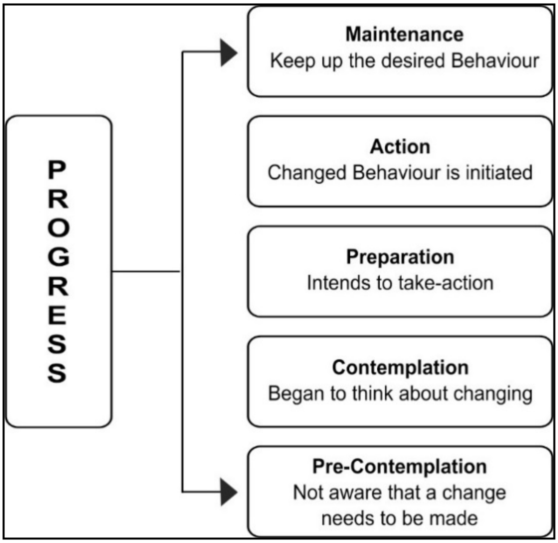

Figure 5. Stages of the Changes Model in Self-Management.

Diabetes Mellitus (DM) is considered a public health problem worldwide, fostered by increased population, unhealthy living, physical inactivity, and dietary lifestyle. The use of a Self-management education system helps diabetic patients, improvesglycaemic outcomes, and delays chronic consequences (Miezah et al., 2024).

The Figure 5 model nicely explains that it is very useful and helpful model for public health. This model also elaborates on the role of self-efficacy and how to take the decisional balance in the initiation of behavioural changes. Self-efficacy is the behaviour-specific confidence that a person has taken according to his or her abilities to perform in each moment. As the use of the Trans-theoretical model depends on individuals' own cognitive and emotional abilities, as one of the treatment modalities, it is feasible, challenging, and affordable. This model improves biopsychosocial interaction, and interpersonal relationships with patients, doctors, nurses, and family members. Thus, patients can stay healthy (Harwood & Frye., 2024).

Advantages of the Using the Biopsychological Model

- Encourage patient and family involvement with caregivers
- Motivate patient participation
- Improve patient satisfaction
- Facilitate better adherence to treatment
- Reduce complications and limit hospital admission
- Helps in finance budget

Disadvantages or Barriers of Using the Biopsychological Model

- Time consuming
- Lengthy adherence
- Need patience
- Need self-motivation and self-control
- In case of lack of family support, it is difficult to introduce or maintain to follow up
- Psychological, Social, and Physical involvement sometimes problematic issues for patient or family member

- Communication support, self-efficacy, or evaluation of progress is sometimes a barrier
- Frequent social occasionsand gatherings are sometimes not allowed to control glycaemic control though the model is in practice

Collaborative Self-Management (IDF Module 2024)

Collaborative management needs skills of

- Listening to what an individual is trying to say verbally, non-verbally, or through body language
- Allowing the free flow of emotions related to diagnosis and treatment
- Listening carefully and responding to the person about hearing
- Examining barriers to the individual's self-care and helping with problem-solving solutions
- Showing empathy towards self-management

The Stages of Acceptance of Self-Management Under Biopsychosocial Behavioural Approaches

- *Denial:* People diagnosed with type-2 diabetes may not have an attitude toward self-management. May not feel sick or may feel it will automatically come down and the lab made a mistake(Lin et al*.,* 2021).
- *Anger:* The stage after denial is anger. People may feel angry that they have diabetes and ask questions, What have I done to deserve this or Why it is with me?
  I should not eat a calorie diet, I am maintaining my healthy diet, then why is it with me?
- *Guilt Bargaining:* Anger often turns into guilt and bargaining. Most of the time people try to say, Maybe it is due to my mistake as I quit the gym, If I start the gym, then my diabetes will be under control.
- *Depression:* At this stage, people realize that diabetes is a lifelong chronic disease, and their life as they know to be stay and manage

with diabetes. They should adopt self-management and should take advice from doctors, dietitians, and family members.

- *Acceptance:* At this stage, people come to accept they do have diabetes but they can take self action to manage diabetes like diabetes self-management.

Psycho-Social Barriers of Self-Management *(IDF Module, 2024)*

Sometimes people may feel barriers to performing daily activities. These are;

- *Time:* Most people believe that self-care activities require much more time, and will interfere with job or daily activities
- *Alcohol and Drug use:* Most people, mainly young people frequently take alcohol. It will create barriers to control diabetes.
- *Family Support:* Sometimes family support is lacking, for which self-management is getting problematic
- *Gender:* Most of the time female gender is not getting much more attention compared to males. Self-care is hindered due to over-burdened family responsibilities.
- *Low income and Low knowledge:* Sometimes lower income is a barrier to self-care management. Lack of education about dietary calorie intake is problematic for glycaemic control.
- *Eating Disorders:* Eating disorders are commonly seen in adolescent girls, young males, and women with diabetes. Social gatherings, occasions, and the availability of tasty foods are the most common barriers to managing diabetes.
- *Access to Care:* It is difficult to schedule an appointment with the doctor or educators because of daily activities, transport, or other family responsibilities.

People accept the diagnosis, or hyperglycemia, and then engage in self-management mainly based on the Health Belief Model Application.

Health Belief Model Application in Diabetes Self-Management

The Health Belief Model was first developed in the 1950s, by a group of social psychologists to understand why people engage in or do not engage in disease screening or disease preventive measures. This Health Belief Model (HBM) tries to give information to people to perceive barriers, acknowledge benefits, and maintain self-efficacy, with a comprehensive relationship of beliefs and behaviours (Wang et al*.,* 2023). Figure 6 describes how it helps and manages glycemic control among diabetic patients.

Components of the Health Belief Model

1. Perceived Susceptibility
   HBM plays a significant role in the prevention of diseases and ensuressignificant relationships between beliefs and behaviours. This model shows how individual perceptions, beliefs, and fears about health problems help people in the evaluation of health benefits and overcome barriers under perceived susceptibility. People who feel that their diabetes will not progress, or they will not develop complications may be in the denial stage; in this case, HBM insists behavioural changes and points out that good management from the beginning will be the best way to prevent later complications. For example- one can be careful about diabetic foot ulcers by perceived susceptibility to avoid later complications.
2. Perceived Severity
   The next part of HBM is Perceived Severity. Most people do not think type 2 diabetes is a very serious type of disease, especially if they are not under medication. Here, HBM insists on understanding the depth of seriousness of the disease. Therefore, it is very important to ask people with diabetes how much they know about their problems and how serious they think about diabetes. For example- when one has seen the severity of a diabetes foot ulcer, then how seriously one has perceived the disease progression or preventive measures.
3. Perceived Benefits
   Sometimes people with diabetes have seen others take medication and subsequently develop complications. This may result in the perception that medication does not work. People are afraid of side

effects. For example- Fear of side effects on insulin administration and its efficacy or fear of developing diabetic foot ulcer despite taking medication. Here HBM helps people to understandthe benefitsof nutritional management, the use of a signal system diabetic menu plan, fiber intake, the importance of physical activities, self-management of foot care, and eye care to overcome the barriers and achieve the glycaemic benefits under Perceived Benefits.

4. Perceived Barriers

HBM explains preventive measures of self-efficacy are better than Expected Barriers. Before making a change, people will try to weigh the barriers or difficulties they are likely to encounter. Barriers are preventable and it should be encountered by the peopleto understand of their beliefs and the reality of the disease condition.HBM empowers the behavioural changes. Like not eating a more calorie-containing diet rather than following a signal menu plan. It is not a teaching method or technique, but rather a vision or philosophy of self-education and care to overcome the barriers.

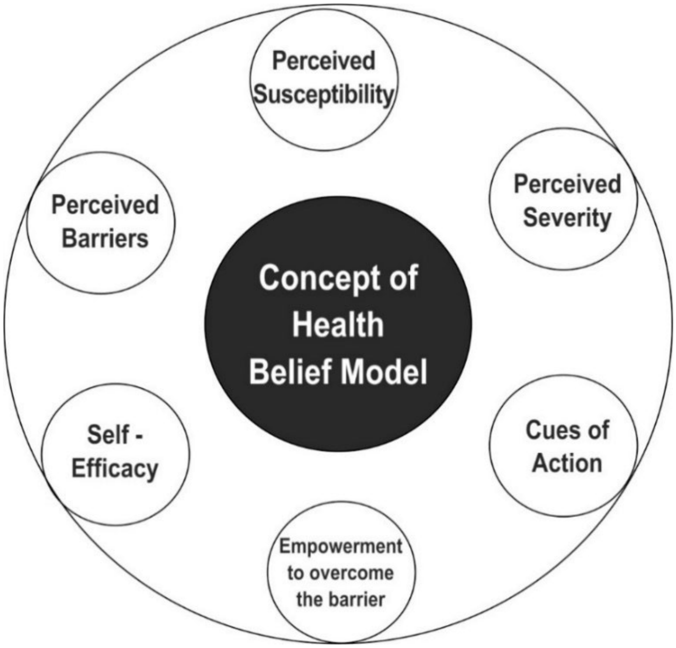

Figure 6. Application of the Health Belief Model for Self-Management.

5. Cues of action – Self-efficacy:
   After empowerment to overcome the barriers, one should adopt healthy cues of self-efficacy activities to engage in cost-associated healthy outcomes.

Issues and Problems Related to Self-Management in Diabetes

1. Ethical issues
   - *It includes understanding and addressing barriers to clinical research*
   - *Types of Research and its involvement, practice, or application of any new practice*
2. Health Issues
   - Macro-vascular Disease
     - Cardiovascular Disease: Dyslipidaemia, Hypertension, Heart failure
     - Cerebrovascular disease: Ischaemic Stroke, Haemorrhagic Stroke
   - Microvascular Diseases
     - Diabetic Retinopathy: Blurring of Vision, Glaucoma, Cataracts
       - Diabetic Neuropathy: Ischaemic Ulcer, Neuropathic Ulcer, Foot Ulcer, Sexual Dysfunction, Bladder Dysfunction, Gastrointestinal Dysfunction
     - Diabetic Nephropathy: Chronic Kidney Disease, Chronic Kidney Failure
3. Economic Issues: Cost of the treatment, Absenteeism decreases productivity or growth
4. Psycho-social issues: Feelings of burden in family, Depression about treatment or prognosis, Worried about complications, Lack of social eating or gathering for eating
5. Others
   - Hyperglycaemia: Hyperglycaemia Hyperosmolar State, Diabetic Ketoacidosis
   - Hypoglycaemia: Mild-Moderate Hypoglycaemia, Severe Hypoglycaemia

- Gestational Diabetes: Severe Hypoglycaemia, Big Baby (Macrosomia), Birth Defects, Neonatal Hypoglycaemia

Essential Self-Management in Diabetes

1. Maintain desirable weight
   - For men: Height in centimeters minus hundred (100) is equal to the desirable body weight.
     (e.g., 170cm (height of a person) -100= 70 kg is the desirable weight
   - For Women: Height in centimeters minus hundred and five (105) is equal to the desirable body weight
     (e.g., 170 cm (height of a woman)-105= 65 kg is the ideal weight of women).
2. Maintain actual BMI

$$BMI = \frac{Weight\ (in\ kg)}{Height\ (in\ meters)^2}$$

   (e.g., BMI of a person of 50 kgs weight and 1.5 meters height=50 kg/1.5x1.5m=22.22 kg/m^2)
   - Normal Weight (kg/m^2)- 18.5-22.9
   - Underweight < 18.5
   - Overweight 23-24.9
   - Obesity >25 or more
3. Maintain normal Waist Circumference
   - Male>90 cm
   - Female > 80 cm
4. Follow Nutritious Low-Calorie Diet
   - Normal body weight, BMI, or waist circumference,
   - Healthy eating plan. There is no such fixed eating plan but one must follow the principles of the dietary menu.
   - Highly nutritious, low-cost, locally available, affordable, and hygienic.
   - Rich in nutrients
   - High-fibre diet
   - Low calories

- Avoid frequent social gatherings to avoid high-calorie food

Individuals or family members should emphasize evidence-based menu plans in comparison to glycemic records (American Diabetes Association. 2023).

Nutritional Self-Management

- Plate Method
  The plate method is a useful tool for people who have recently been diagnosed with diabetes and are trying to learn about self-management of menu plans (Cloyd, 2023)
  Half the plate should be covered with vegetables, preferably two kinds.

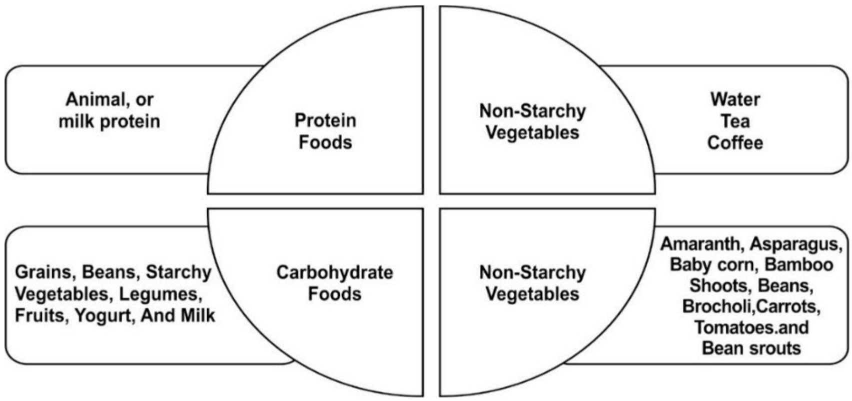

Figure7. Self-Management by Using Healthy Diabetes Plate.

Half of the plate should be with non-starchy vegetables, and protein foods, meat, or meat substitutes should be a fourth of the plate. Carbohydrates such as grains, starchy vegetables, beans, fruit, milk, and yogurt, should be on the final fourth of the plate, and water or another low-calorie beverage should be added as a drink with the meal (Jiaet al., 2022). Figure 7 nicely explains that the plate method very efficiently manageshyperglycemia. How self-management including dietary management helps in controlling diabetes that can be followed up under regular blood check-ups and self-monitoring (Figure 8).

1. *Non-starchy vegetables:* Broccoli, carrots, salads, cauliflower, mushrooms, peppers.
2. *Protein foods:* Chicken, lean beef, turkey, pork, fish, tofu, nuts, eggs, and cheese.
3. *Carbohydrate foods:* Grains, fruit, yogurt, milk, and starchy vegetables like potatoes, corn, and beans.
4. *Water or another low-calorie drink:* Water, tea, and coffee are good choices for meals.

- Estimating portion sizes with hand method
  It is difficult sometimes to measure food and know exactly how much the actual quantity is being consumed. People can use their hands to estimate the correct portion size of food that they should eat.
- Signal System Glycaemic Self-Management
  Diabetes Mellitus is a chronic illness that needs a lot of self-effort to manage. Periodic blood tests and follow-up along with self-management is very important self-efforts in the management of diabetes. The signal system is a useful aid in educating large numbers of people. The signal system is based on a traffic light concept to create awareness among them.
  Food can move from the green to the red zone depending on the method of processing and cooking. Therefore, it is important to a take note of healthy and unhealthy food choices while planning a diet for people with diabetes (Table 1 and Table 2).

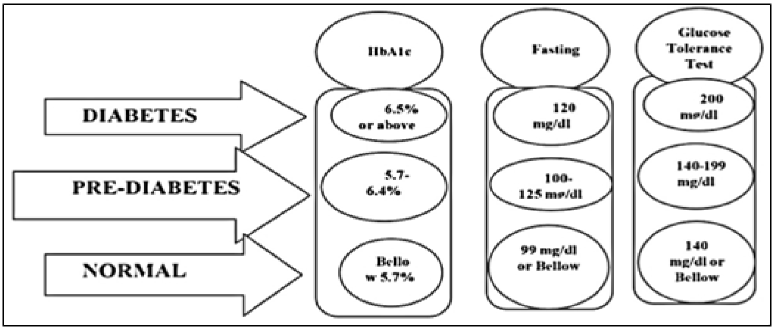

Figure 8. Normal to Diabetes Road to Self-Management Plan.

Table 1. Signal method of self-management

Food Groups	Green Zones	Yellow Zones	Red Zones
Rice	Steamed Rice	Pulao	Fried Rice/Biriyani
Bread	Whole wheat bread	White Bread	Croissants and Cakes
Noodles	Steamed noodles		Deep Fried noodles
Indian breads	Chapati	Plain Nun	Butter Nun/Puri
Potatoes	Baked Potatoes		French Fries
Vegetables	Steamed vegetables	Sauteed vegetables	Deep Fried Vegetables
Salad	Green Salad		Salad with mayonnaise
Sauce	Tomato Based		Cream Based
Fish	Streamed fish	Fish Curry	Fried Fish
Chicken	Grilled Chicken	Pan Fried	Butter Chicken
Fruit	Apple, Orange, peach, guava	Unsweetened fruit juice	Sweetened Fruit Juice

Table 2. Signal system dietary self-management plan

Food Groups	High Fiber Foods	Low Fiber Foods
Cereals	Whole cereals like whole wheat Dalia, whole wheat flour, whole wheat bread (brown bread)	Refined cereals like rice, white bread, Suji, Maida and its products, noodles, macaroni, etc.
Pulses	Whole Dals and Dals with husks	Washed, Dehusked dals
Meat, Fish, Poultry		Eggs, chicken, fish
Vegetables	Vegetables like peas, beans, lotus, stem, etc.	Vegetables like potatoes and yams
Fruits	Apples, cherries, pears, peaches, plums, guava, etc.	Fruit Juices, Squashes
Fats		Fats, Oils, Ghee, Butter, Vanaspati

Physical Activity: Self-Management

Regular physical activity or exercise has been found to provide physiological and psychological benefits that can improve blood glucose control.

- Benefits of Exercise
    - Reducing chronic diseases – heart disease, cancer, depression,
    - Reducing weight, lower insulin requirements
    - Improve glycaemic control
- Type of Exercise/Physical Activity
    - Aerobic Exercise

Aerobic exercise uses large muscle groups and requires oxygen for sustained periods. A total time of about 30-45 minutes a day at least 5 days a week is recommended for most people. Exercises can be continuous or with divided hours. It can be by swimming, cycling, walking, playing tennis, aerobic dancing, rope skipping, or treadmill.

  - Anaerobic Exercise

    Anaerobic Exercise (resistance) exercise uses large muscles that do not require oxygen for short periods of exercise. It helps build strong bones and muscles; lowers blood glucose makes the action of insulin more effective.

    These types of exercises are yoga, pranayama, Surya Namaskar, and different range of motion flexibility exercises with short-duration activities.

- Special Points to Remember
  - Walk instead of drive or use vehicles
  - Walk while talking in phone calls
  - Use staircases instead of elevators
  - At the workplace, walk and meet the co-worker instead of calling or emailing
  - Play with children
  - Do household work every day
  - Park the car at the far end of the shopping center lot and walk to the store.

Hypoglycaemia Self-Management (IDF. 2015)

Hypoglycemia will only occur among people taking insulin or secretagogues. If blood glucose is less than 100 mg/dl Carbohydrate should be taken before exercise is started. If not treated sugar 100mg/dl and start exercise, there may be an occurrence of hypoglycemia. The signs and symptoms of hypoglycemia are:

- A sudden change in sweating
- A sudden increased heartbeat
- Feeling shaky or anxious
- Feeling hungry

- Self-management-Hypoglycemia

Hypoglycaemia can be managed by the rule of 15; Eat 15g of Carbohydrate.

- 3 teaspoons of sugar or glucose
- ½ glass of fruit juice
- 3 teaspoons of rooh-afza
- 3 teaspoons of raisins
- 3 glucose biscuits
- Wait for 15 minutes and follow-up till increase to 70 mg/dl
    - Self-medication Self-management
- Oral Diabetic Agents
- Insulin

Oral Anti-Diabetic Agents

Different studies reported that diabetes mellitus can be manageable by lifestyle modifications such as diet, exercise, self-activities, yoga, and pharmacological therapies to meet one's glycemic goals. Oral pharmacological agents and lifestyle modifications should always be combined mainly for type 2 diabetes mellitus people. People with Type-2 diabetes mellitus must know about what type of medication they are taking with their indications, mechanisms of action, results, and significant adverse effects, or any contra-indications, they should monitor. Self-management of oral anti-diabetic medication always depends on one's self-consistency and self-evaluation (Ganesan et al., 2022).

Types of Oral Anti-Diabetic Agents

- Biguanides and Thiazolidinediones reduce glucose production in the liver
- Insulin secretagogues stimulate the pancreas to release more insulin
    - Sulphonylureas and Meglitinides increase insulin production and should be used cautiously in people with renal and liver disease. Needed for monitoring hypoglycemia.
- Alpha-glucosidase inhibitors slow the absorption of sucrose and starch

    - They slow the absorption of sucrose and starch from the intestine and therefore cause a slower and lower rise in glucose after meal.
- Thiazolidinediones and biguanides reduce insulin resistance
    - They reduce peripheral tissue insulin resistance or increase sensitivity to insulin
    - DPP-4 Inhibitors: They increase the levels of hormones called incretins- incretins help the beta-cells release more insulin only when it is needed. Incretins also reduce the amount of glycogen released by the liver.

GLP-1 (Incretin Mimetics)

They increase the response of the beta cells to circulating levels of glucose and have other actions as well.

Insulin (IDF. 2024)

Insulin is a hormone secreted by the beta cells in the islets of Langerhans. When the blood circulates through the body, the beta cells can read the level of glucose and secret the appropriate amount of insulin (Petersen & Shulman, 2018)

- At the cell level binds to the receptor of the cell surface
- Suppressing glucose output from the liver
- Regulates the conversion of glucose into triglycerides and then from triglycerides to fatty acids. The adequate level of triglycerides stored in the fat cells, when the level of insulin falls, then supply.
- Insulin inhibits enzyme lipase, which breaks down stored fat into fatty acids and glycerol
- Assist muscle cell enzymes to maintain muscle mass by promoting the uptake of amino acids and preventing the breakdown of protein.

People with diabetes mellitus must know about insulin, its mode of action, types, side effects, and self-management.

Types of Insulin

- *Rapid Acting Insulin analogs:* They are faster than regular insulin and work for shorter periods.
  - Should be taken before meal
  - Proper meals should be taken otherwise hypoglycemia can occur
- The Longer-acting insulin Analogs: This type of insulin works consistently for up to about 24hrs thus acting more like a true basal rate.

There are many brands of insulin available that fit into four categories based on their action, generally referred to as rapid-acting, short-acting, intermediate-acting, and long-acting insulin. Depending on the type of insulin, self-management should be activated to manage hyperglycemia or hypoglycemia.

Injection Site

People with diabetes need to learn the appropriate site for insulin administration. These sites are:

i. Any four quadrants of the abdomen, always at least one inch away from the umbilicus
ii. Front or outer aspects of both thighs
iii. Outer and rear surfaces of upper arms
iv. The upper outer area of the buttocks

Self-Management Tips for Insulin Administration

- Always inspect the injection sites before administration.
- Avoid the sites with lipo-hypertrophy, oedema, inflammation, or signs of infection.
- Bathe with soap and water daily.
- Rotate sites of injection every day to avoid lipo-hypertrophy.
- Do not reuse the needle

Insulin Pen Utilisation

An insulin pen looks like a fountain pen. They are convenient and easy to use. There are two basic types: disposable and reusable (Singh, Samuel & Jacob, 2018).

- Disposable pens come already filled with insulin. When a pen is empty, expired, or has been open for a month it is simply to be discarded.
- Reusable pens have a replaceable cartridge of insulin. The dose of insulin is dialed in and then delivered by pressing a button on the top of the pen. The pen may be kept in a pocket or purse at room temperature while in use for up to a month. Insulin should not be exposed to sunlight. Should be administered at a normal temperature.

Timing of Insulin Administration

- Short Acting Insulin (Soluble- Regular) should be administered 30-45 minutes before the meal.
- Rapid Acting Insulin- Should be administered 15 minutes before meal.
- Intermediate-acting insulin- (Split or Mixed) method Insulin- should be given in the morning and evening before meals.
- Long-acting insulin – can be given when advised, with no relation to food.

Diabetes self-management plays an important role in glycemic success. Individual patients have individual self-efficacy and preferences on adherence to biopsychosocial methods to improve glycaemic control. Advanced technology introduced readymade pen insulin for diabetes patients for better outcomes. One study was conducted to assess diabetes patients' perception of insulin therapy and self-management, and data reported that 71% of diabetes patients found new connected pen insulin therapy useful (Consoli& Formoso, 2023).

Diabetes Foot Care

Diabetic patients should inspect daily the entire surface of both feet and the inside of the shoes that will be worn; wash the feet daily (with careful drying, particularly between the toes); use emollients to lubricate dry skin; cut toenails straight across (Zhu et al., 2023). Diabetic patients should not walk barefoot, in socks without shoes, or in thin-soled slippers, whether indoors or outdoors Diabetic patients should inspect daily the entire surface of both feet and the inside of the shoes that will be worn; wash the feet daily (with careful drying, particularly between the toes); use emollients to lubricate dry skin; cut toenails straight across. Diabetic patients should not walk barefoot, in socks without shoes, or in thin-soled slippers, whether indoors or outdoors

- Diabetes foot care includes regular self-inspection, palpation of venous pulsation, and taking care of feet. Self-efficacy needs comprehensive foot evaluation at least every six months or annually to find out the risk factors (Care, 2022).
- Patients with a history of loss of sensory perceptions like pain, burning, and numbness should do their feet inspection with the help of a mirror regularly.
- Regular vascular assessment, including checking of peripheral pulsation in the legs and feet is very essential.
- Patients with symptoms of intermittent claudication or decreased or absent pedal pulses should be referred for ankle-brachial index assessment for vascular assessment.
- Self-management includes the use of therapeutic footwear to avoid foot ulcers.

Discussion

Diabetes is a leading cause of disability, with the number of cases expected to rise to 643 million by 2030 and 783 million by 2045 (Hossain, Al-Mamun & Islam, 2024). The standard of care in 2024 emphasizes empowering individuals to manage their own health using a biopsychosocial model (Bowman et al., 2024). The chronic nature of diabetes often leads to serious micro and macrovascular complications (Vlachoet al., 2024). However, these complications can be effectively controlled and managed by educating individuals on self-management strategies based on the health belief model (Afrasiabi, Aeen & Jahromi, 2022). Current healthcare guidelines advocate for individuals with chronic diseases to take responsibility for their self-care. Health professionals, particularly nurses, play a crucial role in training and educating patients to develop the necessary skills for self-managing their health and disease processes (Huang et al., 2020).

Recent literature has highlighted therapeutic education programs that support the holistic self-management of chronic conditions. These programs address not only treatments and therapies but also the social and emotional needs of individuals and their families (Catarino, Charepe & Festas, 2021; Beak & Kim, 2021). In the context of managing chronic diseases, particularly Type 1 Diabetes (DM1), therapeutic education interventions provided by nurses offer significant benefits for adolescents. These benefits include a reduction in hospitalizations and future complications, increased adherence to treatment regimens, improved quality of life, and enhanced biopsychosocial well-being (Catarino, Charepe & Festas, 2021).

Kelly et al. (2024) proposed that integrating the biopsychosocial model of healthcare discussions and support into routine healthcare visits is crucial for improving outcomes for people with diabetes. Diabetes education, which enhances self-efficacy in controlling glycemic outcomes, utilizes another approach called the trans-theoretical model (Miezah et al., 2024). Diabetes is currently a global public health issue. It can be managed with medication and meticulous nutritional planning (Jung et al., 2024). An international study conducted from 2005 to 2020 assessed the effectiveness of the biopsychosocial model in glycemic control. This study included aspects such as behavioural changes, dietary planning, physical activities, foot care, and routine medication adherence. The results showed significant improvements in glycemic outcomes, including a reduction in HbA1c levels (Asmat et al., 2022).

Conclusion

The use of the Biopsychological Model, like the Health Belief Model, or Transtheoretical Model is a stage-based model of behavioural changes over time through several stages. To engage individuals regularly in exercise or activities, individuals must have positive thoughts and good self-confidence, which push them, educate them, and help them, to stay motivated with a perception of benefits of good glycaemic outcomes. Diabetes self-management is an effective self-management system for controlling high glycemic index and engaging people in different self-care activities. Many research studies prove it.

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Chapter 12

Possible Neglected Case Detection of COVID-19 in a Boarding School

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Abstract

The symptoms of Acute Respiratory Infection (ARI) are similar to those of COVID-19, although most people exposed to this virus will experience mild to severe symptoms. These symptoms are often experienced by children, including Islamic boarding school students or 'pesantren.' This study aimed to identify symptoms of respiratory infection that can be used to predict COVID-19 infection. The method used was a survey with a cross-sectional approach in a male Islamic boarding school in TAPAN, Tulungagung, East Java. The research was conducted in August with interviews using a questionnaire containing the description of the Islamic boarding school and the environmental condition of the 'pesantren'. Symptoms of respiratory problems experienced by male students, types of examinations carried out, and healthy living habits in washing hands. The number of samples was calculated using the Lemeshow or Slovin formula, with a prevalence of 0.5, then a minimum sample size of 97 was obtained. In this study, the number of samples or subjects was 100 students. Self-administered questionnaires were conducted with the assistance of teachers whom the researcher had given prior explanations. The analysis descriptively shows the frequency and percentage of each variable. Students' main signs and symptoms were sneezing (90%), headache (68%), nasal congestion (64%), colds (55%), and muscle or body aches (50%). Other

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symptoms were sore throat, shortness of breath or difficulty breathing, fever or chill, and nausea or vomiting. The most common symptoms of COVID experienced by the student were headache, nasal congestion, muscle or body aches, shortness of breath or difficulty breathing, fever or chill, and nausea or vomiting. Some students may have COVID-19. Surveillance is needed to trace and follow up on the condition of the students and their families using swab PCR tests. It needed research to identify the symptoms of COVID-19 conducted in female Islamic boarding schools and any other schools.

Keywords: COVID-19, symptoms, Islamic boarding school, male

Introduction

Formal education in Indonesia is held by schools in general managed by the Ministry of Education and Culture and Islamic boarding schools or '*pesantren*' managed by the Ministry of Religion. '*Pesantren*' is one of the essential pillars of Indonesia's education and culture worldwide. In Indonesia, there are two types of *pesantren*: traditional and modern. Both of them usually provide education by boarding school or staying overnight, so that *pesantren* provides dormitory accommodation. Dormitory conditions are different for each school, depending on the conditions of the *pesantren* concerned. Usually, students or so-called '*santri*' sleep together with friends of the same sex, so there are particular female and male dormitories.

The problem of environmental sanitation in Islamic boarding schools is complex because it is triggered by various factors, namely the physical, social, and cultural environment. These factors are interrelated and cannot be separated from each other, forming student behaviour that is less clean and healthy (Rahayu, 2023). One of the problems students face in pesantren is a lack of cleanliness (Rianti et al., 2019).

Students at the Al-Jihad and Annur modern Islamic boarding schools have adopted a clean and healthy lifestyle (Pulihasih et al., 2024). The location of Islamic boarding schools in urban centers supports students' access to health services, so access to health service facilities is relatively easy. In fact, in the TB screening section, 32 people were found to have had coughs for more than 3 weeks. Three (1.3%) students had tuberculosis (TB), and 20 (10.2%) students had contact with TB sufferers. The symptoms most frequently experienced by students were frequent itching and redness of the skin at night with small spots, as many as 28 (14.29%) students. There were 20 people (10.2%) with diarhoea (Pulihasih et al., 2024).

The learning process at Islamic boarding schools during this pandemic is conducted face-to-face and strictly adheres to health protocols (Salim et al., 2021). This is demonstrated by the Islamic boarding school's response to maintaining Islamic boarding school values due to the impact of COVID-19, such as taking up learning time in the classroom, taking the capacity of students per classroom, and taking action to interact with the students in class (Salim et al., 2021). In addition, Islamic boarding schools are vulnerable to COVID-19 because they interact in a limited environment (covid19.go.id, 2020). Life in the *pesantren* becomes extremely vulnerable to the transmission of COVID-19 cases considering there are many students in one location. If one person suffers from COVID-19, the transmission will be swift (Hendayana, 2021). A survey conducted at Islamic Boarding School 'X' in Tangerang found that most students were infected with COVID-19 while participating in face-to-face learning activities (Haninda et al., 2022)

The Clean and Healthy Behaviour (CHLB) Program, which the government launched in 2011, has been implemented in several Islamic boarding schools in Indonesia. The problem that is often encountered in almost all Islamic boarding schools is the vulnerability of students to various infectious diseases, such as scabies, diarhoea, vomiting, typhoid, smallpox, itching in the head due to lice, hepatitis A, tuberculosis, COVID-19, and others. Almost all diseases mentioned above can be prevented through clean and healthy living behaviour (CHLB). (Hendayana, 2021).There is a significant relationship between ventilation conditions and the incidence of upper respiratory infection (URI) and between clean and healthy living behaviours and ARI among students at the Amanatul Ummah Islamic Boarding School in Surabaya (Adriansyah et al., 2021). Respondents who live in rooms that do not meet ventilation requirements have an 11.13 times higher chance of experiencing ARI than those who live in rooms that meet ventilation requirements.

Symptoms of ARI are similar to those of COVID-19. However, most people exposed to this virus will experience mild to moderate symptoms and will recover without needing to be hospitalized. The most common symptoms are fever, dry cough, and fatigue. Slightly uncommon symptoms include sore throat discomfort and pain, diarhoea, conjunctivitis (pink eye), headache, loss of sense of taste or smell, skin rash, or discoloration of the fingers or toes. Severe symptoms are difficulty breathing or shortness of breath, chest pain or pressure in the chest, and loss of ability to speak or move. Some of these symptoms are similar to ARI symptoms that children, including Islamic Boarding School students, often experience.It was also found that there was a significant relationship between clean and healthy living behaviour and the incidence of Acute Respiratory Infection (ARI) among students at the Amanatul Ummah Islamic Boarding School in Surabaya (Adriansyah et al., 2021).

People with COVID-19 have a wide range of reported symptoms – from mild to severe; symptoms may appear 2-14 days after exposure to the virus (Centers for Disease Control and Prevention, 2021b). Anyone can experience mild to severe symptoms (Centers for Disease Control and Prevention, 2021b). Pre-symptomatic transmission occurs in at least 15% of the 100 secondary cases of COVID-19, and the earliest pre-symptomatic contact event occurred five days before the onset of symptoms of the index case (Zhang et al., 2021).

The main symptoms of coronavirus (COVID-19) are a high temperature – this means feeling hot to touch on the chest or back (it does not need to measure the temperature), a new, continuous cough – which means coughing a lot for more than an hour, or three or more coughing episodes in 24 hours (if usually having a cough, it may be worse than usual), and a loss or change to your sense of smell or taste – this means it has noticed that someone cannot smell or taste anything, or things smell or taste different to normal (NHS, 2021). People with these symptoms may have COVID-19 (Centers for Disease Control and Prevention, 2021b): fever or chills, cough, shortness of breath or difficulty breathing, fatigue, muscle or body aches, headache, the new loss of taste or smell, sore throat, congestion or runny nose, nausea or vomiting or diarhoea. This list does not include all possible symptoms (Centers for Disease Control and Prevention, 2021b).

Seek immediate medical care if a person has COVID-19 Emergency Warning Signs (Centers for Disease Control and Prevention, 2021a) such as the following: difficulty breathing, persistent pain or pressure in the chest, new confusion, inability to get up or stay awake, pale skin, lips, or nail beds are gray, or blue, depending on skin tone. For any other symptoms that are severe or concerning to a patient should contact a healthcare provider (Centers for Disease Control and Prevention, 2021a).

The World Health Organization divided the symptoms of COVID-19 into four groups (World Health Organization, 2020); they are the most common symptoms, the symptoms that are less common and may affect some patients, Symptoms of severe, and other less common symptoms. The first category, the most common symptoms of COVID-19, are fever, dry cough, and fatigue. Secondly, other symptoms that are less common and may affect some patients include loss of taste or smell, nasal congestion, conjunctivitis (also known as red eyes), sore throat, headache, muscle or joint pain, different types of skin rash, nausea, or vomiting, diarhoea, chills or dizziness. Thirdly, the symptoms of severe COVID-19 disease include shortness of breath, loss of appetite, confusion, persistent pain or pressure in the chest, and high temperature (above 38°C). Lastly, other less common symptoms are irritability, confusion, reduced consciousness (sometimes associated with seizures), anxiety, depression, sleep disorders, and more severe and rare neurological complications such as strokes, brain inflammation, delirium, and nerve damage. These classifications can be found in Table1.

The evidence suggests that about one in five infected people will experience no symptoms, and they will transmit the virus to significantly fewer people than someone with symptoms (Nogrady, 2020). Infected people with no symptoms must be noticed because a person with this condition usually does activities such as getting to work, working in the office, going to school, etc. This phenomenon can also happen to schools or Islamic boarding schools taught face-to-face ('*luring*' or offline learning). The Minister of Religion acknowledged that there are currently many Islamic boarding schools and religious education institutions that have held face-to-face learning (Kepri.kemenag.go.id, 2020). Students who participate in this face-to-face learning are provided that all students do a rapid antibody or antigen test. This rapid test is known to not 100% describe the actual condition. The standard gold test is the swab test with PCR. Researchers are divided on whether asymptomatic infections act as a silent pandemic driver (Nogrady, 2020). These infections indeed endanger students, teachers, and other administrators of a pesantren because testing in most countries is targeted at those with symptoms (Nogrady, 2020).

There is a group called asymptomatic and pre-symptomatic. Asymptomatic is someone who has never experienced symptoms during the disease, and pre-symptomatic is someone who has mild symptoms before they develop symptoms. Research early in the pandemic showed that the rate of asymptomatic infection could be as high as 81% (Nogrady, 2020). Estimates of the one in six prevalence of asymptomatic COVID-19 cases and rates of asymptomatic transmission are lower than many published studies but still sufficient to warrant policy attention. The review also found that asymptomatic individuals were 42% less likely to transmit the virus than symptomatic individuals (Byambasuren et al., 2020). One of the reasons why scientists want to know how often asymptomatic people transmit the virus is that these infections go largely undetected (Nogrady, 2020). Asymptomatic people can transmit SARS-CoV-2 to others for a long time, perhaps more than 14 days (Akilli & Koylu, 2021). The absence of COVID-19 symptoms in a person infected with SARS-CoV-2 does not necessarily imply the absence of danger (Akilli & Koylu, 2021).Of the students at an Islamic boarding school in Tangerang, the majority of students have a low level of knowledge (71.9%), negative attitudes (51.3%), and bad behaviour (53.2%) regarding COVID-19. Most students contracted COVID-19 (88%) (Haninda et al., 2022).

In Indonesia, there are two types of pesantren, namely traditional and modern; of course, there are differences, although there are similarities. Many studies have been conducted on pesantren, but not all mention whether pesantren are traditional or modern. The factors widely studied are environmental factors, knowledge, and behaviour, including Clean and Healthy Life Behaviour and Islamic boarding school facilities and infrastructure. The study results indicate several potential diseases in Islamic boarding schools, including upper respiratory tract infections. The research results are still controversial, for example, personal hygiene, environmental and behavioural factors, and sanitation with the incidence of infection in the pesantren environment.

Some respiratory diseases that students often experience, including Islamic boarding school students, are symptoms of COVID-19, such as fever or chills, cough, shortness of breath or difficulty breathing, headache, sore throat, congestion, or runny nose. Knowing the symptoms of respiratory disorders can be used as early detection or case findings of COVID-19 before it becomes severe. Therefore, it is necessary to research to identify the symptoms of respiratory disorders that can be used to predict or make a sign of COVID-19 infection.

Methods

The method used was a cross-sectional approach in a male-only Islamic boarding school in the Tapan District, Tulungagung, East Java, conducted in August 2020. The number of samples is calculated using the Lemeshow or Slovin formula, with a prevalence of 0.5 each; usually, a minimum sample of 97 is obtained. This number will be selected systematically based on the number of classes and students. In this study, the number of samples or subjects was 100. The subjects were students in Class 10, 11, and 12 and the Preparatory Class for Aliyah.

Data collection was conducted in Islamic boarding schools with the help of teachers trained to fill out the questionnaires beforehand by the researcher. The questionnaire was filled in based on the conditions experienced by the students in the last six months. The questionnaire contained the pesantren's identity, the condition of the pesantren, symptoms of respiratory disorders experienced by male students or students, the types of examinations carried out, and clean and healthy living behaviour, namely washing hands.

The study also reviewed the COVID-19 symptoms to determine the classification of the symptoms based on the severity or urgency to seek medical care, common symptoms, and most symptoms that appear.For this reason, three sources are used, namely WHO (World Health Organization, 2020), CDC (Centers for Diseases Control and Prevention,

The data were analysed descriptively to show the distribution of the frequency and percentage of each respiratory symptom related to the symptoms of COVID-19 experienced by the subject during the last six months, the type of chest examination, and handwashing behaviour. The analysis is also based on the grouping of COVID-19 symptoms based on WHO (World Health Organization, 2020), CDC (Centers for Diseases Control and Prevention, 2021b) (Centers for Diseases Control and Prevention, 2021a), and NHS (NHS, 2021).

The study was conducted at Islamic boarding schools that attend school or offline; the assumption is that these students are healthy. However, with the data collection on COVID-19 symptoms, data analysis uses the CDC 'may have COVID-19' classification, namely by identifying and counting to the number of 12 symptoms: fever or chills, cough, shortness of breath or difficulty breathing, fatigue, muscle or body aches, headache, the new loss of taste or smell, sore throat, congestion or runny nose, nausea, vomiting, and diarhoea. The cumulative percentage is calculated to determine the most symptoms experienced by students to determine the possibility of getting COVID-19 in less than six months.

The results section presents all analyses in tables. This research has received ethical approval from the Ethics Review Team of the Faculty of Public Health, with the number Ket-612/UN2.F10.D11/PPM.00.02/2020.

Results

The analysis's results are presented in three tables: the distribution of the frequency of symptoms (Table 1), the cumulative number of symptoms (Table 3), and the classification of symptoms (Table 3).

Table 1. Distribution of the frequency of respiratory symptoms, types of examinations, and handwashing practices

Variable	Jumlah	Persentase
Symptoms of respiratory disorder:		
Bersin	90	90.0
Congestion nose	64	64.0
Sore throat	41	41.0
Difficulty breathing	15	15.0
Fever	39	39.0
Headache	68	68.0
Muscle or body ache	50	50.0
Shortness of breath	22	22.0
Nausea	53	53.0
Vomiting	38	38.0
Diarhoea	47	47.0
Handwashing behaviour:		
Handwashing	90	90.0

Students mainly experienced sneezing (90%), headache (68%), nasal congestion (64%), colds (55%), and muscle or body aches (50%). Other symptoms were sore throat, shortness of breath or difficulty breathing, fever or chill, and nausea or vomit (Table 1).

Table 2 shows the review of the classification of symptoms based on the WHO, the CDC, and the NHS.

From Table 2, it can be seen that a person may have COVID-19 if she/he has symptoms of fever or chills, cough, shortness of breath or difficulty breathing, fatigue, muscle or body aches, headache, the new loss of taste or smell, afternoon throat, congestion or runny nose, nausea or vomiting, or diarhoea (Centers for Diseases Control and Prevention, 2021b). Loss of appetite (of taste and smell) is the most common symptom and also less common and severe symptoms (World Health Organization, 2020), as well as the primary symptom (Centers for Disease Control and Prevention, 2021b). However, it is still considered possible that someone is suffering from COVID-19 (NHS, 2021).

Table 2. Classification of COVID-19 symptoms

Type symptoms	WHO (World Health Organization, 2020)				CDC (Centers for Diseases Control and Prevention, 2021a)		NHS
	Most common	Less common and may affect some patients	Severe	Less common	May have COVID-19	Seek medical care immediately (it has Emergency Signs)	Main symptoms
Fever	✓				✓		
High temperature (above 38°C)			✓				✓ a high*
Dry cough	✓				✓		A new, continuous
Fatigue (tiredness)	✓				✓		
Loss of appetite (taste or smell)	✓	✓	✓	✓	✓		✓
Nasal congestion (runny nose)		✓			✓		
Conjunctivitis (red eyes)		✓					
Sore throat		✓			✓		
Headache		✓			✓		
Muscle or joint pain Or body pain		✓			✓		
Different types of skin rash		✓					
Nausea or vomiting		✓			✓		
Diarhoea		✓			✓		
Chills or dizziness		✓			✓		
Shortness of breath (difficulty breathing)			✓	✓	✓	✓	
Confusion			✓				
Persistent pain or pressure in the chest			✓			✓	
Irritability				✓			
Loss of speech or mobility							
Confusion				✓		✓	
Reduced consciousness (sometimes associated with seizures)				✓			

Table 2. (Continued)

Type symptoms	WHO (World Health Organization, 2020)				CDC (Centers for Diseases Control and Prevention, 2021a)		NHS
	Most common	Less common and may affect some patients	Severe	Less common	May have COVID-19	Seek medical care immediately (it has Emergency Signs)	Main symptoms
Anxiety				✓			
Depression				✓			
Sleep disorders (Inability to wake or stay awake)				✓		✓	
Pale, gray, or blue-colored skin, lips, or nail beds, depending on skin tone.						✓	

Notes:

*: a high temperature – this meansfeeling hot to touch on the chest or back (it does not need to measure your temperature).

**: coughing a lot for more than an hour, or three or more coughing episodes in 24 hours (if usually having a cough, it may be worse than usual).

Fever (World Health Organization, 2020) (Centers for Diseases Control and Prevention, 2021b) and high temperature (above 38°C) (World Health Organization, 2020) (NHS, 2021) are considered the main and common symptoms that allow a person to suffer from COVID-19 at a painful level (severe); even though fever or high-temperature symptoms is not always considered an emergency or someone should seek medical care.

Table 3. Distribution frequency of 'may have COVID-19' symptoms based on CDC classification

Number of Symptoms*	Frequency (n)	Percentage (%)	Cumulative Percentage
11 and 12	-	-	
10	1	1.0	1.0
9	3	3.0	4.0
8	3	3.0	7.0
7	6	6.0	13.0
6	16	16.0	29.0
5	14	14.0	43.0
4	20	20.0	63.0
3	15	15.0	78.0
2	14	14.0	92.0
1	5	5.0	97.0
0	3	3.0	100.0

Note:

*) Gejala 'may have COVID-19' were fever or chills, cough, shortness of breath or difficulty breathing, fatigue, muscle or body aches, headache, the new loss of taste or smell, sore throat, congestion or runny nose, nausea, vomiting, and diarhoea.

**)There were no cough and loss of appetite symptoms recorded.

Gejala paling banyak dialami siswa jumlahnya adalah 4 gejala (20.0%). Hanya ada 3.0% siswa yang tidak yang mungkin mengalami sakit gejala COVID-19, karena tidak mengalami gejala satu pun syarat 'may have COVID-19'. Meskipun yang mempunyai 10 gejala hanya satu orang (1%), namun yang memiliki minimal 6 gejala ada 29%.Hal ini dapat dilihat pada Tabel 3.

The total number of symptoms experienced by students was four types (20.0%). Only 3.0% of students did not have symptoms of COVID-19 because they did not experience any of the symptoms for 'may have COVID-19'. Although only one person had ten symptoms (1%), 29% had six symptoms. These results can be seen in Table 3.

Discussion

The research was conducted in an Islamic boarding school where the students were all male and were in good health, so they went to school. When the research was conducted, students were in a face-to-face or offline learning process. In the last six months, students have experienced respiratory problems, COVID-19, and diarhoea. The symptoms experienced by students mainly were sneezing (90%), headache (68%), nasal congestion (64%), colds (55%), and muscle or body aches (50%). The other symptoms were sore throat, shortness of breath or difficulty breathing, fever or chill, and nausea or vomiting. Some symptoms of respiratory infection and diarhoea can be associated with COVID-19 symptoms. Those who enter the school for the learning process and have symptoms of COVID-19 will be a problem and need attention.

Many cases of COVID-19 are asymptomatic, meaning a person is not sick; moreover, there are asymptomatic COVID-19, and some are pre-symptomatic. It means that if someone is true positive for COVID-19, it can immediately spread to other students or even teachers and other administrators. This person can infect other people, which allows that person to become sick (severe). This situation happened in this school since some students have symptoms that may lead to COVID-19. The COVID-19 transmission must be prevented either in an Islamic boarding school or other schools, especially since the boarding school is closed and usually boarding or students live in boarding schools.

Many factors are involved with transmission efficiency, and it appears that asymptomatic/pre-symptomatic transmission is measured by direct contact tracing studies (Slifka & Gao, 2020). There is some evidence that SARS-CoV-2 infection in contacts of persons with asymptomatic infection is less likely than in contacts of persons with symptomatic infection (0.35 relative risk, 95% CI 0.10–1.27) (Buitrago-Garcia et al. al., 2020).

The Minister of Religion of the Republic of Indonesia acknowledged that there are currently many Islamic boarding schools and religious education institutions that have held face-to-face learning. Some guidelines stipulate that the leaders of Islamic boarding schools and religious education coordinate with the task force to accelerate handling regional COVID-19 and health service facilities or the local health office. Coordination ensures students' health conditions are safe from COVID-19 (Kepri.kemenag.go.id, 2020). Every Islamic boarding school or any other type of education, regardless of its form, needs disaster emergency response training so that all schools are responsive and can continue to run smoothly. Furthermore, for the Government, there should be a need for technical standardization of emergency response for every form of an existing educational institution so that the teaching and learning process and all learning activities can continue (Kahfi & Kasanova, 2020).

An Islamic boarding school has implemented five-step policies to break the transmission of the COVID-19 chain (covid19.go.id, 2020). First, implement a one-door or "one gate" system to limit the traffic of people entering. This application makes students' interactions with the community simple to monitor. Second, it is mandatory to wear masks while in the boarding school environment for students, teachers, and managers and provide a fine of IDR 250,000 for violators. Third, outside teachers who live in Islamic boarding schools or choose to teach online must not infect their students. Fourth, restrict the number of parents who can visit their students during the pandemic to no more than 80 individuals per week. Parents of students also need to register online beforehand. Fifth, students entering the Islamic boarding school must pass four stages, including a rapid test. Then, after the results are negative, students must undergo independent isolation before joining other students. So, the protocol at the pesantren already exists, but several things need attention, such as the rapid tests.

Understanding pre-symptomatic and post-symptomatic transmission will increase, which will be critical for future public health initiatives to control the COVID-19 pandemic (Slifka & Gao, 2020). Asymptomatic patients can transmit SARS-CoV-2 to others, but the findings of a systematic review suggest that these individuals are responsible for fewer secondary infections than people with symptoms (Qiu et al., 2021).

The contribution of pre-symptomatic and asymptomatic infections to overall SARS-CoV-2 transmission means that combined prevention measures, with improved hand hygiene, masks, testing track, and isolation and social distancing strategies, will continue to be needed (Buitrago-Garcia et al., 2020). Despite a growing understanding of asymptomatic infections, researchers say that people should continue to use measures to reduce the spread of the virus, including social distancing and wearing masks, regardless of whether they have symptoms (Nogrady, 2020).

The contact tracing period should be earlier and highlight the importance of preventing the chance of transmission long before the onset of symptoms (Zhang et al., 2021). The focus of testing programs for SARS-CoV-2 should be expanded substantially to include people who do not have COVID-19 symptoms (Akilli & Koylu, 2021). Further strong epidemiological evidence is urgently needed, including in subpopulations such as children, to understand better how asymptomatic cases contribute to the pandemic (Byambasuren et al., 2020).

This study discovered several symptoms that suggested that they may be suffering from COVID-19. Important aspects of this finding include the possibility that some students tested positive for COVID-19 but did not feel sick. His family may also be sick. The absence of swab tests with PCR or non-reporting prevented the detection of these students. We must address this issue, as failing to examine sick students or their families could potentially spread the infection to other students, teachers, or other school personnel. Therefore, we must conduct surveillance to track the health of students, teachers, and their families, ensuring a positive COVID-19 diagnosis through an accurate COVID-19 examination method.

This study has several limitations or weaknesses, namely the possibility of biases that must be minimized. Firstly, the study was conducted to measure the symptoms experienced by students six months before filling out the questionnaire, and the calculations of the symptoms were accumulated. We know that the symptoms of COVID-19 until they appear as a disease are 2-14 days (Centers for Disease Control and Prevention, 2021b). It is necessary to conduct research with a symptom period of 2-14 days. If symptoms are found, either most common (World Health Organization, 2020), main symptoms (NHS, 2021), or less common (World Health Organization, 2020). 2020) such as fever, loss of taste and smell, and fatigue must be followed by tracing and following up on the progress of the disease. Secondly, the students with symptoms were not examined accurately, namely with a swab test with PCR. According to the existing health protocol guidelines, students must do a rapid test, and the results must be negative. It is known that rapid tests for both antigen and antibody still have false positives and false negatives, meaning that they do not 100% describe the actual condition. Furthermore, the test used must be a swab PCR test; although this is costly, the school, through the government, must take this risk. Thirdly, this research was only done in a male Islamic boarding school, so it did not represent the condition of the Islamic boarding school at all. That is how research conducted in female Islamic boarding schools and any other school is suggested.

Conclusion

Male students from Islamic boarding schools who attend the school have experienced symptoms of COVID-19 in less than six months. The most common symptoms were sneezing nasal congestion, and headaches. Some students may have COVID-19.

Surveillance needs to be carried out to follow up on students who found COVID-19 symptoms and trace their families usingPCR swab tests. Research to identify the symptoms of COVID-19 conducted in female Islamic boarding schools and any other schools is suggested.

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Chapter 13

Health Challenges in Conscious Intubated Patients

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Abstract

Patients benefit from maintaining consciousness throughout intubation, but they may experience a variety of adverse physical and mental consequences, such as pain, dyspnea, fear, helplessness, loss of control, speech difficulties, and anxiety. The physical and psychological well-being of cognizant intubated patients is adversely affected by communication difficulties. Health care professionals tackle this matter by utilizing a range of available communication instruments in addition to traditional approaches such as assessing through sign languages and gestures. Enhancing communication between healthcare professionals and conscious intubated patients can be achieved through the use of Augmentative and Alternative Communication (AAC) devices, which are readily available. While there are various communication aids at the disposal of clinical caregivers, they should utilize the most patient-centric communication technologies possible, despite the fact that several alternatives exist.

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Keywords: communication, intubation, conscious, communication difficulties, communication methods, augmentative and alternative communication

Introduction

In healthcare, professions that are deeply personal and emotional include nursing. Communication plays a crucial role in this field. Nurses are directly involved in the ongoing care process of patients. Sometimes, conditions of the patient and the treatment regimen make verbal communication impossible. One such life-saving technique that impedes verbal communication is intubation.

An evolutionary change is underway in intensive care units, marked by a growing trend toward reduced sedation (Chanques et al., 2017; Devlin et al., 2018; Stollings et al., 2022). Nevertheless, procedures involving light or no sedation constitute a substantial shift in clinical practice, which may present challenges for patients. Placing conscious patients on a mechanical ventilator can induce stress. Despite the comfort tracheostomy offers, some patients still require prolonged days of endotracheal intubation.

Modern strategies aimed at keeping patients awake during intubation pose significant communication challenges for critically ill patients due to resulting cognitive, sensory, and communication deficiencies (Russotto, 2021). A health challenge for patients that must be addressed is the experience of being conscious during endotracheal intubation and tracheostomy tube placement, particularly concerning communication difficulties. These challenges also affect healthcare workers who attend to the needs of conscious patients without their ability to speak.

Studies are discussing patients' and healthcare providers' experiences with barriers to communication, which impact the standard course of care (Happ, 2021; Holm et al., 2020; Karlsen et al., 2020). This shift in focus has gradually led to a greater understanding of how long-term intensive care therapies affect patients' desire for communication, as well as the necessity for healthcare providers, particularly nurses, to foster a caring and humanizing environment (Kvande et al., 2021; Bueno & La Calle, 2020).

While techniques and resources are available to enhance communication with people who cannot speak (Beukelman and Light, 2020), shedding light on the current state of communication practice requires new perspectives and a more advanced understanding of care concepts (Im & Meleis, 2021). A greater comprehension of these underlying ideas may also impact the creation of strong, meticulously planned care strategies to overcome communication difficulties.

General Objective

The aim is to understand the health challenges among conscious intubated patients in light of communication difficulties.

Specific Objectives

To determine the impact of communication difficulties among conscious intubated patients.

To describe the barriers of communication between nurses and conscious intubated patients.

To list the methods adopted to improve communication among health care workers and conscious intubated patients.

Communication Model in the Context of Communication Challenges

People can establish and uphold interpersonal connections due to their communication skills. These connections promote understanding among individuals (Mumba & Phiri, 2019). Communication models play a crucial role in effectively streamlining communication processes. However, communication in real life is not as simple as it appears in the model. Various circumstances, such as disruption of verbal communication in mechanically ventilated patients, can lead to a breakdown in the communication process. The disruption in the communication process can be understood through Berlo's Model of Communication, which includes four components: sender, channel, message, and receiver. Each element further consists of five subcomponents. If all the components synchronize effectively between sender and receiver, communication is effective. However, asynchronous communication poses risks, as neither the sender nor the recipient receives immediate feedback about the message's effectiveness. This also prevents the message from being clarified more effectively (Janse, 2018). A breakdown in the communication process can result from various circumstances within the four components and their respective subcomponents. A detailed discussion referencing Berlo's Model of Communication (Muyanga & Phiri, 2021) is provided in Figure 1.

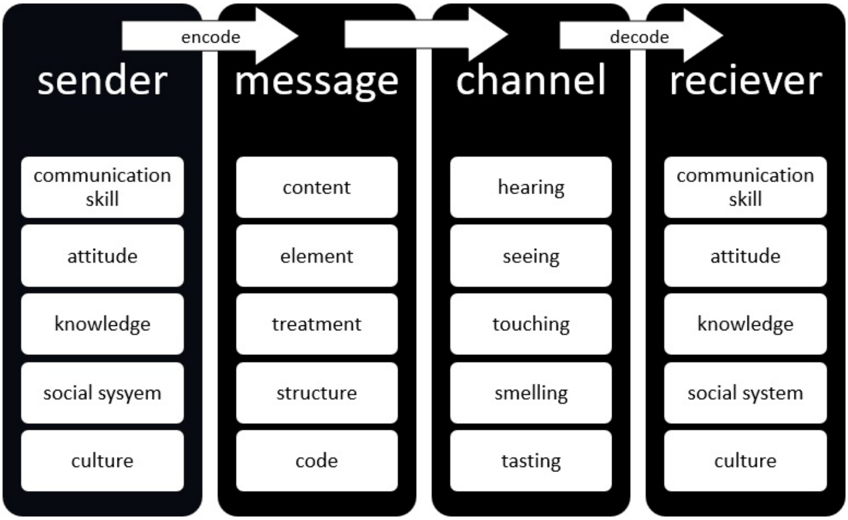

Figure 1. Berlo's SMCR Model (1960).

Disruption in the Communication Process

A disrupted communication process may arise from a variety of conditions in patients.

Sender

The message sender must encode the message to ensure it is fully understood by the recipient. They may choose to convey this verbally, but in the case of intubation, nonverbal communication techniques are adopted by conscious patients. In such cases, a message rarely conveys the entire meaning. Sometimes, a message may not even fully reach its intended recipient (Rathiram et al., 2022), often due to misinterpretation of sign languages by nurses.

Message

The sender must initially transform, or translate, the messages into symbols that the recipient can understand. These symbols can encompass sounds, images, or other sensory data in addition to words (e.g., touch or scent). The sender's mental images can only convey meaning to others through these symbols (Al-Yahyai et al., 2021; Karlsen et al., 2019). The message might be misinterpreted if the intended symbols are not effectively encoded by the sender. This situation may arise in the case of conscious intubated patients who are unable to speak but can only express themselves through writing or sign language without using any communication aid.

Channel

Three types of channels may be utilized as communication channels to transfer messages between senders and recipients: written, spoken, and visual (Muyanga & Phiri, 2021). Additional means of transmission include physical distances between the transmitter and the recipient, contact, and gestures. The channels of communication may be disrupted due to intubation, where the ability to speak is hindered. Other environmental factors in the intensive care unit setting, such as noise, light, and medical devices, also contribute to the disruption of the communication channel. Non-intentional interruptions in message delivery occur accidentally and can happen, for instance, when a sender employs incomprehensible gestures that make it difficult for the recipient to interpret the message.

Receiver

Patients' willingness to accept treatment, take personal responsibility for their health, and actively participate in their treatment depends on the strength of the nurse-patient relationship and communication (Mumba & Phiri, 2019; Muyanga & Phiri, 2021). This may be strained when verbal communication is impossible for the patient. Also, therapeutic communication has been shown to be hampered by the cultural and belief system gaps between nurses and patients. For example, nodding may be interpreted in different ways in different cultures.

Moreover, the willingness of the receiver to interpret sender's symbols also has great importance in establishing effective communication. Sometimes the personal attributes and belief system of the receiver, the nurse, may hamper communication. The attitudes of healthcare providers might limit the quality of care. Often the nurses attend less to the patients who cannot verbalize than those who can.

Impact of Communication Difficulties among Conscious Intubated Patients

Communication challenges may affect both psychological and physical aspects of patients' well-being.

Psychological Impact

Research studies have reflected some common feelings of conscious intubated patients who lack capability to speak due to the presence of intubation.

1. Fear
2. Despair
3. Anxiety
4. Anger
5. Panic
6. Frustration
7. Dismay
8. Helplessness

Critically ill patients lose their ability to speak when they are intubated. Being unable to communicate can be frightening, distressing, and prevent patients from taking an active role in their care and treatment choices (Danielis et al., 2020; Holm & Dreyer, 2018; Guangquan et al., 2024). Results from research have linked patients' communication issues brought on by endotracheal intubation to upsetting emotional experiences like despair, anxiety, and distorted recollections (IJssennagger et al., 2018; Mortensen, Kjær & Egerod, 2019).

One of the biggest sources of stress for patients on artificial respiration is communication problems, and having a tube inside might make them feel anxious, afraid, or uncomfortable (Baumgarten & Poulsen, 2014). Research indicates that experiencing a lack of communication might lead to emotions of powerlessness (Karlsen, Ølnes, & Heyn, 2019) and that communication problems might elicit feelings of anxiety, frustration, and anger in patients (Egerod et al., 2015). Patients have described experiencing panic, unease, uncertainty, despair, depression, loneliness, fear, worry, anxiety, and hallucinations (Topçu et al., 2017).

The studies demonstrate the empathetic vulnerability, a state of fear, anxiety, and loneliness among conscious intubated patients during their treatment period. When the managing health care team's primary concern is on the patients' life-threatening conditions, these aspects of the patient experience are mostly overlooked (Leong et al., 2023). This group of patients with transient communication problem cause them to reflect on unpleasant things which were not properly addressed during conscious intubated days.

Physiological Impact

In order to decide on the best course of treatment patients must be aware of their medical issues and able to convey their physical needs.

Studies describe the common physical needs perceived by patients whom they were unable to express due to intubation and inability to speak includes the following.

1. Pain
2. Dyspnea
3. Throat pain
4. Itching
5. Massage
6. Elimination needs
7. Thirst
8. Headaches
9. Discomfort
10. Drowsiness
11. Nausea

Conscious intubated patients find it difficult to communicate their physiological complaints like pain, dyspnea, throat pain, thirst and itching etc. to their nurses when they face communication difficulties**.** These patients become extremely frustrated and restless when these essential demands are not communicated. This results into erroneous patient assessments along with recommendations for pharmacological and physical restraintwhich may lead to poor patient outcomes (Dithole et al., 2017; Hetland et al., 2018).

The most common physical discomforts reported by intubated patients include pain, tiredness, unease, weakness or impulsivity, noise, thirst, headaches, discomfort from endotracheal tubes, and difficulty swallowing (Leong et al., 2023). Among the physical discomforts intubated conscious patients' primary unmet medical need is thought to be inadequate pain management. This deficiency was ascribed to challenges in precisely identifying and evaluating pain (Hasegawa, 2017).

Other needs which could not be addressed properly and timely due to failure in speech werebathing, eye and mouth care, as well as equipment positioning and adjustment. Also, concerns were shown both from patients and their family caregivers on involvement of the latter in such cares (Schwartz et al., 2022). Author during her clinical care tenure have found that post extubating the patients identified medical devices that caused discomfort included the oxygen mask, saturation prop, and nasogastric tubes, which they could not express during intubated period.

Communication barriers faced by patients in expressing their physical discomfort and demands, need to be addressed by all health care professionals as it is crucial to have a safe space that builds self-worth, a sense of security and drive for faster recovery (Scott et al., 2019). Nurses must initiate strategies to overcome the communication barriers faced by conscious intubated patients especially when nurses are able to express verbally to the patients and the patients are unable to reciprocate verbally in the communication process.

Barriers of Communication Between Nurse and Conscious Intubated Patients

Communication between nurses and conscious mechanically ventilated patients (N-CMVPC) encounters numerous obstacles, including technological, psychological, and physiological ones. These obstacles encompass the patient's critical condition, level of consciousness or sedation, delirium, and neurological diseases that hinder the patient from communicating with nurses or expressing their needs. (Ghiasvand et al., 2023).

One of the complications associated with critical patients is that, most of the time, they have altered state of consciousness, either due to pathology or external factors. This limits their ability to communicate, which makes the nurse-patient relationship challenging (Espinoza-Caifil et al., 2021).

It might be difficult to achieve patient-centered care and communication in clinical interactions between nurses and patients since there are always constraints relating to the environment, human behaviour and communication. Given their links in clinical contacts, healthcare practitioners need to recognize these barriers of communication as well as patient-centeredcare. Four categories are used to classify the obstacles to communication: institutional and healthcare system-related barriers, communication-related barriers, environment-related barriers, and personal and behaviour-related hurdles. Despite being covered under different topics, these obstacles are intricately tied together in clinical practice (Kwame & Petrucka, 2021).

Institutional and Healthcare System-Related Barriers

The healthcare system or its institutional procedures are the root cause of many of the obstacles that nurses face when attempting to provide patient-centered care and communication during nurse-patient interactions. Some of these elements are connected to managerial approaches and styles, or to policies pertaining to healthcare (Al-Kalaldeh et al., 2023; Yoo et al., 2020).

A complex impediment to effective care delivery at the institutional and healthcare system levels was the lack of nursing staff, the heavy workload, burnout, and time constraints (Al-Kalaldeh et al., 2023). Researchers discovered that lack of adequate number of staff meant that nurses were unable to spend enough time with patients and their caretakers. A heavy workload and staffing shortages in the nursing department resulted in fewer interactions between nurses, patients, and caregivers (Kwame &Petrucka, 2021). Similarly, other studies too discovered that the biggest barrier impeding therapeutic communication in nurse-patient interactions was the significant nursing workload (Amoah et al., 2019).

Time constraints have been seen to impact nurse-patient relationships, communication, and the quality of care provided by nurses, patients, and their caregivers (Yoo et al., 2020).

But some healthcare researchers have criticized nurses' concerns about time constraints, despite the fact that a shortage of nursing personnel is a key obstacle to patient-centered care and communication that healthcare institutions and administrators must be awareof (Engle et al., 2019; Mandal, Basu, & De, 2020). The excuse of inadequate therapeutic communication during clinical contacts cannot be justified by nurses' claims of being very busy. Positive nurse-patient interactions and communication are not usually the outcome of spending a lot of time with patients. As a substitute, nurses are urged to cultivate self-awareness, introspection, and a dedication to making sure patients receive the care they require (Wune et al., 2020).

The healthcare system's emphasis on task-centered care is another institution-related impediment to patient-centered care and communication. The completion of care procedures takes precedence above meeting the needs and preferences of patients and caregivers among healthcare practitioners. Many studies recognize this obstacle to patient-centered care and communication. Many studies recognize this obstacle to patient-centered care and communication (Papadopoulos et al., 2020). In a similar study, researchers noted that when ICU nurses prioritized finishing duties that directly impacted patients' health (such stabilizing vital signs) above talking to patients about their individual needs, it had an impact on nurse-patient communication. According to this data, nurses who are more task-focused see patients and caregivers as entities and objects that need to be treated in a certain way in order to get cured. Studies have indicated that nurses who prioritize task-oriented care may find it challenging to offer patients comprehensive care, as well as to instruct and interact with patients, even during periods of reduced workload (Yoo et al., 2020).

Communication and interaction between nurses and patients are impacted when nurse managers train their nursing staff to use task-centered care techniques. Furthermore, it affects how nurses respond to patients' care demands when nurse managers ignore the mental health needs and personal struggles of their team. For instance, nurses have reported that when nurse managers are unsupportive or insensitive to their needs, it negatively impacts nurse-patient communication (Kwame &Petrucka, 2021). In order to address and support nurses' concerns, nurse managers and care administrators must keep an eye on nurse-patient engagement and communication, particularly in settings with limited resources and frequent patient turnover (Camara et al., 2020; Kwame &Petrucka, 2020).

Communication-Related Barriers

Language difficulties between patients and healthcare professionals makes communication difficult (Al Shamsi et al., 2020). Communication among healthcare professionals and patients influences the quality of care received as well as the results of that treatment (Amoah et al., 2019). Patients' incapacity to communicate verbally because of their health, particularly in ICU, or end-of-life care situations pose communication-related obstacles (Camara et al., 2020). Nurses depend mostly on the non-verbal communication made by the patients, which is difficult. Moreover, cultural cognition has a major impact on how people interpret information from various sources like non-verbal communication and endorses practices they might agree with or disagree with (Rachlinski, 2021). Symbols may not imply the same thing to the sender and the recipient of a message, leading to misinterpretation and misunderstandings. Ineffective processing of these could result in prejudice, discrimination, and stereotyping (Aririguzoh, 2022). Interactions between patients and nurses may be impacted by cultural differences in the meanings of specific nonverbal communication acts, such as head nodding, eye gaze, and touching (Kwame &Petrucka, 2020). In patients on mechanical ventilation, miscommunication or misreading patient messages causes anxiety and distress and can have detrimental effects (Happ, 2021). Because in health care setting, there can be a significant cultural and communication gap between nurses and patients, even though they may both speak same languages. Variations in language, speech rate, age, past events, knowledge with medical equipment, education, physical ability, and experience can all contribute to these differences.

Healthcare organizations must make provisions for interpreters and translators to help with nurse-patient interactions when there is a language barrier in order to overcome communication-related difficulties. In addition, nurses who work in intensive care units and other such settings must become proficient in using several kinds of communication to engage with patients who cannot speak due to health conditions.

Environment-Related Barriers

Patients, families, and medical staff all have unique experiences in the complicated setting of the intensive care unit (ICU) (Latour et al., 2022). Patients in intensive care units are subjected to stressful situations, which can exacerbate uncomfortable symptoms. Patients in intensive care units frequently and inconsistently report experiencing discomfort as a symptom (Baumstarck et al., 2019; Gunnels et al., 2024; Luckhardt et al., 2022).

Patients are greatly impacted by the ICU setting, which is associated with increased levels of stress, anxiety, and depression (Arora et al., 2022). Intensive care units are constantly busy, it can be challenging to keep noise levels low enough to promote patient restful. ICUs may be quite upsetting for patients, and noise from staff activities and equipment is commonly mentioned as making patients more anxious. It might be difficult for healthcare professionals (HCPs) in intensive care units (ICUs) to communicate with the patients who are very sick. Clinicians can alter the ICU setting, the care given, and the communication with patients by comprehending the experiences and elements of their distress (Latour et al., 2022).

From patients' perspectives studies refer noise, too much light, medical devises and uncomfortable beds as identified discomforts in ICU environment (Vlake et al., 2021; Luckhardt et al., 2022). It is not unexpected that patients describe noise as a major impediment to proper communication and even getting a decent night's sleep in an environment where peak sound levels > 100 dB can occur up to 16 times per hour (Darbyshire et al., 2021). Impacts of sound levels in the intensive care unit alsoinclude staff distraction, patient sleep disturbance, and communication difficulties.

When designing an ICU, it's important to take communication-promoting environmental features including noise reduction, natural light availability, the presence of a phone, TV, and clock, as well as privacy preservation, into account (Latour et al., 2022). The well-being of caregivers has a direct impact on the healing process of patients; consideration of the built environment within ICU must be taken into account for the requirements of both staff and patients' well-being.

Personal and Behaviour-Related Hurdles

The effective communication is two-way conversation between two people. Effective communication between nurses and patients is crucial to achieving effective outcomes in tailored patient care. Inefficient communication between nurses and patients lengthens hospital stays, aggravates client complaints, and wastes resources (Wune et al., 2020). In order to ensure that patients are treated with respect and dignity and as human beings rather than just as bodies, nurses must communicate with patients who are on mechanical ventilation. Nursing care for awake intubated patients is not the same as that for sedated patients. It needs more time, nonverbal cues, consistency, and nurses paying close attention (Nadia et al., 2023).

The quality of nurse-patient engagement and communication has an impact on patients' willingness to fully participate in the care process, follow medical recommendations, and take personal responsibility for their health. Poor communication among nurses can have a negative impact on patient care, nursing procedures, and safety. Nurses who care for adult patients stated they felt accountable for patient communication. However, due to misunderstandings because of difficulty in communication due to intubation, nurses frequently felt responsible for giving inadequate patients care that exacerbated their dissatisfaction and ultimately led to patients being left dismissed (Hur & Kang, 2021). For this reason, it is suggested that communication competency is a necessary ability for those in the nursing profession (Kwame & Petrucka, 2020).

The differences in demographics, language and cultural origins, beliefs, and worldviews on health and illnesses, attitudes held by nurses, patients, and caregivers can have an impact on communication between nurses and patients as well as the quality of care. For example, cultural and belief system discrepancies between nurses and patients have been found to constitute obstacles to therapeutic communication and treatment (Al-Kalaldeh et al., 2023). It's crucial to communicate nonverbally. High amounts of procedure-related touch and low levels of comfort- or affection-related touch are characteristics of the intensive care unit. Patients' thresholds for contact vary, which may be influenced by their cultural upbringing and personal experiences (Verma et al., 2022).

However, behaviours on the part of nurses can also have a significant impact on the quality of treatment and communication in the nurse-patient relationship. Patient disclosures, treatment results, and nurse-patient interactions are all impacted when nurses treat patients with disregard, verbally abuse (such as yelling at or scolding them), and discriminating against them based on their socioeconomic position (Al-Kalaldeh et al., 2023; Madula et al., 2018). Communication between nurses and patients can be difficult when nurses are unwilling to listen to patients' feelings and anxious expressions. Patients may experience worry, discomfort, and a lack of trust in nurses when nurses deny them the opportunity to express thoughts and participate in their care planning. This can lower patient satisfaction with the treatment received (Al-Kalaldeh et al., 2023). Additionally, nurse-patient communication and patient-centered care practices suffer when nurses ignore the worries of patients and caregivers, compel patients to follow their rules and directions (Amoah et al., 2019), or neglect to offer patients the information they require.

A tremendous workload, little free time, inadequate pay, and a lack of staff can cause some nurses to experience emotions of hopelessness, emotional detachment, and indifference toward their work. These conditions can result in low self-esteem or a negative self-image, which can influence interactions between nurses and patients (Yoo et al., 2020).

Methods Adopted to Improve Communication among Healthcare Workers and Conscious Intubated Patients

In order to build humanized ICU care, one of the most crucial tasks is to evaluate the needs and experiences of patients (Leong et al., 2023). And the more challenging part of providing care for conscious intubated patients is coordinating nursing care and performing intricate tasks, where patients are unable to express their needs verbally. Evidence-based methods and instruments for helping critically sick patients who are awake and unable to communicate are still not routinely used in all contexts (Happ, 2021).

Some findings suggest that a range of accessible communication tools might potentially be used to improve care for 50% of conscious intubated patients (Modrykamien, 2019). Despite the availability of a number of tools, such as tracheostomy speech valves, pen and paper, communication boards with an alphabet or electronic and manual pictograms, above-cuff vocalization, and more, there is no consensus regarding the most practical or effective communication aid for patients undergoing mechanical ventilation (Carruthers et al., 2017; Kuyler & Johnson, 2021).

Although effective communication techniques have the potential to improve the long-term health outcomes of ITU survivors, their use is not very common in critical care settings due to potential barriers. Even in situations where written or nonverbal communication is feasible, it rarely occurs quickly and in a timely manner (Happ, 2021).

There are plenty of communication tools available to communicate with conscious intubated patients which are commonly known as Augmentative and alternative communication (AAC). The term Augmented Alternative Communication (AAC) refers to communication strategies that can be utilized in addition to standard speech and writing approaches when these are compromised. In other words, for those with communication disabilities, augmenting or replacing speech with nonverbal forms of communication is known as augmentative and alternative communication, or AAC (ASHA, 2018; American Speech-Language-Hearing Association, n.d.). AAC encompasses assisted approaches ranging from low AACs like pictorial charts to the most advanced High AACs like computer technology whichare now available to make communication easier alongside the unaided systems like signing and gesture (Ahmalia, Aljaberi & Said, 2024).

AAC can be used as an augmentation to speech that is already present, as an alternative to speech that is nonexistent or nonfunctional, or as a temporary measure when patients in care setting (Elsahar et al., 2019).

The different types of available AACs are enlisted in Table 1.

Table 1. Types of Augmentative and Alternative Communication Tools

No technology AAC tools:	Low technology AAC tools:	High technology AAC tools:
Gesture Sign language like thumbs up or thumbs down for Yes or No Nods, Facial expressions, Purposeful look and handshake	Communication boards/cards/ images/books Alphabet board Symbol board Pen and Paper	Speech generator Eye controlled assistive technology Electrolarynx Specific software Tablets Tracheostomy tubes (fenestrated) with inflated cuff (speaking tracheostomy tube) Speaking valve

Benefits of Adopting Communications Methods

Studies have propounded that it is possible for awake intubated patients to use various communication tools, which could facilitate communication and lessen patients' anxiety and widespread use of aided communication techniques is necessary to enhance communication in these patients (Hosseiniet al., 2018).

Following are the benefits observed in different studies with improved communication using different types of communication devices.

1. A rise in communication frequency and constructive communication practices (Happ et al., 2014)
2. Enhanced ability to manage pain and other issues (Happ, 2021)
3. Easier communication ways for patients and health care providers using AAC techniques (Happ, 2021).
4. Improved communication is one of the cornerstones of patient safety (Carruthers et al., 2017).
5. AAC techniques work well, helping patients feel more satisfied and have fewer communication problems (Mobasheri et al., 2016).
6. Maintaining good lines of contact with conscious intubated patients is crucial to raising the standard and security of the treatment given (Carruthers et al., 2017).
7. AAC techniques reduce stress and raise satisfaction levels (Hosseini et al., 2018).
8. The usage of AAC techniques was associated with useful nursing staff behaviours, such as allowing patients to use the various AACs; improving pain management while minimizing the requirement for sedation; and strengthening interaction by enabling patients to communicate and express demands (Nilsen et al., 2014; Neelavathi, 2021; Ju et al., 2021).
9. Good communication shortened the time of the ICU stay and improved patient recovery (Zaga et al., 2019; Modrykamien, 2019).

Many studies have found that for the patients in intensive care units on mechanical ventilation, Alternative and augmentative communication methods, both high- and low-tech, are widely employed with proven benefits. However, in order to support significant patient-centred clinical outcomes, communication needs must be systematically assessed, and communication interventions must be put into place (Kuruppu et al., 2023).

Also, it must be considered that communication tactics ought to cater to the specific communication requirements of each patient, taking into account factors like age, gender, degree of sedation, cognitive and psychological state, and amount of time needed for device training (Freeman-Sanderson et al., 2019; Duffett, 2017).

Thus, for the best use of AACs for better patient outcomes a scoping review by Kuruppu et al., (2023) showed five key patternsfor consideration:

1. Nurse and patients' participatory approachin designing of augmentative and alternative communication tools,
2. The training needs of patients and healthcare professionals to use AACs,
3. The application of accepted techniques for communication evaluation before use of AACs,
4. The amalgamation of multiple communication methods/approaches, and
5. The high-tech augmentative and alternative communication technologies demand technical proficiency.

Addressing the five key points while using AACs will help health care practitioners to adjust the way they communicate with conscious intubated patients, which may be linked to a reduction in the amount of time patients spend with intubation in a care setting (Holm et al., 2021).

Every benefit comes with meticulously considering the important details of the techniques used. It is more so when patients are at their lowest with no or minimum capacity to communicate their needs. Clinical carers should consider patient centric approach while using the desired types of communication devices.

Conclusion

This chapter takes a broader approach and aims to comprehensively map the impacts of communication difficulties faced by conscious intubated patients on health hazards. A deeper insight into the communication difficulties based on Berlo's communication model sheds light on the reasons for breaks in the communication process. The chapter also highlights the available communication aids in clinical practice, namely AAC tools for such patients. The advantages of utilizing these tools are emphasized to gain a better understanding of what, who, and how AAC tools are used in the critical care environment.

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Chapter 14

Etiology, Management and Treatment of Neurodegenerative Diseases and Its Impact on Society

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Abstract

Neurodegenerative diseases are a group of pathological phenomena associated with neuronal degeneration and microvascular dysfunction in the brain, with an insidious onset and progressive decline that compromise cognition and behaviour. The main neurodegenerative diseases, including Alzheimer's, Parkinson's, Huntington's, Amyotrophic Lateral Sclerosis (ALS) and prion diseases, present similarities, such as the aggregation of proteins in the central nervous system (CNS). However, their biochemical and/or physiological processes are not yet completely known. To date, most neurodegenerative diseases still have no cure. There is treatment available, which consists of mechanisms that only alleviate symptoms. It is important not to forget non-pharmacological interventions, which must be implemented from the moment of established diagnosis, such as education about the disease, mental and physical exercises and community support, among others.

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Introduction

Neurodegenerative diseases, which are expected to be the second most common cause of death among older people in 2040, are a group of diseases that affect neurons and blood vessels in the brain. They start slowly and get worse over time, making it harder to think and act normally (Armstrong, 2020).

The main neurodegenerative diseases, including Alzheimer's, Parkinson's, Huntington's, Amyotrophic Lateral Sclerosis (ALS) and prion diseases, present similarities, such as the aggregation of proteins in the central nervous system (CNS). However, their biochemical and/or physiological processes are not yet completely known (Leal et al., 2012; Leal et al., 2020).

Several methods can be used for the diagnosis of neurodegenerative diseases, such as imaging techniques that allow for the detection of changes in neuromuscular tissues. However, nowadays, biomarkers are used for this diagnosis since they can provide valuable information concerning the possible development of the disease, providing early detection, the course of the disease, and the effectiveness of the applied treatment (Strimbu & Tavel, 2010).

To date, most neurodegenerative diseases still have no cure, however, treatments are available, but they consist of mechanisms that only alleviate symptoms. New strategies to treat neurodegenerative diseases continue to grow (Yang et al., 2019; Leal et al., 2023). In addition to pharmacological treatments, it is important not to forget non-pharmacological interventions, which must be implemented from the moment of established diagnosis, such as education about the disease, mental and physical exercises and community support, among others, that will work as potential factors of protection (Polidori, 2014).

Neurodegenerative diseases are a major problem in the healthcare sector, with implications for caregivers and the entire healthcare system. The burden that the disease causes for caregivers is considerable, with an impact on the family, economy and health. Therefore, intervention with the family should not be neglected (Kada, 2009).

Etiology

Etiology of Alzheimer's Disease

Alzheimer´s disease is considered the most common neurodegenerative disease worldwide. It is a progressive and irreversible disease that begins to affect memory, destroying other mental functions. The largest number of cases occurs in the elderly and, after diagnosis of the disease; a patient with Alzheimer's survives an average of eight years (Rauk, 2009).

Alzheimer´s disease may have a genetic or sporadic cause. In sporadic cases, several factors are responsible for disease appearance, such as changes in cholinergic transmission, in the amyloid cascade, in isoform 4 of apolipoprotein E (ApoE4), and in the tau protein (Yang et al., 2019).

In Alzheimer´s disease, deposition of extracellular senile plates of amyloid-β (Aβ) peptide aggregates and intracellular fibrils of polymerized (hyperphosphorylated) tau protein was observed. The accumulation of Aβ peptide results from the proteolytic cleavage of the Aβ precursor protein (APP) by α-, β-, and γ-secretases. The Aβ peptide can occur in monomer, dimer, oligomer forms, fibrils, and fibril aggregates. The polypeptide chains of the most common Aβ forms are made up of 40 or 42 amino acids. Aβ isoforms that assume greater length are more easily able to rapid aggregation, oligomerization, and fibril formation. The most neurotoxic form is the oligomer (Rauk, 2009).

Axons are largely composed of tau protein and low-molecular mass microtubules. This tau protein has an important role in stabilizing microtubules and inducing their formation. Hyperphosphorylation of the tau protein causes pathological effects that increase neurotoxicity. Oligomers formed from the Aβ peptide cause instability of the tau protein, giving rise to a rapid dissociation from microtubules and breaking of the axon structure, allowing disturbances in synaptic processes and in neuronal death, which, in the first place, affect zones of the hippocampus and neocortex (Maccioni et al., 2010; Hossain et al., 2020).

Alzheimer´s disease can also be induced by the accumulation of inflammatory proteins. Engelhart et al. (2004) found high levels of these molecules in the brains of patients with Alzheimer's disease. The small increase in inflammatory markers is the cause of the development of low-grade inflammation. Thus, the body experiences a small, chronic elevation of these molecules, but not enough to trigger acute inflammation. This low-grade inflammation may contribute to the pathophysiology of hypertension and cardiovascular disease. Likewise, different studies also link low-grade peripheral inflammation with Alzheimer's disease (Nosalski et al., 2017).

The inflammatory process caused by exposure to various substances, for example, the Aβ peptide, leads to the production by microglial cells in the brains of these patients, of neurotoxic compounds, such as superoxide radicals, glutamate and nitric oxide. Furthermore, microglia exposure to Aβ peptide leads to the release of pro-inflammatory factors, such as interleukin (IL)-1, IL-6, IL-8 and tumour necrosis factor (TNF-α). It was proposed by Singhrao and Olsen (2019) that IL-1 favours the continuous deposition of Aβ in the brain (Togo et al., 2001; Walker, 2007).

Nevertheless, Heppner, Ransohoff and Becher (2015) considered that the immune system may also be an important contributor to the pathogenesis of Alzheimer´s disease. As already mentioned, after Aβ deposition, neurofibrillary tangles are formed by hyperphosphorylation of the tau protein. Different studies have verified that the production of neurofibrillary tangles is actually activated by microglial cells, which drive the process of neuroinflammation. This local immune response directed by microglial cells may be sufficient for the activation of tau protein pathology (Heneka, Kummer & Latz, 2014).

Genetic factors are also widely associated with Alzheimer's disease and include, for example, APP, presenilin (PS)-1 and PS-2. However, the presence of an allele of the gene that encodes ApoE4 demonstrated a greater association with the number of senile and vascular plaques, in addition to a reduction in cholinergic function in the brain of patients with this pathology. Inheritance of the gene encoding ApoE4, present in the long arm of chromosome 19, increases the risk of developing Alzheimer's disease by up to four times, and this risk is even greater if the patient inherits the allele from both parents. There is evidence to suggest a strong relationship between lipid deterioration, vascular changes and Alzheimer's disease. Among these associations is the recognition of ApoE4 as the main genetic risk factor for the development of Alzheimer's disease, both in familial and sporadic forms (Hayashi, Homma & Ichijo, 2016; Jones et al., 2016).

Although the various generic risk factors are transversal to all mental illnesses (age, consumption of illicit psychoactive substances, among others), epidemiological studies also demonstrate a direct relationship between high blood cholesterol levels and a higher risk of developing Alzheimer's disease (Raymond et al., 2011).

Metals may play a relevant role in the pathogenesis of neurodegenerative diseases such as Alzheimer´s disease. The interaction between metals and

CNS proteins may be important in the presence or absence of neurodegeneration. Different studies have shown the influence of the homeostasis of certain metals, particularly those involved in the control of redox activity such as copper, iron, manganese and zinc, on the development of neurodegenerative diseases (Leal et al., 2012; Leal et al., 2020).

Etiology of Parkinson's Disease

Parkinson´s disease is the second-most common neurodegenerative disease worldwide. It is a progressive and long-lasting neurological movement disorder that causes disability. This disease has no cure, affecting more men than women. The main symptoms are resting tremor, bradykinesia, muscle rigidity and postural instability (Teive, 2005).

Approximately 90% of cases of Parkinson's disease are sporadic and have no known etiology. Several studies have shown that genetic factors, along with aging and environmental factors, have an important function in the development of the disease. Familial cases can be caused, for example, by variants in the *LRRK2*, *PARK7*, *PINK1*, *PRKN*, or *SNCA* genes. Different studies of familial Parkinson´s disease have identified approximately 20 causative genes. In sporadic Parkinson's disease, genome-wide association studies have revealed more than 200 genes driving the disease. Most of these studies were carried out only in Caucasian populations, limiting the identification of all genetic risk factors for sporadic Parkinson's disease, because genetic backgrounds vary greatly between races (Funayama et al., 2023).

Some processes lead to the atrophy and death of dopaminergic neurons in the brains of patients with Parkinson´s disease. The most crucial factors are oxidative stress, excitotoxicity, mitochondrial dysfunction, and protein aggregation (Weintraub, Comella & Horn, 2008).

In Parkinson´s disease, the presence of multiple monoaminergic dysfunctions is observed, such as deficits in the dopaminergic, cholinergic, serotonergic, and noradrenergic systems. Specific neurodegeneration is observed in the substantia nigra, with a significant decrease in dopamine in all components of the basal ganglia and the presence of Lewy bodies. Lewy bodies are cytoplasmatic inclusions composed of proteins such as α-synuclein (α-syn), parkin and ubiquitin. The ubiquitin proteasomal system is the main mechanism responsible for the elimination of damaged mutant intracellular proteins. This system is composed of the 26S and 20S proteasomes, which contain proteases with multicatalytic action. The loss of α-subunits in the 20S proteasomal system was observed among nigral dopaminergic neurons, causing instability of the proteasomal system, loss of function and triggering the neurodegenerative process (Togo et al., 2001).

It has recently been recognized that neuroinflammatory processes may be involved in dopaminergic loss. Accumulation of α-syn causes the secretion of pro-inflammatory cytokines, leading to chronic neuroinflammation in patients with Parkinson´s disease. Acute systemic inflammation has been documented to worsen the motor symptoms of Parkinson´s disease (Haghshomar et al., 2019).

Epidemiological studies also demonstrate that anti-inflammatory drugs, especially non-steroidal anti-inflammatory drugs, have neuroprotective effects and reduce the risk of Parkinson´s disease, which strongly supports the afore-mentioned hypothesis (Bassani, Vital & Rauh, 2015).

Etiology of Huntington's Disease

Huntington´s disease is an autosomal dominant progressive neurodegenerative disease that affects movement, causing cognitive impairment. The main symptoms are excessive uncoordinated motor movements (chorea) and gait disturbances. The disease becomes fatal 15 to 20 years after the first symptoms. The main cause of death is infectious respiratory or cardiovascular complications (Walker, 2007).

In Huntington´s disease, there is gradual neuronal loss in the striatum (caudate nucleus and putamen) and cortex. Other nuclei are also affected, such as the pale globe, thalamus, hypothalamus, subthalamic nucleus, substantia nigra, and cerebellum (Raymond et al., 2011).

Huntington´s disease is caused by the unstable expansion of a CAG trinucleotide repeat in the coding region of the Huntington's disease gene (on the short arm of chromosome 4). This gene encodes the protein Huntingtin (Htt). Mutations in this gene lead to the production of a mutant Huntingtin protein (mHtt), causing degeneration in the striatum and deeper layers of the cortex. Translation of the mutant gene gives rise to a long length polyglutamine (polyQ) sequence that will lead to mHtt aggregation. These intracellular mHtt aggregates are inclusion bodies. The elimination of inclusion bodies can happen through different cellular processes, such as molecular chaperones, the ubiquitin proteasomal system and autophagy pathways. These processes can detect mHtt as a threat and initiate beneficial defence responses, allowing only a delay in the development of the disease (Jones et al., 2016).

The immune system may be involved in the pathogenesis of Huntington´s disease. Increased activation of components of the innate and adaptive immune systems has been observed in the CNS and peripheral tissues of patients with Huntington´s disease. Specifically, compared to controls, increased concentrations of TNF-α and IL-6 were observed in the plasma of Huntington´s disease mutation carriers (Björkqvist et al., 2008).

Etiology of ALS

ALS is a rare neurodegenerative disease with progressive loss of motor functions and respiratory capacity. Neurodegeneration is mainly observed in the motor cortex, brainstem, and spinal cord, being more common in men than in women. The first symptom is symmetric weakness in one of the limbs with progressive muscular atrophy. Mortality is mainly caused by respiratory repercussions in the late stages of the disease (Hayashi, Homma & Ichijo, 2016).

Approximately 90% of ALS cases have no genetic component or known cause, being sporadic. The remaining 10% have a genetic component, being familial (fALS). More than twenty genes have already been identified as being involved in the development process of this disease, the four main ones being the genes that encode superoxide dismutase 1 (SOD1), TAR DNA-binding protein (TARDBP), sarcoma fused protein (FUS) and an alteration in the 72 reading frame—a high repetition of the "GGGGCC" sequence—of chromosome 9 (C9orf72) (Masrori & Van Damme, 2020).

ALS involves mitochondrial dysfunction, oxidative stress, metal accumulation, neuroinflammation, glutamate excitotoxicity, apoptosis, a decreased supply of trophic factors, cytoskeletal abnormalities, and extracellular SOD1 toxicity. SOD1 is one of the main cellular defence mechanisms against oxidative damage. Carriers of SOD1 gene mutations experience rapid neurological decline after late middle age. The processes by which misfolded SOD1 species cause ALS are not yet completely understood. The involvement of disturbances of mitochondrial function, induction of endoplasmic reticulum stress, and disturbances and aggregation of axonal transport have been proposed. Mutated SOD1 binds to the endoplasmic reticulum, mitochondria, glial NADPH oxidase (NOX)/Rac1 complex, causing endoplasmic reticulum stress, mitochondrial dysfunction, and overproduction of reactive oxygen species (ROS), respectively (Hayashi, Homma & Ichijo, 2016; Carrì, D'Ambrosi & Cozzolino, 2017).

Furthermore, glutamate, as a neurotransmitter throughout the CNS, has become the target of several studies due to its ability to cause cell damage when present at levels higher than normal. This process is called glutamate excitotoxicity. Researchers found that, when compared to healthy individuals, ALS patients have higher levels of glutamate in plasma and cerebrospinal fluid (CSF). Nowadays, studies attempt to understand the mechanisms that lead to unnecessary glutamate accumulation in the CSF and how it may contribute to the progression of ALS (Van Den Bosch et al., 2006).

Etiology of Prion Diseases

Prion diseases, also known as transmissible spongiform encephalopathies (TSEs), are neurodegenerative diseases that can affect both humans and animals. Human Prion diseases are commonly divided into three etiological categories: sporadic (85–90%), genetic (10–15%), and acquired (<1%) (Figgie & Appleby, 2021).

Sporadic Creutzfeldt-Jakob disease (sCJD) is the most common of the prion diseases. It has several subtypes that are classified according to the genotype of the prion protein gene (*PRNP*) at codon 129. Genetic Prion diseases, all linked to mutations in the *PRNP* gene, account for 10–15% of cases, and include genetic Creutzfeldt-Jakob disease (gCJD), Gerstmann–Sträussler–Scheinker disease (GSS) and fatal familial insomnia (FFI). More than 50 different *PRNP* mutations have been associated with prion diseases with familial predisposition. Acquired Prion diseases, such as iatrogenic CJD (iCJD), Kuru, and variant CJD (vCJD), are the rarest causes of prion diseases but remain important for public health reasons (Figgie & Appleby, 2021).

Prion diseases present progressive and/or complete degeneration of nerve cells, causing a debilitating and incurable state that leads to death. These diseases have long incubation periods, an inability to induce an inflammatory response and extrapyramidal motor manifestations (tremors, ataxia, myoclonus and postural instability) (Chen & Dong, 2016).

Prion proteins (PrPs) are transmissible infectious particles of a protein nature. A normal cellular prion protein (PrPC) is present principally in the CNS, lymphatic tissue, and neuromuscular junctions. PrPC has a fundamental function in neuronal processes like circadian rhythm, neuroprotection, and neuroplasticity. Nevertheless, PrPC can become abnormal or infectious and is called scrapie prion protein (PrPSc) (Chen & Dong, 2016).

Prion diseases are associated with the conversion of PrPC into the insoluble conformer PrPSc. The conformation of PrPC fundamentally consists of α-helical helices and PrPSc is mainly composed of β-sheets. PrPSc thus becomes resistant to proteinase K digestion (PrPRes), resulting in a slow and progressive accumulation in the brain (Venneti, 2010).

Signs and Symptoms

Signs and Symptoms of Alzheimer's Disease

The main symptoms of Alzheimer's disease include a gradual loss of memory, an inability to learn, thinking disturbances, deterioration, and changes in personality and humor. In this way, patients lose their understanding of whom or where they are, which causes panic and distress. Cognitive deficiencies include agnosia (loss of perceptive capacity concerning sensory realization); apraxia (incapacity to realize the proper use of things); and dysphasia (inability to organize vocabulary in a significative form) (Martone & Piotrowski, 2019).

These behavioural changes may lead to alterations at the orofacial level. Several studies have shown that patients with dementia have more dental root retention as well as a higher incidence of dental caries and consequent orofacial pain (D'Alessandro et al., 2018).

Moreover, Alzheimer's disease patients have a higher prevalence of periodontal problems, such as periodontitis and gingivitis, gingival bleeding, mouth and lip inflammation, oral candidiasis and xerostomia. Xerostomia is a common symptom in elderly resulting from the natural aging process or being a collateral effect of medication. Patients with Alzheimer's disease usually take several medicines that can cause xerostomia and reduction of saliva flow. Xerostomia is associated with dental caries, periodontal disease, fungus infections and chewing discomfort. The change in saliva flow can lead to increased accumulation of dental plaque, caries, periodontal inflammation and halitosis (Gao, Chu & Young, 2020; Lau et al., 2019).

The loss of teeth is an indicator of poor oral health, but it is believed that this relationship is bidirectional in nature. Dementia can lead to deficient oral hygiene and consequent tooth loss. But the reverse can also be true. The loss of teeth can lead to poor chewing function that can affect food intake and the functioning of the brain due to the decrease in pyramidal cells and acetylcholine levels in the hippocampus, possibly contributing to memory loss and aggravating the dementia status (Campos, Ribeiro & Garcia, 2018).

Non-controlled periodontal disease can develop and increase the neuroinflammation observed in Alzheimer’s disease, since periodontal inflammation will provide pro-inflammatory cytokines at a systemic level and, therefore, at the CNS level, which might contribute to the increase in neuroinflammation (Gaur & Agnihotri, 2015).

Some periodontal microorganisms can invade the brain. *Aggregabacter actinomycetemcomitans*, *Fusobacterium nucleatum* and *Porphyromonas gingivalis* (*P. gingivalis*) have been found in brain abscesses. In 2019, Dominy et al. suggested that the infection by *P. gingivalis* is involved in the development of Alzheimer’s disease via the production of gingipains that provoke nerve damage. These researchers observed that immune responses promoted by gingipains in the brains of Alzheimer’s patients were considerably bigger than in control individuals. It was observed in this study that, besides being able to increase the production of Aβ, gingipains were capable of fragmenting the tau protein, favouring its hyperphosphorylation. DNA from *P. gingivalis* was detected in the brains of individuals with Alzheimer’s disease and in the cerebrospinal fluid of individuals diagnosed with probable development of Alzheimer. This suggests that *P. gingivalis* DNA in cerebrospinal fluid can be used as a biomarker in differential diagnosis, facilitating the early diagnosis of this pathology. Tiisanoja et al. (2019) observed that dental caries, the number of decayed teeth and inflammatory load are linked to an increased probability of developing Alzheimer’s disease.

Signs and Symptoms of Parkinson’s Disease

Parkinson’s disease is clinically characterized by motor changes such as muscle rigidity, resting tremor, bradykinesia (slow movements) and changes in posture and gait (Cabreira & Massano, 2019). Patients also show non-motor symptoms such as depression, pain, mood swings, changes in sleep and dysphagia, which become more severe as the disease progresses (Atik, Stewart & Zhang, 2016).

As discussed for Alzheimer’s disease, several oral manifestations are associated with Parkinson´s disease. Because of the lack of orofacial muscular control, these patients tend to have compromised oral and periodontal health. They also show hypo- or hypersalivation, deficient oral self-care due to decreased hand dexterity, cognitive problems, depression, apathy, and changes in motor behaviour, among others. Consequently, a higher susceptibility to the increase in periodontal disease, dental caries, early loss of teeth, bacterial plaque and problems with dental prosthetics is present (Barbe et al., 2017).

Changes in swallowing (dysphagia) are common in Parkinson's disease. When an individual has difficulty eating and swallowing, their oral and systemic health can be altered, especially if this affects their medication. Dysphagia can also lead to sialorrhea, the accumulation of saliva in the oropharynx. This excessive salivation leads to frequent lip cleaning, which can often cause angular cheilitis. Sialorrhea is observed in 32-74% of Parkinson’s patients (Ou et al., 2015).

Due to the intake of medication such as tricyclic antidepressants, anticholinergics, antipsychotics, antihistamines and β-blockers, 55% of these patients can show xerostomia, which is a stimulator of dental caries and periodontal disease. Xerostomia also has a negative influence on the retention of dentures by reducing the capillary effect necessary for their adhesion to the mucosa (Zlotnik et al., 2015).

Signs and Symptoms of Huntington’s Disease

The main signs and symptoms of Huntington's disease include changes at the motor, cognitive and psychiatric levels. Symptoms of the disease usually start to develop in the range of 30 and 50 years of age, with an average lifespan of 17-20 years. The main causes of patient death are pneumonia and suicide. In juvenile Huntington’s disease, symptoms show-up before the age of 20. It is believed that the number of repetitions of the CAG triplet is related to the age of disease development (Quarrell et al., 2013).

Motor alterations include involuntary movements such as chorea, observed first in the distal extremities (fingers and toes) and also in the muscles of the face. Initially, patients feel difficulties walking and look a little drunk. Gradually, the involuntary movements spread to all other muscles. Due to the involuntary movements, talking and swallowing gradually become difficult and can lead to choking. Patients in advanced phases of this pathology can become mute. During the development of the disease, dysarthria and dysphagia are usually outstanding. It is common for all patients to develop hypokinesia, akinesia, and rigidity, which will lead to difficulties in walking and standing, as well as ataxic gait and falls. The first motor sign of this condition can be dystonia, such as torticollis (Zhunina et al., 2019; Ellin et al., 2023).

Between 33 and 76% of patients with Huntington's disease show psychiatric disturbances that are usually developed at the initial phases of the disease and usually before the appearance of the motor changes. The most frequent psychiatric symptom is depression. Another frequent sign is anxiety resulting from uncertainty concerning the course of the disease. Irritability is usually the first sign, being expressed in varied forms, such as ugly discussions and physical assault. Patients can also show obsession and compulsions. The full clinical scenario of these patients is similar to schizophrenia, showing hallucinations (Li et al., 2021).

The main psychiatric sign is cognitive decline, which starts much earlier than the motor symptoms. However, in some patients, cognitive changes can be very soft, even in the late phases of the disorder (Wilton et al., 2023).

These patients also show secondary symptoms that are dramatically debilitating. These include unintended weight loss that probably results from decreased appetite as well as difficulty handling food and swelling but can also come from hypothalamic neuronal loss. Moreover, sleep disturbances and dysfunction of the autonomous nervous system can also develop (Arnulf et al., 2008).

Signs and Symptoms of ALS

ALS is described as a rare, incurable and fatal progressive neurodegenerative disease that affects the CNS. This condition involves the degeneration of brain and spinal cord motor neurons, affecting both upper and lower neurons. However, it does not affect sensory pathways or higher cortical functions, such as intelligence and memory. In patients with this disease, the voluntary muscles are disturbed, consequently patients progressively lose strength and become unable to move their arms, legs or even their bodies (Loyola et al., 2022).

Disease onset starts at 58-60 years of age and the average life expectancy of these patients after the development of the first symptoms is around 3-4 years. However, some ALS patients survive for more than 10 years after the development of symptoms. Men are slightly worse affected than women (1.4:1 ratio) (Talbott, Malek & Lacomis, 2016).

ALS patients often develop xerostomia, dysphagia and sialorrhea, which are oral manifestations that affect their quality of life. According to Bergendal and McAllister (2017), dysphagia, characterized by difficulty swallowing, is caused by dysfunction of the oropharyngeal and respiratory muscles due to progressive degeneration of the motor nuclei of cranial pairs IX, X, XI and XII and the corticobulbar tract. As a consequence of oropharyngeal dysphagia, aspiration pneumonia stands out. According to Spataro et al. (2010), this is the leading cause of death in ALS patients.

Sialorrhea is one of the most disabling symptoms in these patients and can be caused by dysfunction in one of two processes - salivary production or oropharyngeal clearance. Excessive saliva production is usually caused by the drugs used to treat the disease. Oropharyngeal clearance can be caused by dysphagia (Loyola et al., 2022).

In addition, changes in the quality and quantity of saliva produced by these patients can affect the integrity of the oral tissues, which makes them more prone to dental caries, periodontal diseases and oral candidiasis. The accumulation of bacterial plaque is also a risk factor for aspiration pneumonia, as well as the presence of halitosis (Bergendal & McAllister, 2017).

Signs and Symptoms of Prion Diseases

Diseases caused by prions have very long incubation periods (many years) and with the onset of symptoms, there is a progressive worsening of the clinical condition, which is most of the time very rapid. The most frequent signs and symptoms are difficulty in thinking and judgment, along with memory problems, apathy, agitation, depression, confusion and disorientation. These patients can also show a decrease in coordination, insomnia, speech problems and vision changes that can reach blindness (Piñar-Morales, Barrero-Hernández & Aliaga-Martínez, 2023).

Moreover, patients with prion diseases usually develop behavioural and psychiatric symptoms. However, these symptoms are usually difficult to evaluate due to the language dysfunction experienced by these patients, which limits their ability to describe the inner experience of psychiatric symptoms (Thompson et al., 2014).

Most symptoms observed in prion diseases are common with other neurological illnesses, making it very difficult to recognize this disease

(Figgie & Appleby, 2021). Moreover, the full group of symptoms is only present in the late stages of the disease.

Diagnoses

The diagnosis of neurodegenerative diseases can be performed using imaging techniques for the detection of neuromuscular tissue alterations. Moreover, biomarkers are currently being used in disease detection, helping in the early detection and follow-up of the treatment (Strimbu & Tavel, 2010).

A biomarker is a molecule or trait that is measured to evaluate the possible presence of a pathology or the responses to therapeutic strategies. Several sources of biomaterial samples can be used for the quantification of biomarkers and, in the case of neurodegenerative diseases, peripheral blood and CSF are the preferred sources. However, although CSF is the ideal sample source to analyse the CNS, lumbar puncture gives an increased risk to the patient, along with discomfort and, consequently, patients feel reluctant towards this procedure. Now, several studies are being done to provide an easier source of quantifiable samples, such as saliva. Several promising salivary biomarkers for neurodegeneration are under study, such as Aβ42, Tau and lactoferrin in Alzheimer’s disease, α-synuclein and DJ-1 in Parkinson’s disease, and chromogranin A in ALS (Farah et al., 2018).

Diagnosis of Alzheimer’s Disease

Nowadays, Alzheimer is mostly diagnosed in the advanced phases of the disorder, when several of the signs and symptoms begin to be present. In 1984, the National Institute of Neurological and Communicative Disorders and Stroke—Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) and the Diagnostic and Statistical Manual of Mental Disorders of the American Psychiatric Association (DSM-IV) defined the first diagnostic criteria for this pathology. These criteria classify Alzheimer's disease as a syndrome, with its diagnosis divided into three degrees: probable, possible and definitive. The last one generally requires confirmation by post-mortem histopathological analysis (Lloret et al., 2019).

In 2011, the National Institute on Aging and the Alzheimer's Association (NIA-AA) established another diagnostic criterion that identified three clinical steps of the disease. It starts with the pre-clinical phase, showing pathological alterations in the brain that may have been going on for decades before the establishment of the disorder, where no obvious clinical symptoms are present. In this phase, changes in CSF biomarkers and imaging can be observed, although it is not possible to foresee if these individuals will acquire dementia. Mild cognitive impairment is characteristic of the second stage, which involves memory loss without interfering with independence. This stage can or cannot evolve into Alzheimer's disease. The last step is Alzheimer's disease. At this stage, symptoms are sufficient to provoke the patient's inability to be independent (Lloret et al., 2019).

Later, a new classification emerged with the help of biomarkers, the A/T/N system, drawn up by the NIA-AA. This classification is based on a binary system (positive or negative) according to the biomarker being measured. "A" corresponds to the level of an amyloid biomarker (amyloid in positron emission tomography (PET) or Aβ42 in CSF), "T" is the measure of a tau biomarker (hyperphosphorylated tau protein (p-Tau) in CSF, or tau PET), and "N" to biomarkers of neurodegeneration or neuronal damage (18-fluorodeoxyglucose (18FDG) by PET or total tau protein (t-Tau) in CSF). An individual having a positive "A" biomarker is diagnosed as having Alzheimer's pathological changes, and people with positive biomarkers in both the "A" and "T" are defined as having Alzheimer's disease. Although it is not suitable for use in clinical contexts, this classification brings together all the biomarkers. This classification makes it possible to change the idea of Alzheimer's disease from a clinical disease to a biological disease that, in fact, starts long before any symptoms appear (Lloret et al., 2019).

Cognitive assessment is carried out using evaluations like the "mini-mental state examination,"which characterizes perception of time and space, registration (by the number of attempts to remember the name of three objects), attention, calculation (through serial subtractions) and memory (trying to remember the name of the three objects), as well as language, writing and reading skills (Santiago, Simões & Pereira, 2008).

To date, 3 biomarkers can be quantifiable in CSF and hence might be useful in the diagnosis of Alzheimer's disease: Aβ peptide, t-Tau and p-Tau. Two isoforms of Aβ peptide are present in extracellular plaques in Alzheimer's patients, the Aβ40 and Aβ42. Aβ42 is responsible for promoting peptide aggregation, tau protein phosphorylation and plaque formation, therefore being more pathogenic than Aβ40 (Simrén et al., 2020).

Increased p-Tau levels are observed in these patients, which is associated with the pathogenesis of Alzheimer's disease. Therefore, p-Tau is a potential biomarker for the diagnosis and evaluation of the evolution of Alzheimer's disease. This protein measurement can also be used to monitor patients during their pharmacological therapy (Zou, Abdullah & Michikawa, 2020).

The combination of decreased levels of the Aβ42 peptide and increased contents of t-Tau and p-Tau in the CSF, is a sensitive, accurate and differential biomarker diagnosis of early Alzheimer's disease (Simrén et al., 2020).

Besides the previously mentioned biomarkers, other molecules may help in the diagnosis of Alzheimer’s disease. One of them is lactoferrin, an antimicrobial protein present in saliva, that has defensive functions against bacteria, yeasts, fungi, viruses and protozoa. This protein is able to attach to iron and Aβ and it has been seen to increase the expression of the lactoferrin receptor in the neurons and capillaries of patients with neurodegenerative diseases. It has been observed that patients in the preclinical stage of this disease have decreased levels of salivary lactoferrin and, hence, this could be used as a potential biomarker for the diagnosis of individuals with early phases of this pathology (Bermejo-Pareja et al., 2020).

Neurotransmitters levels, such as taurine or histamine, can also be used as biomarkers of cognitive changes. Patients with dementia, including Alzheimer’s disease, have shown reduced taurine levels in saliva. By being a glutamate receptor agonist, taurine has a neuroprotective role, preventing Aβ peptide neurotoxicity (Rafiee, García-Serrano & Duarte, 2022). On the other hand, salivary histamine is higher in dementia patients (Figueira et al., 2016). In fact, pathological changes in the histaminergic system are associated with cognitive changes.

Another parameter that can show changes in dementia is the activity of acetylcholinesterase (AChE) in peripheral body fluids. However, although some studies report a decreased activity of that enzyme in plasma and CSF, other studies did not detect considerable changes. These differences can result from different sampling methods (Liang & Lu, 2019).

AChE is responsible for the conversion of the neurotransmitter acetylcholine into acetic acid and choline. During the initial phases of Alzheimer’s disease, cholinergic neurons, crucial for memory and learning, are destroyed. This leads to a pronounced reduction in acetylcholine in these patients (Nunes-Tavares et al., 2012). Hence, the activity of acetylcholine esterase was proposed as a biomarker of cholinergic potential since it is produced exclusively by cholinergic neurons.

The level of AChE activity in saliva can be indicative of dementia since salivary glands are under cholinergic innervation, thus indicating a large connection between enzymatic activity and potential brain cholinergic function. In this way, Bakhtiari et al. (2017) reported decreased levels of salivary AChE.

Patients with dementia usually also demonstrate disturbances in thyroid hormone levels, however, no consensus exists concerning the association between the levels of these hormones and Alzheimer's disease. Recently, Dolatshahi et al. (2023) compared 32 studies and reported that total and free triiodothyronine (T3) plasma levels, as well as total T3 content in CSF, were decreased in Alzheimer's patients when compared with controls.

Another metabolite, C-reactive protein (CRP), is associated with the presence of neurodegenerative diseases, being used asa biomarker of chronic inflammation. It is believed that Aβ plaques can trigger the conversion of the polymeric form of CRP into monomers. Slevin et al. (2015) concluded that the upper content of monomeric CRP was linked with decreased production of βA/tau protein, which highlights a possible role of monomeric CRP in dementia development.

Most patients with neurodegenerative diseases show higher plasma content of CRP, resulting from inflammation that triggers neurodegeneration. However, so far, no consensus about this relationship with Alzheimer’s disease exists. While several researchers observed a consistent association between high CRP levels and Alzheimer’s disease and cognitive impairment, other works did not find that connection. Instead, the link between CRP and Alzheimer´s disease or any kind of mild cognitive disability was not observed. Moreover, diverse studies have stated the presence of an inverse association (Gabin et al., 2018). These data observed decreased CRP in patients with established Alzheimer´s disease.

Diagnosis of Parkinson’s Disease

The accuracy of the diagnosis of Parkinson's disease depends on the professional's experience in identifying the cardinal signs as well as the associated symptoms, especially in the first phases of the disorder. Besides the expertise of the health professional, other factors can influence the diagnosis, such as the duration of the disease and the age of the patient

(Postuma et al., 2015). Therefore, these patients require careful anesthesia and a clinical examination inherent to their physical and psychological problems. At an early stage, the signs and symptoms are difficult to identify and go unnoticed due to the normal changes of ageing.

To diagnose Parkinson's disease, it is necessary to take into account the presence of the following symptoms: tremor, rigidity and bradykinesia, usually with an asymmetrical onset. Postural instability, although also considered a cardinal sign of the disease, is not used to make the diagnosis as it usually manifests itself mainly in more advanced stages. The absolute diagnosis of this pathology can only be ensured by autopsy, where between 75% and 95% of diagnoses are confirmed (Postuma et al., 2015).

Biomarkers show great potential in the way they can reflect the pathogenesis of Parkinson's disease. The samples that are easily accessible from a clinical point of view are CSF, blood, urine and saliva. Potential biomarkers for Parkinson's disease are α-syn protein, DJ-1 protein, cortisol, insulin, urate and complement proteins. The most tested biomarkers are α-syn and the DJ-1 protein (Ren et al., 2015).

α-Syn is a small protein present in high levels in presynaptic terminals. This protein has a very important participation in the pathogenesis of Parkinson's disease since it is the main constituent of Lewy bodies and is present in biological fluids such as CSF, saliva and blood. Blood α-syn content is higher in the brains of Parkinson's disease patients than in controls. Salivary levels of α-syn in these patients are lower than in healthy individuals (Atik, Stewart & Zhang, 2016).

DJ-1 protein can assume an antioxidant and transcriptional regulatory role but also acts as a stress sensor, increasing in situations of oxidative stress. The quantification of DJ-1 and the investigation of structural alterations, such as its oxidation, could serve as useful biomarkers in the diagnosis of Parkinson's disease. One study found that CSF DJ-1 levels in these patients were higher in the first stage of the disease; thus, this protein can possibly be used as a potential biomarker in the early phases of this pathology (Saito, 2014).

Another possible biomarker of this condition is cortisol, since high cortisol levels have been reported in patients with depression, anxiety or Parkinson's disease. Cortisol secretion may be altered by physiological stress, a very common non-motor symptom observed in Parkinson's disease. One study showed that salivary cortisol levels were increased in Parkinson's disease patients than in controls (Törnhage et al., 2013).

Urate, the anion of uric acid, is present intracellularly in all body fluids. Urate is produced by the action of xanthine oxidoreductase, which oxidizes hypoxanthine to xanthine, which is further converted into urate. Uric acid may play a protective role in brain cells, functioning as an endogenous antioxidant. Since it is strongly present in the brain and blood, it can diminish oxidative stress since it can suppress reactive oxygen and nitrogen species (Lotankar, Prabhavalkar & Bhatt, 2017).

The serum level of uric acid was found to be decreased in Parkinson's disease patients, and this finding was more pronounced in males than in females. In this way, uric acid levels may be used as a biomarker of Parkinson's disease (Lotankar, Prabhavalkar & Bhatt, 2017).

Studies point to the association between CRP and the pathogenesis of neurological disorders as being considered a risk factor for Parkinson’s disease. Several studies revealed that CRP content in the blood and CSF was considerably elevated in Parkinson´s disease patients (Qiu et al., 2019). Hence, CRP can be considered a risk factor for Parkinson´s disease, leading to an inflammatory response that correlates with motor and non-motor severity in these patients.

Diagnosis of Huntington’s Disease

Usually, the diagnosis of Huntington’s disease is done using a combination of tests and other information, including medical history, neurological and laboratory tests, brain imaging, and genetic testing. The primary diagnosis of this condition involves patient answers to questions, a physical exam, an analysis of family medical history, as well as neurological and psychiatric exams. The neurological exam includes tests on motor symptoms, such as reflexes, balance and muscular strength, sensory tests (sense of touch, vision and hearing) and the existence of psychiatric symptoms (mood and mental condition). Simple tests will be used to evaluate the patient's memory, reasoning, mental agility and language.

The psychiatric exam includes an analysis of the emotional state, patterns of behaviour, judgment capacity, signs of disordered thinking and possible drug abuse. Brain-imaging tests may also be required, giving important information concerning possible changes in the brain, characteristic of Huntington’s disease. Later, diagnosis is normally confirmed by genetic testing, through the identification of an increased CAG repetition number in the huntingtin gene. The detection of a positive result for this condition in an asymptomatic individual can bring strong psychological distress as well as psychiatric morbidity. Prenatal and early diagnosis can be performed (Stoker et al., 2022).

The quantification of Htt and mHtt can also be used as biomarkers for the diagnosis of this pathology. It has been observed that soluble mHtt in CSF is higher in symptomatic individuals than in pre-symptomatic individuals, having a good correlation with the degree of symptoms. Quantification of plasma levels of mHtt can also be a diagnostic method. Moreover, it was observed that saliva also contains increased amounts of total Htt in Huntington's disease patients (Corey-Bloom et al., 2018). So, the quantification of mHtt can help in the monitoring of the applied therapeutics since a decrease in mHtt should be observed (Caron et al., 2022).

Light chain neurofilaments can be quantified in CSF and in blood and constitute the most promising biomarker for Huntington's disease onset and progression. Increased levels of this biomarker in CSF and blood are observed in several conditions, such as Alzheimer, Parkinson, ALS, Huntington's diseases, among others. For this reason, neurofilaments are considered a general marker of neurodegeneration and neuroinflammation (Martí-Martínez & Valor, 2022). Nevertheless, light chain neurofilament allows better discrimination between pre-symptomatic and symptomatic phases than mHtt levels and permits the prediction of the age of disease onset (Byrne et al., 2017).

Another non-specific biomarker of neurodegeneration is tau protein. High amount of total tau in CSF has been observed in Huntington's disease patients (Niemelä et al., 2017).

Physiologically, TNF-α and IL-6 are pro-inflammatory cytokines released into the blood as part of the acute-phase response. Plasma IL-6 concentrations increase in individuals as early as 16 years before the appearance of Huntington's disease. The cytokines showing an earlier increase during the course of this pathology are IL-6 and IL-8, both belonging to the innate immune response (Björkqvist et al., 2008).

The production of CRP is up-regulated in hepatocytes through the regulation of IL-6. Since, in the acute-phase response, the levels of CRP increase, this protein might be regarded as a positiveacute-phase protein. Significant correlations were found between acute-phase protein levels and Total Functioning Capacity (TFC) score, apathy severity, cognitive changes, and the use of antipsychotics. CRP content was increased in mutation carriers who had continuous use of antipsychotics during the follow-up, compared to the group that never used these drugs. This work provides evidence that Huntington´s disease mutation carriers under the use of antipsychotics are prone to triggering an acute-phase response (Bouwens et al., 2014).

According to Sánchez-López et al. (2012), CRP amounts were increased in Huntington´s disease mutation carriers that were in more advanced stages of the condition. Moreover, it has been reported that CRP is increased in Huntington´s disease mutation carriers in the advanced stages of the disorder. However, Silajdžić et al. (2013) found that CRP decreased in the early stages of the disease.

Diagnosis of ALS

The diagnosis of ALS in patients who have a typical presentation of the disease is relatively simple and is based on the identification of signs of degeneration of the upper and lower motor neurons, or in the presence of a progressive worsening of symptoms or signs within a region or to other regions (Masrori & Van Damme, 2020).

The "El Escorial" diagnostic criteria were published in 1994 by the World Federation of Neurology with the intention of standardizing the diagnosis of ALS. In 1998, these criteria were revised to improve the diagnosis, becoming known as the "Revised El Escorial Criteria" or "Airlie House Criteria" (Carvalho & Swash, 2009). These criteria categorize patients into "clinically definite," "clinically probable," "clinically probable with laboratory support" and "clinically possible" ALS. However, these criteria are not suitable for early diagnosis and clinical practice. In 2000, a new set of diagnostic criteria was suggested, called the "Awaji Criteria," increasing the ability to detect ALS patients (Carvalho & Swash, 2009).

The existence of a specific diagnostic or prognostic biomarker would allow big advances in early diagnosis, however, to date, there is no biomarker that is specific for diagnosing ALS. Some molecules, such as chromogranin A and neurofilaments, have been tested and could be potential biomarkers for this pathology (Kaiserova et al., 2017).

Chromogranin A is a glycoprotein present in several neuroendocrine tissues. It is stored in vesicles in the adrenal medulla and sympathetic nerves with catecholamines, being secreted by exocytosis. Studies suggest that the overexpression of this protein speeds up the development of the disease by interacting with mutant SOD1 (Verde et al., 2018). Higher salivary chromogranin A levels were found in ALS-terminal patients than in patients with moderate ALS, vascular dementia and healthy individuals. Higher CSF concentration was also found in ALS patients compared to healthy control groups (Kaiserova et al., 2017).

Neurofilaments are proteins that make up most of the neuronal cytoskeleton, expressed in neurons. Neurofilaments in CSF and in blood have been described as promising biomarkers of ALS since their quantity can be significantly high in ALS patients. Neurofilaments have three subunits that differ in molecular mass (light, medium and heavy chain). Light chain neurofilaments and phosphorylated heavy chain neurofilaments are examples of neurofilaments used as biomarkers. Since they are relatively stable in biofluids, their detection is relatively simple and can be performed by immunological assays (Vu & Bowser, 2017).

Studies found that light chain neurofilament levels were above normal and correlated with the rate of progression of the disease. It was also observed that blood levels of light chain neurofilaments were significantly higher in ALS patients than in healthy controls and asymptomatic patients (Vu & Bowser, 2017).

Moreover, levels of phosphorylated heavy chain neurofilaments in CSF and blood have prognostic use, being useful to determine disease progression and survival. It has been shown that individuals with ALS present higher values of this type of neurofilament in CSF than healthy controls or individuals with other neurodegenerative disorders. On the other hand, higher plasma levels of phosphorylated heavy chain neurofilaments were observed in ALS patients than in healthy individuals, but no differences were found when compared to controls with other neurodegenerative diseases (Vu & Bowser, 2017).

Nakazato et al. (2022) were able to show that some molecules (ribose-6-phosphate, N6-acetyllysine, dyphylline and 3-methoxytyrosine) could give considerable accuracy in the diagnosis of ALS. These metabolites are directly associated with the metabolism of skeletal muscle (fatty acid degradation and creatine metabolism). These researchers also observed that taurine content was correlated with the strength-duration time constant, an indicator of axonal excitability, used to estimate survival. Consequently, blood taurine levels can be a useful biomarker of axonal excitability in ALS.

CRP is a biomarker of inflammatory response and gives a considerable prognosis in various cases of cancer, cardiovascular disease and rheumatic disorders and neuroinflammation as in ALS. Lunetta et al. (2017) stated that, in ALS patients, plasma CRP is associated with the severity of functional changes. These data indicate that if these patients have increased plasma

CRP, the disease will develop faster than in patients with lower CRP amounts.

Moreover, Ryberg et al. (2010) observed considerable increased CRP in the CSF of ALS patients compared to a control group. However, these researchers did not find differences in CRP content between the ALS and multiple sclerosis subgroups. Researchers justify this finding since both disorders involve inflammation of the CNS. Keizman et al. (2009) observed a significant relationship between the clinical incapacity of ALS patients and biomarkers of inflammation, such as CRP. These results favour the possible utility of CRP as an ALS biomarker. However, Nagel et al. (2017) did not find any association between adipokines and CRP and the risk or prognosis of ALS.

Diagnosis of Prion Diseases

It is difficult to diagnose prion disease since it has similar symptoms to other neurodegenerative disorders. Usually, diagnosis is performed by the analysis of the manifested symptoms, medical history, imaging methods such as magnetic resonance imaging that helps to identify changes in brain structure typical of this disease, andelectroencephalography that allows the detection of abnormal electrical activity in the brain of these patients. Moreover, CSF testing for detection of markers associated with neurodegeneration and specifically with human prion disease can also be performed. However, a brain biopsy after death is the only way to confirm the diagnosis of this disease.

Several available biomarkers are non-specific to prion diseases and, for this reason, are preferentially useful as a complementary diagnostic analysis and not a specific disease test. Already studied CSF biomarkers applied in the evaluation of prion diseases include t-Tau and p-Tau, neurofilaments, α-syn, among many others. These molecules are neurodegenerative markers, but some of them do not show increased levels throughout the course of this pathology and are non-specific to prion diseases (Figgie & Appleby, 2021).

Concerning tau protein, Hamlin et al.(2012) found that almost all patients with Prion diseases show t-Tau CSF levels above 500 pg/mL. Moreover, a high t-Tau to p-Tau ratio is specific in a range of 94–97% for the presence of prion diseases (Skillbäck et al., 2014). Levels of tau can help to distinguish prion diseases from Alzheimer's disease, since tau CSF levels were 41 times higher in prion diseases than controls and in Alzheimer's patients only 3.1 times higher (Ermann et al., 2018).

Another biomarker that may be helpful as a screening test is CSF neurofilament light chain. It has been reported that its levels are significantly higher in sporadic prion diseases compared to other neurodegenerative diseases such as Alzheimer. Moreover, similar to tau, CSF neurofilament light chain is usually significantly higher in prion diseases than in other neurodegenerative pathologies (Zerr et al., 2018).

Besides neuronal loss, tissue damage is a characteristic of the advanced phases of prion diseases. When there is damage to tissues, acute-phase proteins are usually present in blood. This is the case of CRP, a molecule present in the acute phase that is an indicator of inflammation and tissue damage. This association can justify the high CRP and IL-6 (CRP inducer) plasma levels in individuals with prion diseases. Fratini et al. (2012) observed significantly higher plasma amounts of different acute-phase inflammatory proteins, including CRP, in sporadic prion diseases than in neurologic and healthy controls.

A diagnosis test that is very sensitive (from 90.3-97.2%) and very specific (98.5-100%) for prion diseases is the second-generation real time quaking induced conversion (RT-QuIC) that is useful in pre-mortem diagnosis in CSF samples (Figgie & Appleby, 2021). This is the first clinical analysis that does not use brain tissue. This method is based on the capacity of the mutant pathological protein observed in CSF to trigger the transformation of the normal protein to the mutant form, which will further associate and form clusters. The production of these aggregates can be followed in real time by the use of fluorescent molecules (Green, 2019).

Work is being done on the application of RT-QuIC to other tissues, like skin, eyes, and olfaction epithelium. Bongianni et al. (2017) reported that the use of RT-QuIC on CSF combined with the same analysis on olfactory mucosa allowed a diagnosis with 100% sensitivity and specificity, and Mammana et al. (2020) observed 89% sensitivity and 100% specificity of RT-QuIC in skin punch biopsies. However, despite the specificity of RT-QuIC, this method is not useful for prognosis and, in atypical prion diseases, shows lower diagnostic accuracy (Figgie & Appleby, 2021).

Since there are some genetic forms of prion diseases, this pathology can also be diagnosed by a genetic test that involves *PRNP* gene sequencing and detection of *PRNP* gene mutations (Figgie & Appleby, 2021). Several mutations have already been identified, including point mutations, octapeptide repeat insertions and deletions, associated with the genetic form of prion diseases. From all the mutations identified so far, the most frequent in the world is E200K (Wood et al., 2022). Another mutation in this gene, R136S, when present in the homozygous state, is responsible for the early onset of prion diseases (Ximelis et al., 2021). This analysis can be very useful to differentiate the genetic form of this condition from the sporadic form, since clinical symptoms are very similar.

Treatment

To date, most neurodegenerative diseases still have no cure. There are treatments available that consist of mechanisms that only alleviate symptoms. Drugs that target a single mechanism are not sufficient to treat neurodegenerative diseases. To be useful, a combination of drugs must have different properties, such as controlling the formation of ROS, decreasing the deposition of Aβ peptides, regulating enzymes associated with the disease mechanism, metal chelation capacity and increase blood-brain barrier (BBB) permeability. The incorporation of a safe and effective metal chelator into the therapeutic regimen may allow the effective dose of the drug to be reduced and complement its actions (Yang et al., 2019; Leal et al., 2023).

Treatment of Alzheimer’s Disease

Existing therapy for Alzheimer's disease is far from ideal. At the moment, therapy only serves to alleviate cognitive symptoms, such as the behavioural and psychological symptoms of dementia and slow down the progression of the disease. There are several classes of drugs currently approved by the US Food and Drug Administration (FDA) that are used as a therapeutic strategy for this pathology: antidepressants, antipsychotics, benzodiazepines and psychostimulants, anti-inflammatories, antagonists of N-methyl-D-aspartate (NMDA) (memantine), inhibitors of AChE (donepezil, rivastigmine, galantamine and tacrine, which were discontinued) and antioxidants (Mendiola-Precoma et al., 2016).

There is no consensus on a single pathogenic target to be treated in Alzheimer´s disease, with the assumption that a treatment with effective results will need to be able to attack the various pathophysiological targets. Thus, it is understood that there is a need for action on Aβ aggregates, neurofibrillary tangles arising from hyperphosphorylation of the tau protein, neuronal and synaptic loss, as well as all mechanisms that promote the deposition of the Aβ peptide. To treat Alzheimer's disease, it is essential to inhibit the formation of oligomers. It is already known that the Aβ42 peptide is the one with the highest toxicity, even higher than the Aβ40 peptide, and a greater propensity to elicit a self-propagation cascade (Rauk, 2009).

So far, most Alzheimer´s disease therapeutic strategies have centered on limiting the production of Aβ species. However, none of these strategies resulted in cognitive improvement. Therefore, there is a requirement for alternative therapeutic approaches. It has been considered a promising alternative to pharmacologically altering metal ion homeostasis in patients with Alzheimer´s disease. Metal chelation therapy can be very important for complexing accumulated metal ions at the brain level, thus decreasing the neurotoxicity induced by them. While different metal chelators have already been approved for clinical use in the treatment of metal overexposure diseases, including Wilson's disease, lead toxicity and rheumatoid arthritis, no metal chelator has yet been approved for use in the treatment of neurodegenerative diseases. In Alzheimer´s disease, the metal chelators act by chelating metal ions and dissolving Aβ. But they also activate the neuroprotective signalling pathways of cells. The metal chelators can block the formation of ROS and inhibit the aggregation of Aβ (Mitra et al., 2014; Acevedo et al., 2019).

However, the possible adverse effects arising from the removal of essential metal ions from the brain and their low BBB permeability because of their hydrophilic nature are the principal obstacles to the use of metal chelators. Clioquinol (PBT1) and its derivatives reduce metal aggregates in the brain, effectively cross the BBB, chelate metal ions, and inhibit Aβ deposition. Therefore, more research is needed to develop more selective metal chelators that can enter the brain without causing systemic effects (Leal et al., 2023).

Treatment of Parkinson's Disease

Parkinson's disease has no cure. The treatment aims to control the symptoms, considerably increasing the life expectancy of the treated patients. Parkinson's disease treatment strategies can be divided into pharmacological measures, non-pharmacological measures, and surgical treatment. Drug treatment aims to increase the levels of dopamine, which is reduced at the substantia nigra level, while maintaining the range of movement, preventing stiffness and muscle contractions, reducing tremors, and stimulating facial expression and motor activities that involve precision. The pharmacological alternatives currently available for Parkinson's disease are limited to the following options: dopaminomimetics (L-3,4-dihydroxyphenylalanine (L-DOPA or levodopa)), dopaminergic agonists (ropinirole, pramipexole, rotigotine), anticholinergic agents, selective monoamine oxidase B (MAO-B) inhibitors (selegiline, rasagiline, safinamide), catechol-O-methyltransferase (COMT) inhibitors (entacapone, opicapone) and amantadine (Acevedo et al., 2019; Tan, Jenner & Chen, 2022).

The administration of medication is usually initiated when symptoms interfere with the patient's levels of functionality. Levodopa has been used to treat Parkinson's disease since the 1960s and remains the most effective and benchmark drug, although in some individuals the effectiveness of the medication is diminished. By being captured by the remaining neurons of the basal ganglia and transformed into dopamine, levodopa facilitates synaptic transmission and allows partial normalization of dopaminergic transmission in the nigrostriatal system.

The effect of levodopa diminishes over time, and after at least 5–10 years of treatment, half of the patients are refractory to the medication. The effect of levodopa varies over a 24-hour cycle with an active period (ON) and an inactive period (OFF), in which the drug is ineffective. Levodopa can be prescribed alone or in combination with other drugs, such as carbidopa, entacapone and benserazide. These drugs increase the amount of levodopa available in the brain as they prevent its conversion into dopamine in the systemic circulation (Campos, Ribeiro & Garcia, 2018).

Incorporating a safe and effective metal chelator into the therapeutic regimen currently used for Parkinson's disease allows the reduction of the effective dose of the other drugs and complements their actions. The metal chelator has the potential to prevent metal-inducing ROS, oxidative stress and α-syn aggregation (Duce & Bush, 2010; Leal et al., 2023).

Treatment of Huntington’s Disease

Pharmacological interventions can temporarily improve motor control and psychiatric disorders present in Huntington´s disease patients. However, these improvements do not positively modify neurodegeneration mechanisms. Anti-chorea drugs (tetrabenazine or neuroleptics) provide patients with severe chorea, a reduction in constant involuntary movements (Walker, 2007; Kumar et al., 2015).

Tetrabenazine is an inhibitor of monoamine 2 vesicular transport, leading to a decrease in monoamines, specifically dopamine, in the brain. It is used to treat involuntary movements in various pathologies. Drugs that have dopamine depletion in their constitutions lead to late manifestations. These drugs can also cause bradykinesia, rigidity, depression and even sedation. Unlike dopamine receptor blockers, published data document that this drug has never caused tardive dyskinesia, with the first clinical case of use of this drug being described in 1960. Neuroleptics (tiapride and cyamemazine) block post-synaptic dopamine receptors in the mesolimbic system, resulting in the desired effect of antipsychotic action. Blocking dopamine receptors in the nigrostriatal system can result in extrapyramidal motor reactions. Neuroleptics also block adrenergic receptors, central histamine receptors and cholinergic receptors, resulting in other side effects (Walker, 2007; Smith et al., 2017).

Curcuminoids and flavonoids, natural metal chelators, are found in the rural Asian diet. These are thought to be beneficial against neurotoxicity. Curcumin, present in saffron from India, has a wide spectrum of pharmacological action. In recent years, it has been gaining popularity for capturing metal ions and protecting neurons. Epigallocatechin-3-gallate (EGCG), a green tea polyphenolic constituent with metal chelating function, inhibits Htt's misfolding and decreases toxicity. This substance found in berries, cocoa and onions is a catechin with neuroprotective and chemoprotective action. It has iron-chelating properties. However, its applicability needs more research (Mitra et al., 2014; Leal et al., 2023).

Treatment of ALS

Until now, ALS has had no cure. Many palliative, symptomatic, psychological, and patient support measures can be taken. Currently, the only pharmaceutical product approved by the FDA for ALS (riluzole) may increase survival time by 3 months, having no effect on muscle weakness. This drug has at least three properties that can contribute to the effectiveness of the treatment. It inhibits the release of glutamate and NMDA levels in the CNS and stabilizes the inactivity of calcium channels. Adverse effects can be highlighted with increasing doses, such as nausea, vomiting, diarhoea, anorexia, paresthesia, sedation and convulsions. Recently, edaravone was considered effective, with the ability to stop the development of the disease in its initial stages (Jaiswal, 2019).

The treatment of ALS is complex and has changed considerably in recent years. Multiple metal chelators have demonstrated neuroprotective and neuroreparative actions in the case of neurodegenerative diseases like ALS. Metal chelators with components that block iron redox activity and disease progression are a promising neuroprotective strategy. These metal chelators not only attenuate metal levels but also reduce markers of oxidative stress in tissues and reduce neuronal loss and microglial and astroglial activation (Hadzhieva, Kirches & Mawrin, 2014).

It has been shown in several studies that some metal chelators could reverse the reactivity of the mutant SOD1, resulting in protection against loss of motor neurons and a corresponding improvement in life span and locomotor function. Therapeutic mechanisms of action suggest attenuation of metal ion toxicity, decreased levels of metal present in the spinal cord, reduction of lipid peroxidation, decreased oxidative damage and inflammation markers (Acevedo et al., 2019; Leal et al., 2023).

Treatment of Prion Diseases

Although some functions and processes of prion diseases have been clarified, there are still some enigmatic mechanisms in their pathogenesis, which in turn makes the development of really effective therapies very difficult. It is known that neurodegenerative diseases have things in common. One of them is the conformational change of proteins, which appears to be a generic mechanism in the pathogenesis of these diseases. However, transmissibility is a unique aspect of prion diseases (Panegyres & Armari, 2013).

There are several proposals for therapeutic strategies, mainly to avoid converting PrPC to PrPSc, immunotherapy and metal chelating agents. A number of potentially useful drugs (quinacrine, pentosan polysulphate (PPS), tetracyclic compounds and flupirtine) have been used in experimental animal models or in patients in an attempt to alter the course of the disease. Several drugs targeting different stages of disease progression have been developed and evaluated, with some entering clinical trials. Nevertheless, no prophylactic or therapeutic drug for prion diseases has yet been approved (Chen & Dong, 2021).

The involvement of metals (particularly copper, iron, and manganese), oxidative stress and protein aggregation make metal chelation therapy theoretically a good option. This theory is based on the capacity of chelating compounds to sequester metals with redox activity, thus forming a non-toxic and easily excreted metal complex, thus preventing Fenton's activity or reaction from occurring and avoiding possible secondary damage (Panegyres & Armari, 2013; Leal et al., 2023).

Impact on Society

Neurodegenerative diseases, projected to be the second leading cause of death among the elderly population in 2040, are a set of pathological phenomena associated with neuronal degeneration and microvascular dysfunction in the brain, with an insidious onset and progressive decline, compromising cognition and behaviour. According to the World Health Organization (WHO), there are around 50 million people with dementia, a number that could triple by 2050, rising to 150 million. The increase in average life expectancy, in combination with an unhealthy lifestyle, is directly related to new health problems, accompanied by an increase in the incidence of neurodegenerative diseases. In Portugal, it is estimated that by the year 2050, a third of the population will be over 65 years old, the age at which this type of condition will become more common. In addition to age, risk factors such as alcohol consumption, tobacco, an unbalanced diet, environmental pollution and risk conditions such as diabetes and obesity, contribute to a greater incidence of the development of neurodegenerative diseases (Armstrong, 2020).

The cognitive changes observed in neurodegenerative diseases particularly affect executive functions. These patients are unable to organize or plan simple things, losing mental flexibility. These diseases greatly interfere with daily activities like getting out of bed, showering, dressing, toileting, cleaning the house, cooking and eating, making them increasingly difficult. Depending on the type of work the patient performs, motor signals will interfere with their performance, even if psychiatric and cognitive changes are still in the background. Due to their impact on daily life, psychiatric symptoms have a very negative impact on the family.

Therefore, neurodegenerative diseases are a major problem in the healthcare sector, with implications for caregivers and the entire healthcare system. The burden that the disease causes for caregivers is considerable, with an impact on the family, economy and health. Intervention with the family should therefore not be neglected. This is a very demanding challenge that requires all appropriate care for people suffering from dementia, since their behaviour is characterized by aggressiveness and resistance to treatment. To achieve this, it is necessary to aim for appropriate healthcare for an aging population. It is important to monitor the health and socioeconomic conditions of the elderly with an impact on social response, as well as assess the absence or presence of mild cognitive impairment or dementia, identifying risks and protective factors. Advanced age and genetics prove to be inevitable vulnerability factors. Vascular risk factors and certain diseases are preventable agents of vulnerability. Mapping early cognitive, behavioural and emotional signs, which indicate the possibility of decline or dementia, is essential for early treatment (Kada, 2009).

In addition to pharmacological treatments, it is important not to forget non-pharmacological interventions, which must be implemented from the moment of established diagnosis, such as education about the disease, mental and physical exercises and community support, among others, as potential factors of protection. Numerous studies have observed a strong relationship between unbalanced nutrition and the appearance of neurodegenerative diseases. Thus, in recent years, awareness of preventive behaviours through physical and mental exercise and a balanced diet has increased, as has the search for new compounds for the treatment or prevention of neurodegenerative diseases, which has grown exponentially (Polidori, 2014).

Conclusion

The main neurodegenerative diseases, including Alzheimer's, Parkinson's, Huntington's, ALS and Prion diseases, present similarities, such as the aggregation of proteins in the CNS. Nowadays, biomarkers are currently used for the diagnosis of these diseases since they can provide valuable information concerning the possible development of the disease, early detection, the course of the disease, and the effectiveness of the applied treatment. To date, most neurodegenerative diseases still have no cure. There is treatment available, which consists of mechanisms that only alleviate symptoms. New strategies to treat neurodegenerative diseases continue to grow. In addition to pharmacological treatments, it is important not to forget non-pharmacological interventions, which must be implemented from the moment of established diagnosis, such as education about the disease, mental and physical exercises and community support, among others. Neurodegenerative diseases are a major problem in the healthcare sector, with implications for caregivers and the entire healthcare system. The burden that the disease causes for caregivers is considerable, with an impact on the family, economy and health.

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Chapter 15

Avenues of Omics in Cancer: Dimensions of Therapy and Treatment

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Abstract

Cancer is one of the world's most prevalent diseases, posing significant social and economic burdens due to its high mortality rate and complex, multi-step progression. It is a multifactorial disease involving single or multiple abnormalities in DNA, RNA, proteins, and metabolites, which arise from endogenous and exogenous carcinogens or dysregulated biochemical pathways. Cancer research, clinical trials, chemotherapy, combination therapy, and tailor-made drug discovery applications are expanding worldwide. In clinical medicine, the complexity, chemical modifications, and spatial and temporal dynamics at different OMICS levels—such as genomics, transcriptomics, metabolomics, and proteomics—vary greatly but can be integrated or analysed through data analytics and bioinformatics to better understand and gauge cancer. This review primarily focuses on the clinical relevance of single-omics and multi-omics approaches in cancer research, particularly in the molecular analysis of human cancer. Through the use of novel omics technologies, cancer cells can be screened for genes, transcripts, proteins, and metabolites, as well as intricate biological systems and interaction networks in response to environmental changes. This screening leads to the discovery of new drug targets, the development

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of personalized medicines, and explanations of drug efficacy and resistance. Consequently, a holistic understanding of cancer pathology and research is emerging, addressing therapeutic vulnerabilities through multi-omics tools, which has become an area of keen interest over the last few decades.

Keywords: cancer, multi-omics, bioinformatics, proteomics, breast cancer, genomics

Introduction

Cancer is a multifaceted, heterogeneous genetic disease caused by mutations, uncontrolled growth, or changes in cell behaviour that can be congenital, but most often is somatic. The most diagnosed cancer is breast cancer, whereas lung cancer is the leading cause of cancer-related deaths. In 2020, there were approximately 10 million cancer-related deaths and 19.3 million new cases of cancer globally (Karaman and Isik, 2023; Sung et al., 2021). It is estimated that by 2040, there may be 28.4 million new cases of cancer if the current pace of incidence rates continues (Karaman and Isik, 2023; Sung et al., 2021).

The widely accepted cause of cancer includes accumulating genetic or acquired alterations in cells. It initiates tumour development, alterations in tumour phenotype and impels tumour progression (Chai et al., 2021). A number of mechanisms, metabolic pathways and different end products may unravel to the cause of carcinogenesis. As cancer is a multi-encompassing issue, number of thoughts, avenues and research are coming out. The seen or unseen relations and interactions, spatial and temporal heterogeneity of tumours, molecular classification of cancer may be dissected by the use of "OMICS" technologies in medical science by enabling universal stratification of mRNA (transcriptomics), genes (genomics), proteins (proteomics), and metabolites (metabolomics) for biological comprehension (Chakraborty et al., 2018).By using these high throughput technologies, it is possible to accumulate vast dataset, cognition of data, networking of data sets and final data integration on a particular molecule in a single experiment. Gene expression microarrays, single nucleotide polymorphism (SNP), protein arrays and other related assays were developed for cancer-specific biomarker discovery and subsequent applications in prediction of drug response (Dijkstra et al., 2016; Raufaste-Cazavieille et al., 2022). The novel biomarker should be standardized in onco-immunomics analysis and to intervene its applicability and reproducibility in inter and intra-cohort bio samples.

For tailored immunotherapy, OMICS technologies should be multi-layered to grasp biological pathways and uncover the signature molecules underlying complex cellular phenotypes in the tumour microenvironment (Eicher et al., 2020). By targeting specific molecules in aberrant cellular cascades and stimulating or inhibiting them, advancements in OMICS techniques have facilitated the development of treatments for multifactorial diseases like cancer (Yoo et al., 2018).

For proper molecular profiling of cancer, it is essential to pinpoint its multifaceted dimensions and analyse them meticulously using OMICS technologies. Multiple analytical layers of OMICS have revolutionized oncology studies, ranging from tumour site classification to the detailed molecular classification of cancer (pan-cancer), thereby creating a cancer atlas that offers new avenues for therapeutic treatment and precision medicine (Menyhárt & Győrffy, 2021). The previously unrevealed intricacy in tumour architecture and the interactions between the environment and its inhabiting cancer niche have furthered our understanding of specific cancers. All these efforts contribute to defining and characterizing all layers of cancer cells, connecting these cells with fluids, molecules, and the environment through interdependent and interrelated networks of processes. This comprehensive approach provides a detailed landscape of the tumour microenvironment (Meerzaman et al., 2016). By integrating multidimensional OMICS data, drug targets and the best courses of treatment can be identified for specific individuals through computational analysis and bioinformatics techniques.

Cancer is generally a disease of various disrupted pathways, where a population of cells gains a selective growth advantage due to modified pathways that govern their survival, fate, daily maintenance, and genome integrity. In the tumour microenvironment, along with clonal propagation of cancer cells, progressive alterations at the epigenetic and genetic levels result in sustained and permanent RNA-level modifications (Chauvel et al., 2020).

Using bioinformatics analysis techniques in conjunction with next-generation sequencing (NGS) technology has transformed our capacity to examine these genomic alterations in cancerous cells from the ocean of life science databases. The Human Genome Project's completion, mark-worthy feat of global collaborations for Human Genome Project and HapMap consortium has improved our knowledge of cancer, namely the role that DNA mutations in various cancer subtypes, and it has aided in the development and prediction of the effectiveness of various innovative therapies (Dopazo, 2014). Genomics deal with genome infrastructure, mapping and editing of genome, recombinant DNA technology, DNA sequencing and genetic polymorphism analysis. A transcriptome is the precursor of a proteome, which is the addresses through all transcripts, all mRNAs, deep sequencing technologies, to narrow down all genes and pathways that react or counteract according to environment (Kong et al., 2020).The multi-omics integration is a biological analysis approach to culminate all datasets obtained from genomics, proteomics etcto characterise or model out the different or same overlapping pathways, nodal molecules and key components at biological functional level (de Anda-Jáuregui and Hernández-Lemus, 2020). The rationale of doing this is to scrutinize the interactions between the diverse biological layers of the cells and build a system of connections that illustrates the underlying intricacy of cancer.

It is important that cancer causing tumours need to be categorized into genetically similar subgroups, to find relations between different subgroups, to tag this classification with clinical history which allows development of cancer genomic profiling for a better prognosis and effective treatment.

Genomics Integration in Cancer Research

Genomic analysis has contributed to the discovery of major disease subtypes by segregating subtype-specific genetic mutations. Once the subtypes are classified, it becomes easier to implement therapeutic interventions and alter tumour-specific treatment approaches (Duan et al., 2021). Genomics primarily characterizes somatic and germline alterations. The application of genomics has the potential to unravel a host of new oncogenes, mutational loads, caregiver genes, complex mutation signatures, gatekeeper genes, and tumour-specific antigens, thereby pinpointing the tumourigenesis mechanisms and improving the clinical management of cancer patients. This association is mainly established by combining clinical data with genomic data while maintaining ethical relevance in data privacy, preclinical history, and data sharing. The revolutionary evolution from Sanger sequencing methods to Next Generation Sequencing or parallel sequencing technologies has enabled scientists to sequence the genome or exome of interest in a given tissue, thereby creating a mutational landscape and discovering specific genomic biomarkers(Finotello&Eduati, 2018).In addition to providing insight into the underlying mechanisms of tumourigenesis and identifying immune checkpoint regulators/inhibitors, the identification of dysregulated molecular cascades in cancer using genomics may also aid in selecting classes of drugs used in cancer treatment or anti-cancer vaccines (if possible). Genotyping has long been performed using microarrays. The application of genomic profiling in clinical trials can generate big data, which is then analysed downstream by bioinformatics (Frost & Amos, 2018). While DNA microarrays are still in use, next-generation sequencing and whole exome sequencing (WES) technologies are rapidly gaining ubiquity. The challenges are also diverse, including the need for higher computational analysis, skilled analysts, different discrepancies in results between frozen and fresh specimens, high costs, efficacy rates, and longer turnaround times required for effective reproducibility.

Cumulative effects of genomic and epigenetic changes cause oral cancer. This cancer manipulates cell division, propagation, differentiation, tissue invasion, specific immune recognition, and metastasis. Thus, genomics plays a crucial role in understanding the carcinogenesis process, predicting prognosis, and determining treatment modalities in oral cancer (Ribeiro et al., 2016). Genomics is essential for identifying inter- and intra-tumour heterogeneity and detecting minute changes in the tumourigenesis process. Researchers have used high-throughput technologies to illuminate these molecular mechanisms and ultimately improve the lives of those diagnosed with oral squamous cell carcinoma (OSCC). To detect epigenomic biomarkers and classify oral squamous cell carcinoma, genomics studies can trace microRNAs, DNA methylation patterns, DNA sequencing, promoter methylation, and modifications of specific genes (Sachdev et al., 2022; Basu, 2020).

Breast cancer is a heterogeneous disease that is influenced not only by family history but also by distinct cellular and somatic changes, resulting in a spectrum of tumour subtypes. Although 15% of all breast cancer patients have genetic predispositions, hallmark genes like BRCA1 and BRCA2 are also significant contributors. Among all the OMICS studies, genomics research in breast cancer has revolutionized patient treatment (Rossi et al., 2022). The era of genomics in breast cancer research involves identifying individual genes, intergenic interactions, and classifying genes based on polymorphisms and mutations. It also includes identifying susceptible genes (low/moderate/high penetrance), hallmark genes like BRCA1 and BRCA2, and employing NGS and genome DNA sequence analyses. Additionally, this research explores the relation of certain genetic syndromes with breast cancer, epigenetic sequencing, RNA transcription group sequencing (RNA-seq), translatomics-based detection, and genome-wide DNA methylation analyses (Neagu et al., 2023).

Epigenomics Vibes in Cancer Research

The regulation of gene expression and various cellular functions are controlled by acetylation and methylation of DNA. Chemical modifications involved in genome-wide identification (like acetylation and methylation of DNA) through epigenomics widened our knowledge in gene expression regulations and various cellular functions (Zhao et al., 2021).

A major role in the epigenetic silencing (methylation-associated) of tumour suppressor genes can be attributed to the pathogenesis of most cancers. DNA methylation is the best-known epigenetic marker, and different tumour types have been described with this epigenetic change (Zheng et al., 2019). Today's epigenetic drugs, like conventional chemotherapy, are associated with side effects (Mancarella & Plass, 2021). These side effects can vary from patient to patient based on the recommended dosage but can be reduced with lower-dose treatments. A future clinical application of great benefit lies in identifying DNA methylation and histone modifications and curating acetylation and methylation profiles of histones related to cancer. This field can be revolutionized by pharmaco-epigenetics. When comparing tumours to normal cells, second-generation DNA sequencing technologies have been employed to find and detect aberrations in genes and genetic and genomic abnormalities in malignancies (Haghjoo et al., 2020). These approaches have aided in identifying DNA regions with distinct histone marks and differential methylation in the field of epigenomics. To identify abnormalities in tumour cells, new approaches for studying cancer epigenomes must be developed for the proper maintenance of normal chromatin structure. ChIP-Sequencing, chromatin immunoprecipitation (ChIP) assays, and methylation analysis (through whole-genome bisulfite/array-based sequencing) coupled with next-generation sequencing are widely used techniques in epigenomics.

Transcriptomics and Cancer

Transcriptomics is the study of the transcriptome (the complete set of RNA transcripts), including their location, functions, expressions, and degradation under specific circumstances. Transcriptome analysis can be performed to compare the expression and interconnection of numerous genes under various developmental, physiological, or pathological conditions using RNA sequencing or hybridization. This analysis can help identify novel genes, non-coding RNAs, and new splicing variants of known genes, serving as an alternative to genome sequencing (Meerzaman et al., 2016). In the post-genome era, transcriptomics is a high-throughput analytical technique that involves statistical data analysis for single-cell and spatial implementations in cancer research.

This method is primarily used to diagnose and predict cancer by analyzing all transcripts based on tumour gene expression in pathological conditions, profiling messenger RNAs (mRNAs) to reveal the molecular constituents of cells and tissues, discovering and delivering drugs based on disease-specific biomarkers (Kori & Agra, 2018). The transcriptomics technique detects and quantifies all kinds of RNA transcripts, including messenger RNA (mRNA) transcripts, long noncoding RNA transcripts (lncRNAs), small RNAs, and microRNAs (miRNAs). Recent advances in understanding tumourigenesis have led to the discovery of microRNAs, some of which may have diagnostic and prognostic functions (Lu & Zhan, 2018). Microarrays can quantify the relative abundance of mRNA for thousands of genes simultaneously, developing gene models; they were the technique of choice for detecting alterations in cellular mRNA levels in a high-throughput manner. Microarrays, slide sequencing, high-definition spatial transcriptome (HDST), and high-throughput sequencing (HTS) are commonly used to identify genes with differential expression levels between cancerous and normal conditions. These techniques are also used to exhibit spatial transcriptome mapping, even at the cellular level. Enormous sets of transcriptome data are available in numerous databases, which offer facilities for reanalysis through data preparation, meta-analysis, and horizontal data integration to exclude variations.

The use of transcriptomics analyses to identify key genes causing breast cancer, gene regulations, protein-protein interactions (PPI), protein-protein interactome networks, and cellular protein content has become one of the most popular approaches for diagnosing, prognosing, predicting (to an extent), and treating breast cancer, as well as for drug delivery (González-Reymúndez et al., 2017). Spatial transcriptomics (ST) methods can also quantify and visualize transcriptomes in individual histological tissue sections in situ. A method for selecting cell types based on their transcriptome profiles in clinical breast biopsies uses automatic selection of non-malignant, ductal carcinoma in situ (DCIS), and invasive ductal carcinoma (IDC) regions (Croft et al., 2016). Enrichment maps, gene ontology (GO), mechanistic interactions of signalling pathways, and RNA sequencing experiments (RNA-seq) may predict breast cancer progression and aggressiveness. Over the last few decades, transcriptomic profiling of breast tumour samples has emerged as a powerful method in holistic oncology and Onco-OMICS strategies (Barriga et al., 2019). This tool is useful for understanding drug bioactivity, discovering new molecular targets, identifying hallmarks of breast cancer heterogeneity for anticancer therapies, and pinpointing potential genomic biomarkers such as mRNAs and miRNAs proposed for breast cancer subtype classification. It also assesses resistance to therapy and identifies breast cancer patients who might be spared endocrine therapy (Neagu et al., 2023; Kanathasan et al., 2024).

The existence of molecular heterogeneity within Oral squamous cell carcinoma (OSCC) was validated by transcriptome expression profiling; single cell RNA sequencing which also demonstrated variations between samples that belonged to the same Tumour, Node, Metastasis (TNM) stage and between anatomic localizations. A group of small RNAs known as microRNAs (miRNAs) selectively regulates the expression of certain genes and plays a major role in the development of tumours. In OSCC, there are several genomic alterations, up or down-regulated miRNAs, putative driver mutation, copy number variant, PPI network (Rai et al., 2018) for precision medicine. Next generation sequencing and cancer Genome Atlas will also revolutionize this concept.

The Proteomics Approach in Cancer Research

The study of cancer genomics has revolutionized our understanding of tumour biology (development and progression) and clinical management (or to include monitoring treatment responses) of cancer and suggests what may be possible when we understand its genetic code, characterization of the germline and somatic defects, different immune-checkpoint inhibitors or to gauge mutational load (Piroozkhah et al., 2023).In contrast to genomics, proteomics assesses proteins, which are the physiological/pathological active key players. In cancer, the link between mRNA-measured gene expression and the corresponding protein level is complex.

Proteomics techniques (an essential field in molecular sciences) have been used to study all sets of proteins in an organism. It analyses a protein in a variety of complex biological samples or fluids, such as cells, tissue, tear fluid, organ, blood, nipple aspirate fluid, saliva and urine; or the whole organism, to better understand the roles that proteins play in cancer patients. This has improved mechanistic studies on tumour (growth, development and metastasis) cancer screening, tumour prediction, diagnosis, tumour classification and prognosis, as well as made it possible to identify new therapeutic targets (or delivery) and aid in drug development(Raufaste-Cazavieille et al., 2022; Ari, Dioso & Sotunsa, 2023).

It is possible to decode protein structure-functions interdependency, dissect protein expression profiling, quantify both cellular protein (in cells, tissues and individuals) expression levels, protein modifications (if present) and protein–protein interactions involved in signalling networks by using proteomics. Using high-throughput proteomics technology to track the pattern of protein expression in tumour cells presents chances to identify putative clinically applicable cancer biomarkers (Pettini et al., 2021). As a complement to histopathology, oncoproteomics may revolutionize clinical practice, including early cancer diagnosis and screening using proteomic portraits. Many cancer proteome databases have been well established and are being shared globally. Those data (related to biomarkers, target modulators, inhibitors and molecular mechanisms) may be accumulated, processed and analysed through bioinformatic pipelines of data comprehension (along with clinical history) to obtain useful information. A rational modulation of therapy (or to identify responders to specific therapy) based on changes/alterations in cancer protein networks associated with prognosis and drug resistance, real-time assessment of therapeutic efficacy and toxicity, and individualized selection of therapeutic combinations that target the entire cancer-specific protein network (that are continuously altering with respect to environmental variations).

The diagnosis, prognosis, pathogenesis, identification of key proteins and prediction of patients' outcomes (to treatment or to drug resistance and further post treatment management) in BC are still largely based on transcriptomics-proteomics classifications, while current clinical tests, monitoring and treatment decisions are largely driven by protein-level investigation (Rossi et al., 2022). Proteomics involves the identification and characterization of protein subgroups, such as exosome (exosomics), kinome (kinomics), degradome (degradomics), proteoforms, secretome (secretomics), and phosphoproteome (phosphoproteomics) and creation of Human Protein Atlas. Exosomes contain miRNA and proteins related to breast cancer were identified that may be used in diagnosis, revelation of new biomarkers and prognosis of the disease (Neagu et al., 2023).

Functional proteomics (to uncover quantitative and qualitative protein variations) is now used to analyse both basal and phosphorylated proteins involved in carcinogenesis, allowing experts to examine the whole protein complements of cells in tissues and secreted proteins in biofluids (secretomes), such as serum, plasma, sweat, urine or saliva. There is clinical value in the use of proteomics tools in treating OSCC (Rai et al., 2018).

Metabolomics and Cancer Research: Some New Dimensions

A dynamic representation of the metabolic state of a living system is called metabolomics using techniques like Positron emission tomography, proton magnetic resonance spectroscopy, magnetic resonance spectroscopic imaging etc non-invasive methods. With this new omics technology, we will be able to obtain a cross-section of the small molecular weight components in body/biological fluids, organs, tissues, cells, and the entire body at any given time. Metabolome may change with lifestyle, nutrition, treatment and exercises. This way, we can determine the functional state at that particular moment based on the arrangement of molecules (amino acids, small lipids, cofactors, monosaccharides etc), molecule-molecule interactions, regulatory inter-relationships between molecules and their relative proportions(Jung et al., 2021).In addition to reflecting both genetic and environmental conditions, the metabolome is the most fundamental biochemical indicator of biological systems (Kong et al., 2020). Oncology has turned to cancer metabolomics as an important research area, with the potential to provide unique insights into cancer development, tumour metabolism, pattern identification and to develop new therapeutic options (Sengupta et al., 2018).Metabolomics can be seen as complementary to proteomics, transcriptomics and genomics, since it more closely represents cell activities at the functional level(Vucic et al., 2012).Metabolomics techniques involves both targeted and untargeted analysis.In targeted analysis, metabolites are concurrently quantified in one analytical procedure to reveal the role of a specific pathway/molecular mechanisms or molecule in a disease. Untargeted analysis of metabolites facilitates the determination of the metabolic profile of a given sample (Wong et al., 2020).

The metabolome is dynamic, and any alterations in metabolite levels and/or ratios can modify the situation to a pathogenic condition in simple diseases or even in complex diseases like breast cancer and leukaemia (Wörheide et al., 2021). Lipidomics, a subfield of metabolomics, plays an important role in discovering potential biomarkers of tumour pathways in breast cancer cell proliferation, invasion, progression and survival. The altered metabolism of lipids results in altered cell growth, plasticity, survival, and metastasis in cancer. Altered lipid metabolism in breast cancer and resistance to drugs (or medication efficiency), paved new dimensions for lipidomics. Lipidomics can be used as a new diagnostic tool in translational oncology (Zhang et al., 2023).

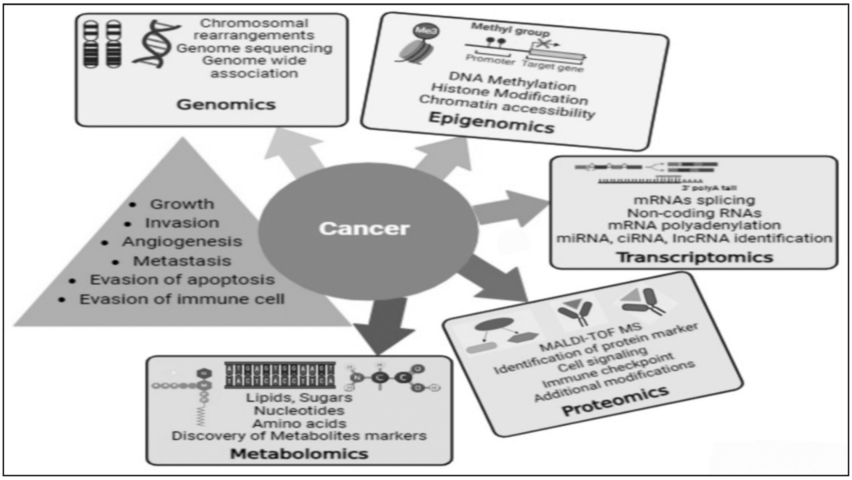
Metabolomics is a promising approach for identifying cancer-specific biomarkers, in cancer surgery and biomarker-based iKnife technology. Oral cancers (like OSCC); leukoplakia and lichen planus may be diagnosed or screened by using the emerging approach of salivary metabolomics (Xu et al., 2020). Saliva is an ideal biological fluid with vast information reflecting the systemic condition of the body.

The Multi-Omics Web in Cancer Research

Cancer is a complex, multifactorial disease involving dysregulation at multiple stages of DNA, RNA, protein, and metabolite networks. These different molecular levels are mutually or antagonistically associated. Multi-OMICS studies provide a deeper understanding of cancerous transformation and carcinogenesis, showing how cancer progression affects the flow of information from one OMICS level to another rather than relying on single-level studies alone (Kaur et al., 2021). Numerous potential novel biomarkers for patient stratification, cancer hallmarks, and therapeutic targets have been identified through multi-OMICS approaches, linking cancer genotypes to phenotypic characteristics or modifications (Arip et al., 2022).

To characterize biological systems at a fundamental level, multi-OMICS employs modern modelling approaches in biology, deep learning networks, and clustering, using multiple high-throughput biomolecular experimental techniques (Figure 1). Multi-OMICS can be applied in drug repurposing, cancer subtyping, biomarker profiling, and tumourigenesis pathway analysis. Identification of clinical subtypes, revelation of biomarker role, individual disease risk prediction, application in clinical studies/clinical trials, application in drug resistance, generation of better drugs, prediction of effective single/combination therapies, increased efficacy in targeted treatments is some of the usage of multi-omics. With the invent of radioomics, computational pathology, digital pathology to dissect tumour immunity has gained popularity. Cancer therapy employing oncolytic viruses, cytokine therapy, antibody-based therapy, immune checkpoint blockades has evolved along with multi omics concept. To grasp the tumour microenvironment, to know the huge diversity of cancer cell subtypes, very intricate single-cell immune-related technologies, single cell sequencing, electron microscopy, spectral flow cytometry, fluorescence microscopy etc may be used to decode different cell subgroups, to classify them in tumour atlas will assist in exploring tumour immunity.

A single study conducted for a specific cancerbased on a definite hypothesis is sometimes insufficient to fully understand the complex pathogenesis of cancer (Eicher et al., 2020). Integration and analysis of individual or multiple data (from various tumour cohort) is essential to cancer research and fits the reality of cancer, which will provide a holistic view of what happened during normal cell to malignant tumour transformation and progression and have the potential to improve targeted therapy and the effectiveness of traditional therapies, in clarification of molecular cascades, cancer therapeutic resistance, discovery of novel biomarkers and targeted drugs.



Source: Raufaste-Cazavieille et al., 2022; Lu & Zhan., 2018, Image created in biorender.com.

Figure 1. Application of Omics in Cancer: Integrate Omics Data by Clustering Algorithms at Each Level to Identify New Drug Targets, Improve Current Therapies and To Discover Predictive Biomarkers.

The huge data depot/repositories like TCGA offer the prospect to reanalyse (or precisely characterize) the omics data (by clustering algorithms) by a pan-cancer method where different spectrum of cancers can be contrasted and gauged in terms of genomic transcriptomic and proteomic profiling (Chakraborty et al., 2018),

Multi-omics is an approach to hypothesis-free revelation of cancer that emphasizes the involvement of a wide range of factors/stages in the development, progression and maintenance of the malignant state, such as genetic aberrations, cancer-specific mutations, epigenetic alteration, identifying altered epigenetic-landscapes, cellular signalling changes, differential expression of mRNA, metabolic changes, protein makeover and many more (Chauvel et al., 2020), (Kori & Agra, 2018). A multi-omic analysis within a systems biology framework makes it possible to explore the complete figure of the different players in tumourigenesis, individual disease risk and tumour establishment more comprehensively usingthe unprecedented power of current high-throughput molecular mechanisms and computational algorithms, machine learning algorithm.

Computation in Multi-Omics: Diverse Applications

The computation method plays central tasks in the analysis of high-throughput experiments of multiomics. Starting from data acquisition, in the management/acquisition of raw files derived from several instruments (simple/high throughput), in the storage and processing of diverse omics information as repository, management of information and lastly arranging all through data model integration or data analysis models, computation plays a pivotal role (Lin et al., 2021). The available computational tools were discussed here.

Method of Data Acquisition and Processing

The acquisition method, processing of data, and manipulation of the vast omics data produced during high-throughput experiments need to be channelled with the help of bioinformatics to obtain the final information required for cancer research (Piroozkhah et al., 2023). As more technologies emerge and complex datasets are generated, it becomes increasingly challenging to process all the information. A workflow must be maintained for proper reproducibility of bioinformatics-generated data at each level. The four basic omics (proteomics, genomics, transcriptomics, and metabolomics) each has their distinct temporal or spatial characteristics. However, when these omics are combined, they provide a thorough picture of the disease, including the complex molecular profiling of involved cells, classification of disease subtypes, identification of regulatory/inhibitory pathways, and analysis of the complex molecular web involved in disease progression, drug response, and bioinformatics data-generated diagnosis/prognosis.To understand cancer and its pathogenesis, it is crucial to pinpoint the key molecules involved, including transcripts, proteins, and genes, and to repurpose drugs. Understanding the molecular basis of signalling pathways helps forecast the phenotypic alterations that occur in normal cells, aiding in the diagnosis and prognosis of cancer (Yoo et al., 2018).

From single omics data, different combination of omics technologies was done. All the layered datasets obtained from experimental designs helped in 3D- modelling of biological processes. At the single omics level, mostly gene expression data were included. Then it was combined with genomics, epigenomics, metabolomics etc .It is necessary to develop unified public repository to access all multi-omics data.

Data Management

The monument of data collected, analysed and derived from different omics platform need to manage and stored. One of the most flourishing repositories to store multi-omics data in cancer is the NIH Genome Data Commons (GDC) data portal. GDC contains a comprehensive genomic dataset. Data can be stored based on assay type (like sequencing, microarray) or based on single omics (genomics, proteomics etc.). GDC contains all data bank spawned fromThe Cancer Genome Atlas (TCGA) project (Wong et al., 2020). TCGA has characterised an array of nearly 20, 000 primary cancers. TCGA is a comprehensive public platform which mainly project on integrative analysis of nearly 30 (or more) different human cancer types. TCGAis a public domain available for collecting different data of molecular alterations in the cancer cells for multi-omics research (Mezhoud, 2020).

TCGA encompasses epigenomic, genomic, proteomic and transcriptomic data for mRNA/miRNA expression, DNA methylation, molecular characterizations of cancer cells, for quantification of single nucleotide variants (SNVs), quantify copy number alterations (CNAs) using high throughput NGS and other related technologies.

TCGA creates a somatic mutational landscape by collecting tumour samples from different patient with varied cancer subtypes. TCGA is pairs with NGS and bioinformatics tools. Challenges of data management include scrutinising the type of data to be stored, process of storing; the policies for public data access, sharing norms, re-use (if any); and long-time archiving policies. The Genome Data Commons mostly contains all the data generated from the TCGA project. TCGA is a public domain to share and access different cancer data but not all data present in TCGA is available or accessible to the public (Lu et al., 2018). TCGA had a huge impact in multi-omics research. As a publicly available repository, it provides the base or platform for different mechanism validation and its proper development (Haghjoo et al., 2020). Several ongoing multi-omics projects have the application of TCGA. Another repository is cBioPortal. In pan-cancer analysis several collaborative projects were coming up to disparate data resources for groundbreaking findings. It involves multi-omics analysis in conjunction with layered bioinformatics and statistical instruments. Comprehensive catalogues of mutational signatures need to be categorised. This opens in recognizing common molecular signatures/markers for the stratification of patients' clinical data along with classification of different cancer types to unravel the intricate of cancer pathology for designing tailor-made cancer subtype therapies (Finotello&Eduati, 2018). This will improve and accelerate scientific discovery, despite ethical drawbacks and technological challenges.

Data Integrations

The inclination towards open data resources in the field of biomedical genomics is imperative to make data available in public archives for better and faster scientific discovery. There should be a paradigm shift from biologically important information to clinically relevant data. Unsupervised data integration creates an unlabelled dataset input, while supervised data integration generates omics data based on available information, phenotype labelling, and gene identification. Ethical and technological drawbacks need to be overcome (Eicher et al., 2020). As omics techniques become available, researchers have integrated them to grasp and visualize a better understanding of cancer pathology holistically. This is achieved by sequentially rearranging omics data, aligning them, and providing biological dimensions based on mathematical aspects. There must be partial or full overlap of at least two omics data. Integration improves the predictive and prognostic accuracy of disease phenotypes in each subtype for better treatment and prevention. It is expected that multi-omics incorporation can provide superior predictive mechanisms than single-molecular technologies because each technology represents just a portion of the whole complex pathological web. Multi-omics data are expected to be valuable for both clinical and basic research, as long as they can highlight biological insights beyond those accessible from simple, minute analytical views (de Anda-Jáuregui & Hernández-Lemus, 2020).

Furthermore, multi-omics concoctions are not necessarily competent of achieving good diagnostic applications. Choosing an optimal omics permutation is not inconsequential, since there are technical and economic challenges in the clinical background in which such diagnostic technologies are to be installed (Chai et al., 2021). Machine Learning Bioinformatics tools play a significant role in the planning of such experimental set-up studies.

Multi-Omics Data Preparations and Representations

Choosing an appropriate dataset that pertain for easy data calculations and manipulation could influence the portrayal of a computational mathematical model and lessen the main impediments to multi-omics data interpretation by improving data science appliances of multiple omics datasets (Pettini et al., 2021).

The Multi-Assay Experiment package presents an eponymous complementary data class to include multi-omics in all experiments. It includes information on different (multi-omics) research, connecting experiments, patients and features in a trilogy. This experiment offers methods and data structures for integrating and representing multi-layered genomic experiments. Manipulation of data was also done to reshape the methods. MultiAssay Experiment was done per cancer type, it demonstrates it simply in conjunction with other public domain multi-omics datasets.

The miss Row, is a R package can be applied to handle missing data. To interpret the missing row values is difficult to ascertain. This multiple factorial packages extrapolate to ascertain analysis values to those missing rows.

The omics Print Package can also be used to offers functionality for cross omic genetic fingerprinting. It assesses data linkage to verify sample relationships through the application of linear discriminant analysis between multiple omics data.

*The STATegRa k*nowledge Base project gives a framework for visualizing multi-omics set of data integration and final analysis. It summarises different types of multiple omics data from different layers on top to form a network graph. The final integration creates *MixOmics*, which is descended from the *integrOmics* project.

The MOSim is a Package technique that suffices methods for the production of synthetic multi-omics datasets. This package simulates multi-omics experiments based on gene expression data to interpolate regulatory interrelationships between them.

Problem in Multi-Omics Data Science

Integrating huge amounts of heterogeneous data (variation in sample, platform and cancer subtypes) is presently one of the major challenges in systems biology, due to the overburden in available data set information (Raufaste-Cazavieille et al., 2022). It is necessary to cluster them according to hierarchy. Multiomics data, though widely used is difficult to apply it in regular practical experiments. The problemof mislabeled and missing samples is a frequent problem in large-scale multi-omics researches. Missing row values for a definite table are hard to manage because major statistical techniques cannot be applied directly to an incomplete dataset. The *missRow* package mostly combines multiple attributions with analysis of multiple-factor to deal with the missing data. The *omicsPrint* method identifies data linkage errors and its relationship with family in extensive multiple omics studies (Kaur et al., 2021).

Exploratory Data Analysis (EDA)

Exploring the nature of the data, analyzing and clustering them is a crucial step in omics. For this purpose, it is probable to use exploratory data analysis (EDA) tools, which acts as a dimensional compass for better evaluations at a further biological modelling step (de Anda-Jáuregui & Hernández-Lemus, 2020). EDA of multi-omics data develops a complex landscape of medicine and its intertwining biology guiding biomedical researchers. Machine Learning is deeply impregnated in EDA is mainly two types a) Supervised, and b) Unsupervised.

Unsupervised learning approaches can endow with a hypothesis-free knowledge of the data behaviour. This will reproduce the nature of the undergoing biology of the disease (Meerzaman et al., 2016). Unsupervised clustering analyses according to hierarchy effort to cluster samples based on the resemblance of their measured characteristics. Multi-omics data interpretation is often done to unravel non-trivial systemic and intricate molecular interactions that are difficult or nearly impossible to see if one relies on a single omics approach. For goal orienting modelling and analysis of biological system, all the datasets obtained from different omics level, need to be visualised. Data visualisation will add 2D or 3D-dimensions to the data set. The main tools for EDA encompass dimension reduction and cluster analysis; both broadly applied to analysis of transcriptomics data (Menyhárt & Győrffy, 2021). While cluster analysis contains of a set of processes for clustering objects into homogeneous groups, based on co-relationships among the samples. To visualize the data, in high-definition form is the main concept of EDA. The dimension reduction is the process of reducing the total number of variables, obtaining a set of variables called "principal." Both cluster analysis and dimension reductions are used in cancer studies, as shown in Table 1.

Table 1. Main cluster analysis and dimension reduction package tools applied to cancer studies

Package Tools	Description	References
OMICsPCA	Omics-oriented tools (R package) for quantitative analysis (PrincipalComponent Analysis) and integration from heterogeneous samples with variation in individuals/samples/cell lines/time points.	Das & Tripathy, 2019.
CancerSubtypes	Contains clustering methods (R package tools) in a standerized workflow for the identification (validation and visualisation) of cancer subpopulations from computing multi-omics data (gene expression, miRNA expression, DNA methylation).	Xu et al., 2017
Omicade4	Developed package for input and analysis of more than two omics datasets. Implementation of Exploratory Data Analysis through multiple co-inertia analysis (MCIA).	Meng et al., 2014
Biocancer	Interactive multi-omics platform using genomic data in a exploratory instrument for multi analysis.	Mezhoud, 2020
iClusterPlus	Integrative cluster analysis combining multiple genomic data	Shen et al., 2009

Source: Pettini et al., 2021.

Together with these dimension reduction and data clustering is also, data visualization is also a significant part of EDA. It is necessary to visualise the data from different angles and perspectives. A network depiction of multi-omics data can improve every facet of the multi-omics interpretation because the functional stage of biological portrayal is fundamentally compiled of molecular interactions.

Conclusion

The advancement in omics technologies results in the repository of enormous data in the field of biomedical research. The availability of such a vast amount of data provides an opportunity to investigate cells, tissues, and organs at multiple levels and to untangle molecular mechanisms for complex pathological conditions like cancer, which is the paradigmatic complex phenotype. A one-step approach of multi-omics, computational modelling, and integration, concoction of bioinformatics channeled from single omics like genomics, proteomics, etc., has been discussed here. With powerful computational tools, one can identify the link between genomic aberrations with differentially expressed mRNAs or proteins, exogenous or endogenous proteins, and metabolites that are related to cancer-driven cellular perturbation. Integration of multi-omics data provides a platform to link the genomic/epigenomic alterations to interconnected transcriptome, proteome, and metabolome networks, which underlie the cellular response to a perturbation. All throughput methods (like next-generation sequencing, ATAC-seq, ChIP-seq), proteomics, genomics, microbiomics, and transcriptomics together constitute a new branch of tumour immunology known as tumour immunomics to comprehend cancer (Figure 1). The dimensions of artificial intelligence, single-cell sequencing to next-generation sequencing have added new edges to tumour immunity. We have aimed to present the current state of the art of computational oncology tools for multi-omics studies of complex cancer phenotypes. We have tried to cover major resources that can provide insight into the application of multi-omics data in the treatment of cancer. Some level of inconsistency lies in multi-omics while integrating data from multiple sites. The field is fast-growing and currently under development, with novel algorithmic approaches being constantly released, but we believe that the present account is a good starting point. The increasing use of artificial intelligence, multi or single omics, bioinformatics may sometimes have serious clinical implications and is a matter of great concern. On the other hand, the decreasing cost (at an exponential cost) of sequencing and the less time required for data acquisition are a boon.

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Chapter 16

The Promising Role of Two-Dimensional (2D) Devices in Smart Healthcare Systems

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Abstract

Smart healthcare comprehensively transforms the conventional medical system, making healthcare more effective, convenient, and personalized. This can be achieved by utilizing new information technologies such as the Internet of Things (IoT), big data, cloud computing, and artificial intelligence. The employment of nanomaterials for biosensing applications has garnered major attention in the smart healthcare sector. In light of this, the present chapter focuses on the emerging application of 2D-materials-based devices in the smart healthcare sector and their promising role in the diagnosis and treatment of diseases. This chapter begins with an exploration of the evolution of two-dimensional-based architectures. Following this, it delves into the extensive deployment of two-dimensional-based devices in the realm of smart healthcare. The subsequent section provides an in-depth analysis of the challenges and prospects associated with the integration of 2D-materials-based devices in the smart healthcare

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sector. It also offers a glimpse into the future direction of nanomaterials in smart healthcare research. The goal of this chapter is to provide new insights into the extraordinary application of nanomaterials in the study of smart healthcare for scientists, researchers, academicians, and others involved in the health science field.

Keywords: smart healthcare, 2D material, nanomaterials, biosensor

Introduction

Medical advancements took off in the early 1990s, establishing as a major area for medical treatment. Since then, several innovations have taken place in healthcare systems, including the ability to treat patients quickly, provide early and appropriate care, remotely monitor healthcare services, and respond quickly in emergencies (Evans, 2016; Farahani et al., 2020). The primary obstacle encountered in the progression of medical care was the requirement for effective machinery to deliver optimal care to patients. Emerging technology can be leveraged to tackle this difficulty (Farahani et al., 2020; Baker et al., 2017). Smart healthcare is a rapidly growing field that aims to improve the quality of healthcare services by leveraging technology (Zeadally et al., 2020). Often referred to as eHealth or digital health, smart healthcare represents the integration of technology into healthcare systems to enhance the efficiency, accessibility, and quality of healthcare services (Onasanya & Elshakankiri, 2021). This transformative approach utilizes digital tools, data analytics, connectivity, and various technologies to improve patient outcomes, diagnosis of diseases, streamline medical processes, and empower both healthcare providers and patients (Lytras et al., 2020; Mohammadzadeh et al., 2023; Kelly et al., 2020).

The key aspects of smart healthcare include telehealth and telemedicine (Ahmad et al., 2021), the Internet of Things (IoT) (Alshehri & Muhammad, 2020), health information technology (Abdullah et al., 2023), remote patient monitoring (Taiwo & Ezugwu, 2020), artificial intelligence (AI) and Machine Learning (ML) (Mansour et al., 2021), cybersecurity in healthcare (Sreedevi et al., 2022; Alabdulatif et al., 2022), personalized medicine (Volkov et al., 2021) and mobile health (Ahmad et al., 2021; Yousaf et al., 2020).

Telehealth and Telemedicine

Digital communication technologies are used in telehealth to deliver medical services remotely. Telemedicine, remote monitoring, and virtual consultations are a few examples of this (Haleem et al., 2021). Besides, telemedicine is known as a subset of telehealth, specifically focusing on clinical services provided at a distance, such as virtual consultations with healthcare professionals. Telemedicine can provide a much-needed solution to the inaccuracies and disorganization of traditional patient records. In addition, it can reduce the patient's requirement for transportation and get beyond any correspondence obstacles that many rural healthcare facilities encounter during an emergency (Gajarawala & Pelkowski, 2021). The five fundamental types of telemedicine are classified as real-time or synchronous telemedicine, store-and-forward or asynchronous telemedicine, self-testing or remote monitoring, health expert to patient and health expert to health expert (Chellaiyan et al., 2019). In order to minimise direct human-to-human contact and decrease the likelihood of infection, telemedicine has emerged as a vital tool during the epidemic. Telemedicine has evolved from providing necessities such as masks and hand sanitizers to offering tele-ICU care (Sageena et al., 2021). In the midst of the COVID-19 pandemic, where physical interaction poses a risk, people are turning to telemedicine as a safer alternative. By utilizing video conferencing and other virtual technologies, medical visits can be reduced, saving both the patient and healthcare provider time and money on treatment costs (Haleem et al., 2021; Purohit et al., 2024).

Health Information Technology

This involves the use of information technology to store, manage, and exchange health information. Electronic Medical Records (EMRs) and Electronic Health Records (EHRs) are key components that facilitate the seamless sharing of patient data among healthcare providers (Quinn et al., 2019). Health information technology contributes to bettering patient experiences, quality of care, and health outcomes. This is achieved by providing patients with access to the latest evidence-based clinical guidelines and resources, enhancing the safety and quality of care, helping patients manage their health, coordinating care among multiple providers, and eliminating the time-consuming, paper-based referral process that can burden organizations and practices (Jen et al., 2017).

Internet of Things (IoT)

In recent years, the use of modern healthcare systems has increased due to rising disease rates and population growth. Providing exceptional healthcare services to hospital staff and patients is challenging due to the lack of accessible and affordable traditional healthcare systems. In response to this challenge, researchers have developed computerized health systems that incorporate IoT devices such as wearable fitness trackers, smartwatches, and connected medical devices (Lu et al., 2020; Dadhich et al., 2022). Real-time monitoring of patients' health metrics by these devices provides data for preventive care, chronic disease management, and early health issue detection (Abdulmalek et al., 2022). Wired or wireless sensors can acquire patient data securely, allowing physicians to access information and make informed decisions. IoT devices including Bluetooth, ZigBee, Z-Wave, WiFi, and Radio frequency identification (RFID) allow devices to communicate with one another and with each other by sensing, visualising, collecting, and sharing data (Pons et al., 2023). The use of IoT in the medical field has grown in popularity as a result of contemporary strategies like smart gadgets, smart regions, and smart cities. Everyone benefits from IoT applications in the healthcare industry since they save costs, extend therapy duration, and offer remote medical assistance. Numerous researchers have put into practice a range of smart health technologies, including automated insulin delivery (AID) systems, drug interaction monitoring, remote care biometric scanners, smart thermometers, sleep monitoring, and more.

Machine Learning (ML) and Artificial Intelligence (AI)

AI and ML algorithms are increasingly being used in healthcare to assist with tasks such as diagnosis, disease outbreak prediction, and personalized treatment plans. These technologies can analyse vast amounts of healthcare data to derive insights and improve decision-making (Alowais et al., 2023; Poddar, 2022). ML algorithms are advancing rapidly in various fields due to their advanced ability to detect and classify objects. ML is important to smart healthcare because it improves services through early-stage prediction, accurate diagnosis, precise discoveries and illness analysis (Javaid et al., 2022). However, managing and classifying amounts of digital medical data presents numerous challenges that need to be overcome. Nonetheless, ML algorithms can provide solutions to different healthcare problems. Applications of machine learning (ML) in smart healthcare include robotic surgery, cancer detection, oral disease detection, tailored medication, medical image diagnosis, and more (Saba Raoof & Durai, 2022). AI-based solutions are used by governments and healthcare policymakers to forecast and control illnesses and outbreaks. One illustration of this is FINDER, a machine-learning model that uses anonymized and aggregated web search and location data to diagnose foodborne diseases in real time (Sadilek et al., 2018).

Remote Patient Monitoring

Utilizing connected devices to monitor patients' health outside of traditional healthcare settings has become increasingly popular. This is especially beneficial for individuals with chronic conditions, as it allows healthcare providers to track vital signs and intervene as needed. Proposals have also proposed remote patient monitoring, such as a smart home healthcare support system (ShHeS), to monitor patients' health status and receive prescriptions from doctors while at home. Furthermore, doctors can diagnose ailments using data collected remotely from the patient. An Android-based mobile application that interfaces with a web-based application has been implemented for efficient patients-doctors dual real-time communication (Taiwo & Ezugwu, 2020). The device incorporates sensors to automatically record the patients' physiological health indicators. Additionally, we have integrated a hyperspace counterpart to context into the existing monitoring framework to enhance system efficiency and obtain precise physiological parameter readings in the home environment, enabling service discovery and context change. With the help of the suggested solution, patients can live more comfortably and have their homes monitored remotely by using certain phone-based smart home automation functions (Taiwo & Ezugwu, 2020).

For effective dual real-time patient-doctor communication, an Android-based smartphone application that communicates with a web-based application has been designed (Kalaiselvan et al., 2021). A new system has been developed to improve remote monitoring of patients from their homes. The system includes a hyperspace analogue to context, which helps monitor service discovery and context changes in the home environment. This allows for accurate readings of physiological parameters and improved system performance. Additionally, the system incorporates features of smart home automation devices that can be accessed through patients' phones, making their lives more comfortable (Rahman et al., 2023).

Blockchain in Healthcare

Blockchain technology has also been researched as a means of improving health data privacy and confidentiality. It ensures data integrity and transparency by providing a decentralised, secure mechanism for transferring and storing medical records. Blockchain healthcare refers to the application of distributed ledger technology (DLT), often known as blockchain technology, to a range of healthcare-related applications (Badr, 2019). Numerous facets of the medical sector stand to gain from the decentralised, irreversible, and transparent financial and data transactions made possible by blockchain technology (Abu-Elezz et al., 2020). Blockchain technology in healthcare can help manage the pharmaceutical supply chain, enable the safe transmission of patient medical records, assist researchers in interpreting genetic codes, and reduce inefficiencies. Blockchain technology has applications in healthcare that include managing the pharmaceutical supply chain, enabling the safe transmission of patient medical records, assisting genetic code researchers, and reducing bureaucracy and inefficiencies. (Liang et al., 2023). Blockchain healthcare can also improve the quality of care and democratize patient data by removing the middleman.

Mobile Health (mHealth)

Formerly, the most cutting-edge field for the digital revolution of healthcare was thought to be mobile health or mHealth. The "m-Health Schism," or the division between mobile health capitalism and the science of mobile health, was brought about by the introduction of smartphones and the worldwide commercialization of m-Health (Istepanian, 2022). This division resulted in a gap between the markets' perception of the health and patient benefits of m-Health and rising levels of inequality in m-Health worldwide. M-Health refers to the use of mobile devices, such as tablets and smartphones, to support the delivery of healthcare services employing mobile-based behavioural health treatments, SMS reminders for medication adherence, and health apps (Heneghan et al., 2021).

Personalized Medicine

An amazing potential to enhance specialised healthcare for every citizen is presented by personalized medicine. Smart healthcare strives to establish individualised treatment regimens that are more effective and have fewer adverse effects by customising medical care to each patient's unique traits, including genetic information, lifestyle factors, and other data (Bohr & Memarzadeh, 2020). Precision medicine makes personalization of care possible through a variety of data collection and analytics techniques. High-throughput genotyping and the broad usage of electronic health records have given researchers an unprecedented opportunity to leverage clinical and biomarker data from real-world settings to find novel phenotypes. These phenotypes could confirm the necessity for further therapies or help with the diagnosis of disease variations when paired with information from electronic health records (Johnson et al., 2021).

Since digital platforms and networked devices play a major role in smart healthcare, strong cybersecurity measures are essential to safeguard patient data and maintain the integrity of healthcare systems. The use of these technologies in healthcare procedures enhances patient empowerment by enabling them to manage their health more actively and increases the effectiveness of healthcare delivery. But some difficulties must be resolved, including those related to data protection, regulations, the necessity of a comprehensive infrastructure, and interoperability standards.

Types and General Applications of Nanomaterials, Biosensing Application in Smart Healthcare

The growing application of nanomaterials has caused a rapid evolution in the field of biological diagnostics. Because of their small size and large surface area—typically less than 100 nanometers—nanomaterials are materials that have special physical, chemical, and biological properties (Khan et al., 2019). They give sensor platforms more adaptability and they enable switching between various detection methods. Combining several nanomaterials can make use of their unique features and additive synergy for the construction of sensors (Pirzada & Altintas, 2019). Nanoparticles, nanocomposites, nanorods and nanobelts, nanoporous materials, quantum dots, dendrimers, and nanogels are a few examples of common nanomaterials used in healthcare (Paramasivam et al., 2021).

Nanoparticles are occupied as powerful imaging agents, catalysts, and medication delivery devices. For instance, gold nanoparticles are widely used in medical diagnostics (Singh et al., 2018). Potential structures for usage in composite materials as sensors and reinforcing agents include nanotubes and nanowires. For instance, tissue engineering and medication administration both make use of carbon nanotubes (Murjani et al., 2022). Owing to their well-defined architectures and capacity to encapsulate medications, dendrimers and nanoporous materials are used in drug delivery, whereas nanorods and nanobelts are used in sensors (Raha & Ahmaruzzaman, 2022; An et al., 2023). Since quantum dots have special qualities that make them suitable for medical imaging, they are widely employed in diagnostics and imaging (Matea et al., 2017). Besides, nanogels are used in drug delivery owing to a three-dimensional network for drug encapsulation, wound healing, and tissue engineering (Cho et al., 2018).

Biosensing Applications in Smart Healthcare

The importance of biosensors in healthcare diagnostics has grown because of their affordable, dependable, quick, and easy-to-use sensing platforms. There are several benefits to biosensing technology over traditional detection methods that use spectroscopy or chromatography. Biosensors are instruments that use a transducer and a biological component (such as cells, enzymes, or antibodies) to identify and translate a biological reaction into a signal that can be measured (Shanbhag et al., 2023). Because of surface regeneration, biosensors can be fully automated, they exhibit improved repeatability, enable real-time and quick analysis, and frequently demonstrate the possibility of reusing. They offer greater sensitivity, mobility, and faster response times while doing away with the requirement for trained operational people. For instance, diseases like anthrax can now be detected in as little as five minutes instead of two to three days thanks to contemporary biosensors (Wang et al., 2021). Early illness screening is made possible by the use of nanotechnology in biosensors, which recognises disease biomarkers at incredibly low abundance. This can enhance the medical methods needed for routine prognostic testing to track patient diagnosis and follow-up operations. Furthermore, in nations without sophisticated medical facilities, combining nanotechnology and biosensing is essential for point-of-care (POC) diagnosis (Pirzada & Altintas, 2019).

Biosensors are essential for tracking many health metrics in smart healthcare. In smart healthcare, biosensing is essential for monitoring glucose, cardiac biomarkers, cancer biomarkers, infectious illness detection, neurotransmitter monitoring, and wearable biosensors. Biosensors are used in many different aspects of medicine. They are used to track blood sugar levels in diabetic patients, giving real-time information that facilitates blood sugar management (Psoma & Kanthou, 2023). Additionally, cardiac biomarkers like troponin, which are useful in diagnosing myocardial infarction and evaluating heart function, can be found using biosensors (Abensur Vuillaume et al., 2022). Besides, biosensors can identify particular biomarkers linked to cancer, which helps with early detection and tracking of the disease's course (Jainish & Prittesh, 2017). Biosensors can be used to measure neurotransmitter levels, which can shed light on neurological diseases and disorders like Parkinson's disease (Abrantes et al., 2022). Heart rate, temperature, and hydration levels are just a few of the physiological indicators that wearable biosensors can continuously measure and record, giving important information for preventive healthcare (Smith et al., 2023). By providing sensitive, quick, and minimally invasive diagnostics, the combination of nanomaterials and biosensing technologies holds significant potential for enhancing smart healthcare and, eventually, improving patient outcomes.

The Evolution of 2D-Based Architecture in Biomedicine

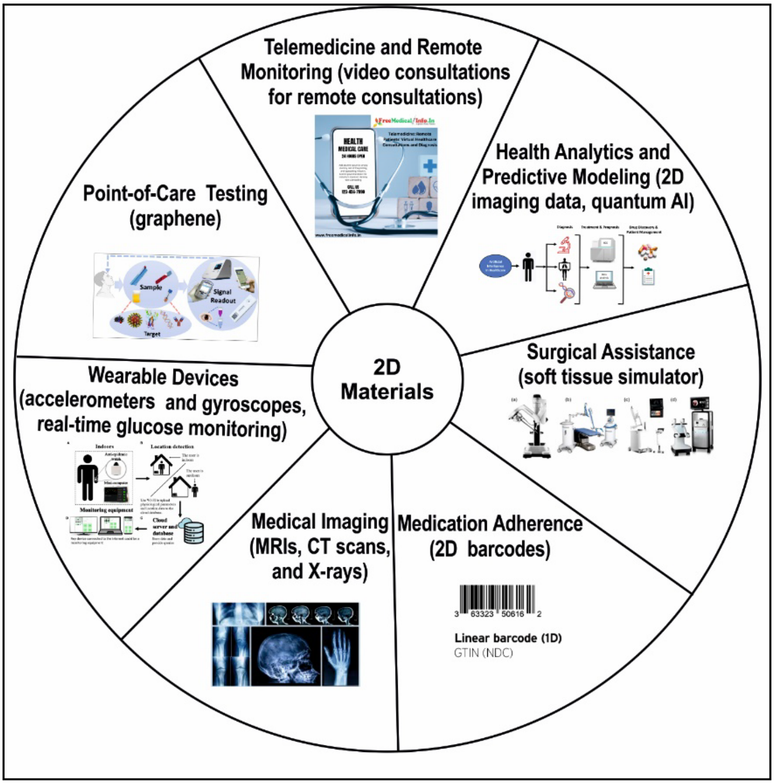
Biomedicine is one of the many fields that has been greatly impacted by the development of two-dimensional (2D) designs, especially in the field of nanotechnology. Due to their special qualities—such as their large surface area, customizable chemical activity, and superior biocompatibility—2D materials have drawn a lot of interest in the biomedical industry (Ranasinghe et al., 2022). For a range of biomedical applications, such as medication delivery, biosensing, imaging, wound healing, and diagnostic platforms, these materials provide adaptable platforms. By offering platforms for focused and regulated medication administration, 2D materials enhance pharmacokinetics and lessen side effects (Davis Jr et al., 2021). The creation of extremely sensitive biosensors for the quick identification of infections, disease indicators, and biomolecules is made possible by functionalized 2D materials (Chen et al., 2023). They also improve the sensitivity and resolution of medical imaging methods by acting as contrast agents in a variety of imaging modalities (Zhang et al., 2023). Furthermore, to encourage tissue regeneration and quicken the healing process, 2D materials can be added to wound dressings (Hada et al., 2022).

Graphene and transition metal dichalcogenides (TMDs) are two distinct examples of two-dimensional (2D) materials possessing unique properties that render them desirable for numerous biomedical uses. Graphene is a single sheet of carbon atoms arranged in a hexagonal lattice with a high surface area, exceptional mechanical strength, and outstanding electrical conductivity. Materials based on graphene can be used as drug-delivery vehicles, offering targeted therapy and controlled release (Khakpour et al., 2023). Moreover, highly sensitive biosensors for the detection of viruses, biomolecules, and cancer indicators are developed using graphene materials (Kulakova & Lisichkin, 2022). Moreover, among other imaging modalities, graphene oxide can be employed as a contrast agent for magnetic resonance imaging and fluorescence imaging (Fusco et al., 2020).

The exceptional electrical conductivity of transition metal dichalcogenides (TMDs), such as tungsten disulfide (WS_2) and molybdenum disulfide (MoS_2), makes them useful in biosensors. They have excellent precision in identifying biomolecules. In order to specifically kill cancer cells, TMDs can also be employed as photothermal agents in cancer therapy (Gong et al., 2017). Nanomaterials based on black phosphorus (BP) are perfect for drug delivery applications since they can load medicines and are biocompatible. BP can be used in cancer therapy because it possesses photothermal characteristics as well (Liu et al., 2021). MXenes are functionalized for application in magnetic resonance imaging and photoacoustic imaging modalities. Owing to their unique properties, MXenes can also be used in tissue engineering and regenerative medicine (Huang et al., 2022). 2D materials are attractive options because of their adaptability in terms of physicochemical characteristics and simplicity of functionalization.

The Deployment of 2D-Based Devices in the Realm of Smart Healthcare

Two-dimensional (2D) devices have the potential to significantly improve patient care, monitoring, and diagnosis in the field of smart healthcare. There is now a great deal more studies on the use of layered two-dimensional (2D) materials in protective coatings and biochemical sensing, among other applications (Bolotsky et al., 2019). These materials are perfect for use as active sensing elements or supporting substrates in a variety of healthcare applications, such as medical imaging, image fusion, smartwatches and fitness trackers, biosensors, continuous glucose monitoring, surgical assistance, health analytics and predictive modelling, telemedicine, and remote modelling (Figure 1).



Source: Bolotsky, A., Butler, D., Dong, C., Gerace, K., Glavin, N. R., Muratore, C., Robinson, J. A. & Ebrahimi, A. (2019). Two-dimensional materials in biosensing and healthcare: from in vitro diagnostics to optogenetics and beyond. *ACS nano*, 13(9), 9781-9810.

Figure 1. The application of two-dimensional (2D) materials in the realm of smart healthcare.

Medical Imaging

Modern 2D imaging methods, such as MRIs, CT scans, and X-rays, may produce high-resolution scans that include detailed views of internal body structures. Image analysis can also be used to detect diseases, tumours, and anomalies early on with the use of sophisticated algorithms and machine learning. Furthermore, integrating 2D images from several modalities such as merging MRI and X-ray images provides a more thorough understanding of the patient's health. These cutting-edge medical imaging methods can be used to diagnose a wide range of critical medical ailments, including neurological disorders, congenital heart disease, complex bone fractures, cardiac diseases, and cancers of various tissues (Hussain et al., 2022). The storing and analysis of medical images in the cloud has become more appealing in recent times due to advancements in information technology and cloud computing (Yan et al., 2023).

Wearable Devices

Wearable sensors have recently attracted attention due to their mobility, ease of use, and real-time health monitoring system. Utilizing 2D sensors like accelerometers and gyroscopes, wearable devices like fitness trackers and smartwatches can detect heart rate, sleep patterns, and physical activity. One can examine this data to look for trends and determine general health as well as facilitate remote patient monitoring. Using commercial wearables, passive and regular monitoring of bodily parameters was recently thought to be a workable approach for non-COVID-19, post-COVID-19 and COVID-19 patients (Khondakar & Kaushik, 2022). Moreover, real-time glucose monitoring using wearable technology using 2D-based sensors might give diabetics important information. Using a variety of technologies, including bioimpedance and electromagnetic, the created wearables have focused on the mouth, skin, eyes, and heart. A few of these systems have been enhanced with machine learning methods, which have produced encouraging results, particularly in the prediction of hypoglycemia (Alhaddad et al., 2022). In particular, the amount of glucose present in tears can be utilised as a proxy for blood glucose levels. Lately, a lot of research has gone into creating smart contact lenses that can continuously check blood sugar levels (Elsherif et al., 2022).

Point-of-Care Testing

"Point-of-care" testing refers to clinical laboratory testing done adjacent to the patient care location, where therapy or care is provided. Point-of-care testing, as opposed to laboratory testing, provides quick test result turnaround, with the possibility to obtain a result quickly so that the right therapy can be adopted, improving clinical or financial outcomes (Larkins & Thombare, 2023). Because 2D materials have special qualities that make them appropriate for biosensing applications, they can be used to create extremely selective and sensitive sensors for identifying particular biomarkers in biological fluids, allowing for quick point-of-care diagnosis. One such material is graphene. Recently, a fibre optic surface plasmon resonance (FO-SPR) portable device was created for the real-time detection of infectious viruses, such as the coronavirus that causes severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Jiang et al., 2023).

Telemedicine and Remote Monitoring

In addition, 2D video technology is frequently utilised in video consultations for remote consultations, enabling medical professionals to visually evaluate patients, offer advice, and talk about symptoms. Healthcare practitioners can receive real-time health data from wearable devices using 2D sensors, allowing for the ongoing monitoring of patients with chronic diseases (Tan et al., 2022). In a previous study, when utilising data from a wearable device worn on the finger, it was shown that the amount of time spent consulting with a neurologist for Parkinson's disease care was much less than that of an in-person clinical assessment (Heldman et al., 2017).

Health Analytics and Predictive Modelling

A more complete picture of a patient's health profile can be obtained by combining 2D imaging data with other medical records as part of data integration, which will help with more informed decision-making. In addition, big datasets produced by 2D devices can be analysed by machine learning algorithms to find trends and anticipate possible health problems, enabling early intervention. Multimodal data can assist medical professionals in tracking a patient's state over time, enabling better chronic illness management and therapy. In order to accelerate conventional training and deliver prompt diagnostic models, more advanced AI technologies, such as quantum AI (QAI), are being introduced into the research area (Al-Antari, 2023).

Surgical Assistance

Additionally, 2D imagery can be included in augmented reality systems to help surgeons by improving precision and offering real-time advice during procedures (Malhotra et al., 2023). Besides, soft tissue deformations are unexpected and controlled, making task automation in robotic surgical systems very challenging. Consequently, having an accurate soft tissue simulator that can interface with robot manipulators is essential. For the interaction of tools and tissues, a unique 2D simulation framework was used, which continuously tracks the manipulator's movements while simulating the deformation of tissue upon impact detection (Han et al., 2020).

Medication Adherence

In medical applications, medication administration is a critical factor in patient safety. The manufacture and expiration dates in particular are crucial. Embedded tags on medical bottles are very desirable for medical purposes as they simplify medication administration. A one-dimensional (1D) barcode is unable to convey the necessary amount of data. RFID and two-dimensional (2D) barcode systems are capable of supporting large amounts of data. 2D barcodes and quick response (QR) codes on pharmaceutical packaging are features of smart pills and packaging that may be read by mobile devices to track medication adherence and offer information on dose directions (Kumar, 2023). The 2D barcodes for vaccines, medical supplies, or pharmaceuticals can help the relevant organisations by promoting an efficient inventory process and by offering vital data for international distribution strategies. Implementing, coordinating, and controlling serialisation requires significant financial outlay as well as a thorough understanding of the relevant regulations (Kumar, 2023).

Additionally, patient education materials utilising 2D visuals and animations can aid in people's understanding of medical diseases, available treatments, and preventive actions (Krüger et al., 2022).

Challenges and Prospects Associated with Integrating 2D-Materials-Based Devices into the Smart Healthcare Sector

The healthcare industry faces opportunities and obstacles when integrating devices based on two-dimensional materials. Finding biocompatible and human-safe 2D materials for medical equipment is a big task. Thorough research is required to determine the long-term consequences of exposure to these materials to avoid any negative reactions or health hazards (Ramezani et al., 2023). Besides, industry standards and regulatory frameworks must be established to ensure product safety, dependability, and quality before 2D materials can be employed in healthcare equipment (Navaz et al., 2021). Besides, the cost-effectiveness of these devices may be impacted by scaling up the production of 2D materials for mass manufacturing, which can be difficult. Therefore, for broad acceptance, scalable and effective production techniques must be developed (Ramezani et al., 2023). Compatibility issues may arise when incorporating devices based on 2D materials into existing healthcare systems, making the seamless integration of new infrastructure and technology with the healthcare system challenging. It is also imperative that 2D materials-based devices have low power consumption and great energy efficiency, particularly for wearable and implantable applications where battery life is a key consideration (Yuan et al., 2022). Besides, Smart medical devices generate and process sensitive health data. Robust data security and privacy protection are necessary for gaining user trust and complying with legal requirements (Ramezani et al., 2023).

The potential for using 2D materials in smart healthcare is evident, notwithstanding the difficulties involved in their use. With the application of 2D materials in smart healthcare, the prospect of usage is highly noticeable. Two-dimensional devices' sensitivity and specificity can be applied to the diagnosis of medical conditions in smart healthcare. Two-dimensional materials with high sensitivity to a wide range of stimuli include graphene and transition metal dichalcogenides. This can be used for very precise and sensitive medical diagnosis (Sulleiro et al., 2022). In addition, 2D materials are renowned for their mechanical strength and flexibility. This qualifies them for wearable and flexible medical equipment, allowing for discreet and pleasant patient monitoring (Vaghasiya et al., 2023). Furthermore, the in-body and implantable applications would benefit from the downsized 2D materials. This may result in healthcare solutions that are more patient-friendly and less intrusive (Hu et al., 2022). Real-time monitoring of physiological data is made possible by the great sensitivity of 2D materials.

This may result in earlier health problem discovery and improved chronic illness treatment. In addition, therapeutic domains where 2D materials can be used include tissue engineering and drug delivery systems. Their unique characteristics can maximise focused pharmaceutical administration and increase treatment effectiveness (Kumbhakar et al., 2023).

The Future Direction of 2D-Materials-Based Devices in Smart Healthcare Research

Future developments in several important areas, leveraging the special qualities of these materials, are expected to drive the direction of 2D-materials-based devices in smart healthcare research. To enhance the sensing capabilities of 2D materials for quicker and more accurate diagnoses, more research is warranted. This can entail creating sensors that are more multifunctional, sensitive, and specialised (Kumbhakar et al., 2023). Besides, improvements in the creation of stretchable and flexible 2D materials for implantable and wearable devices may also result in more long-lasting, discreet, and comfortable health monitoring options. Enhancements in the development of 2D materials that are elastic and flexible for wearable and implanted devices could also lead to more durable, covert, and pleasant health monitoring choices (Silvestri et al., 2022). Machine learning and artificial intelligence are integrated with 2D materials-based devices to facilitate data transmission, remote monitoring, and real-time healthcare analytics. This may lead to better patient outcomes and allow for more individualised treatment (Vaghasiya et al., 2023). The development of biosensors based on 2D materials that can identify particular biomarkers linked to a range of illnesses. Early disease detection and individualised treatment plans may benefit from this (Sun et al., 2022). Apart from this, investigation of 2D materials' potential for energy collection to power self-sufficient medical equipment. This can entail creating technology that draws energy from the environment or the human body to lessen dependency on external power sources (Xu et al., 2021). More investigations are warranted to guarantee compatibility with the human body, lower the possibility of adverse reactions, and increase long-term stability by creating biocompatible coatings and interfaces for 2D materials. 2D materials have the potential to completely transform smart healthcare as research in these areas advances since they provide cutting-edge approaches to monitoring, diagnosis, and treatment methods. To fully utilise 2D materials in healthcare applications, interdisciplinary cooperation and attention to current issues are essential.

Conclusion

Healthcare monitoring and diagnostics could be revolutionised by using 2D materials in flexible devices for smart healthcare systems. Flexible gadgets based on 2D materials have enormous potential to transform intelligent healthcare systems. These devices are ideal for ongoing health monitoring, diagnostics, and potential treatments due to their flexibility, sensitivity, biocompatibility, and energy efficiency. With further advancements in this field of study, the use of 2D materials is probably going to be crucial in determining the future of easily available and customised medical care.

Disclaimer

None.

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Chapter 17

The Preparation of Nanofibers Using Electrospinning and Its Application

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Abstract

Electrospinning is one of the great techniques for forming nanometer-sized polymeric fibers, either hollow or solid. It is one of the most common methods for producing continuous fibers in the nanoscale range. Recently, electrospinning has gained popularity because of its increased application to nanoscale materials and technologies. The main advantage of this technique is its capability to yield polymeric fibers with diameters varying from 2 nm to several micrometers. Electrospinning's low setup costs and ease of use make it an intriguing feature. In 1902 and 1903 Cooley and Morton first patented a new device to spray the liquids under the application of electrical charge. After that Kiyohiko et al. fabricated artificial silk in 1929 using the above device. A high voltage source, a collector, and a syringe pump make up the standard electrospinning setup. Formhals patented a process and apparatus in 1934 that used electric charges to spin synthetic fibers. After thirty years of Formhals' work, Taylor published his research on the behaviour of the polymer droplet at the capillary's end. He discovered that the pendant droplet forms the Taylor cone when electric force balances surface tension. After Taylor's work in 1971, Baumgarten started looking into the effects of changing specific processing and solution parameters. He was able to electrospun the fibers with a diameter ranging from 500 to 1100 nm by adjusting the

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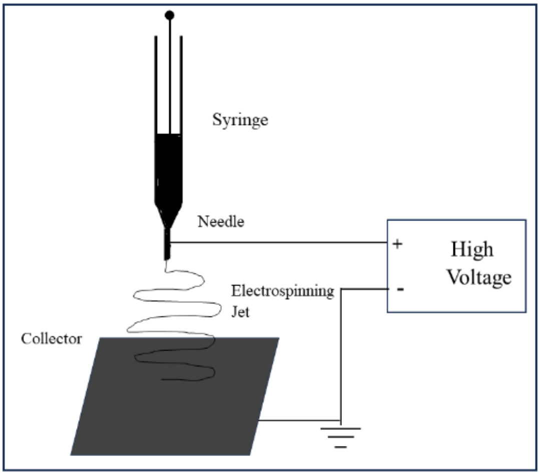
solutions and conditions. After that others were starting to look at the possible uses of electrospun fibrous mats in areas like tissue engineering.

Keywords: electrospinning, nanofibers, tissue engineering, drugs

Introduction

Electrospinning Process

A typical ES setup consists of a grounded collector, a high voltage DC power supply source that injects charges into the liquid and a metal capillary through which the liquid to be electrospun is ejected. A syringe pump is usually used to force the liquid through the capillary forming a pendant drop at the flat tip. The positive electrode of the high voltage source is then connected to the metal capillary (Sill & Von Recum, 2008). After that, the voltage source injects charges into the polymer solution. The attraction forces between the oppositely charged liquid and collector, along with the repulsive interactions among like charges in the liquid, apply tensile forces to the liquid as the electric field strength increases. As a result, the pendant drops at the capillary's tip and grows. The electrostatic forces will reach a point where they balance the liquid's surface tension, leading to the development of the Taylor cone as the electric field strength increases further. If the applied voltage rises above this threshold, the cone's apex launches a fiber jet that accelerates toward the grounded collector. The fiber jet experiences a chaotic bending instability that helps with solvent evaporation and fiber thinning by lengthening the distance and transit time to the collector. Afterward, a grounded collector gathers the solid polymer fibers. Many collector configurations are required depending on the application purpose, such as a revolving drum or fixed plate, can be employed. Using a stationary collector usually results in the formation of a randomly oriented fiber mat. Even though the ES approach is relatively simple to use, there are several processing parameters—both intrinsic and extrinsic—that can have a significant impact on the fiber production, fiber diameter, and fiber shape. Examples of intrinsic parameters include the type of polymer and its molecular weight, the solvent type, the polymer's concentration in the solvent, the viscosity, the solution's electrical conductivity, and its surface tension. The electric field strength, the distance between the nozzle (anode, metallic needle) and the collector (cathode), the solution flow rate, the collector's shape, and its movement are examples of extrinsic parameters. In addition to these, the ES process is also influenced by environmental factors like humidity and temperature.



Source: Munir & Ali, 2018.

Figure 1. Schematic Diagram Illustrating a Standard Electrospinning.

To achieve the desired nanofiber using the electrospinning technique, it is necessary to control certain variables. Solution properties, controlled variables, and ambient parameters are the three categories Doshi and Reneker used to categorize the process control parameters. Viscosity, conductivity, surface tension, molecular weight of the polymer, dipole moment, and dielectric constant are examples of solution properties. The needle tip design, electric field strength, collector-to-tip distance, and flow rate are among the controlled variables. Ambient parameters include temperature, humidity and air velocity. Here, we will discuss the effect of changing electrospinning process parameters and their effect on fiber diameter.

The Effect of Applied Voltage

The applied voltage is the most critical parameter in a controlled variable. When the voltage is low, the needle tip usually suspends the drop, and the jet emerges from the Taylor cone, causing the bead to spin freely. Different applied voltages are required for forming Taylor cones, which are known as critical voltages for different polymer materials. Nanostructures will start to form at the tip of the Taylor cone when the applied voltage exceeds the critical value. A decrease in the Taylor cone's size and an increase in jet velocity at the same flow rate led to the formation of beads with a higher applied voltage and an increase in diameter. Deitzel et al. reported the formation of beads with increasing applied voltage (Deitzel et al., 2001). Deitzel et al. also reported similar findings. Additionally, they reported an increase in the diameter of the nanofibers as the applied voltage increased. Here figure 2 shows the schematic effect of applying voltage on the formation of the Taylor cone.

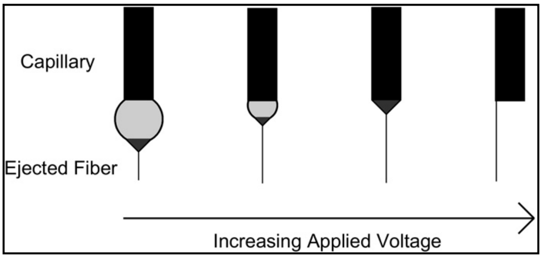


Figure 2. Illustrates How Applying Voltage Affects the Taylor Cone's Development.

Solution Flow Rate

The solution flow rate has a significant impact on the diameter, shape, and porosity of electrospun fibers. According to a study, the polymer solution needed enough time to reach the collector in order to form beadless uniform fiber. For that, a moderate flow rate is required (Zeleny, 1935). An increased flow rate gives higher diameter fiber with the formation of beads (due to an incomplete drying process) on its surface. The high flow rate also led to the formation of unspun droplets and ribbon-like structures.

Capillary–Collector Distance

The separation between the capillary tip and the collector is an important parameter that influences the dimensions and structure of nanofibers.

Varying the distance between the capillary tip and collector can drastically alter the fiber diameter. A smaller distance could form beaded fibers because of the non-evaporation of the polymers, so for that an optimized value of distance is required between the capillary tip and the collector. Often, the electrospinning process fixes an effective spinning distance in the range of 10 to 20 cm. According to Doshi and Reneker (1995), the fiber diameter reduces with increasing distance from the tip to the collector, and the fiber diameter decreases with increasing distance from the Taylor cone. Although a larger fiber diameter with increasing distance is also reported for low applied voltages (Lee et al., 2004).

Concentration of Solution

The concentration of the polymer solution determines whether it can be electrospun or not. The solution must have a high enough polymer concentration for chain entanglements to occur. If the solution is too dilute, then the polymer fiber will break up into droplets and if it is too concentrated, then it is not possible to get fiber because of its high viscosity. Numerous studies have demonstrated that, within an ideal range of polymer concentrations, fiber diameter increases as polymer concentrations rise. For low concentration solutions, polymer droplets will be formed on the collector instead of a continuous fiber. In electrospinning, reducing the molecular weight of the polymer causes more beads to form at the same concentration of the solution, whereas increasing the molecular weight causes smooth fiber to develop. Deitzel et al. reported for the PEO/water study that fibers were not adequately dry at low concentrations of 4%, resulting in the formation of fiber bundles and junctions (Deitzel, 2001). At greater concentrations, we found straight and cylindrical fibers with fewer fiber junctions and bundles. As the solution concentration increased, the electrospun PEO fibers' diameter increased.

Solution Viscosity

Thickness determines the solution's capacity to make nanofibers. Smooth persistent nanofibers can be fabricated at ideal consistency for a specific polymer dissolvable combination. Because of their interconnectedness, it is impossible to evaluate consistency, polymer concentration, and atomic weight separately. For bead free synthesis of electrospun fibers, appropriate solution viscosity is one of the main parameters. Low viscosity solutions are unable to create continuous fibers, and high viscosity solutions are unable to produce the electrical charges necessary to attenuate the solution sufficiently to form fibers. Viscosity increases the number of entangled polymer chains in the solution, transforming the beads' shape from spherical to spindle-like until they form smooth fibers (Jarusuwannapoom et al., 2005). The ideal spinning viscosity is between 1 and 200 poise roughly, while consistent nanofibers can be formed at viscosity levels between 1 and 20 (Bhardwaj & Kundu, 2010). Baumgarten observed that the arrangement of tiny beads had poor drying and less consistency. At higher thicknesses, the fractured drying with polymer caused the beads to collide in midair (Baumgarten et al., 1971).

Surface Tension of the Solution

The degree of cohesive strength between the particles in an arrangement frame is known as surface tension, and it depends on the solvent, polymer, and composition of the arrangement. It is reported that beadless nanofibers can be achieved by reducing the surface tension of the polymer solution and increasing the surface tension causes instability of the fibrous jets. Higher surface tensions lead to the formation of beads as the solvent molecules tend to assemble in a spherical shape. At very low surface tension, the interaction between the polymers and the solvent molecules is greater, causing the solvent molecules to try to spread over the polymer molecules and form a beadless fiber. However lower surface tension is always not favourable to getting the desired fiber diameter in the electrospinning process (Zeng et al., 2003). Therefore, low surface tension materials can be utilized with solvents to minimize surface tension. Yang et al. investigated how solvents affected the polyvinyl pyrrolidone nanofibers and they found that ethanol as dissolvable, generates smooth nanofibers with a reduced surface tension (Yang et al., 2007).

Conductivity and Surface Charge Density

It has been observed that uniform fibers with fewer beads can be obtained by improving solution conductivity. One way to increase the solution conductivity is by adding salt. Alcohol has also been used to improve conductivity and generate smooth fibers. The effect of conductivity plays a vital role in the electrospinning process. An increase in the conductivity of the solution causes a considerable decrease in the diameter of the nanofibers. For the formation of acrylic microfibers, Hayati et al. observed that stable jets could be obtained from semi-conducting fluids by applying sufficient voltage (Hayati, Bailey & Tadros, 1987). In contrast to the original nanofiber, Zong et al. found that after adding salt to the polymer solution, the nanofibers were not only smooth and beadless but also smaller in diameter (Zong et al., 2002).

Solvent Volatility

Because of rapid phase transformation and solvent evaporation due to jet thinning, solvent vapor pressure is a significant factor in determining the drying time and evaporation rate of electrospinning. Because solvent volatility affects the phase separation process, it has a significant impact on nanostructure creation. Lee et al. assessed the impact of the solvent's volume ratio on the morphology and fiber diameter of electrospun PVC fibers. Average fiber diameters decreased as the amount of DMF in the THF/DMF mixed solvent increased. Lee et al. discovered that a crucial element in electrospinning is the solvent's electrolytic character (Lee et al., 2002). It is reported that various THF/DMF combinations lead to significantly lower dimensional microstructures at reduced solvent volatility and distinct nanostructure morphologies at higher solvent volatility (Megelski et al., 2002). In addition, some ambient parameters have a direct influence on fiber diameter such as temperature, humidity etc. Lower solvent evaporation rates at higher ambient temperatures will cause the charged jet to harden more slowly. Additionally, the polymer solution's viscosity drops, which causes the fibers to stretch more and create thinner strands as a result. Moreover, it is also reported that proteins, and enzymes, may lose their functionality at higher temperatures when utilized in electrospinning. The shape and size of the electrospun fibers is influenced by variations in humidity throughout the electrospinning process. Increased humidity during electrospinning causes tiny circular pores to grow on the fiber surface (Casper et al., 2004). Increased humidity levels could lead to the production of fiber with irregular structures. It is found in the report that that at high humidity, water may have collected on the surface of the fibers made from polymers soaked in volatile solvents.

Applications

Fiber meshes and electrospun fibers are frequently utilized in tissue applications, such as vascular, bone, and tendon/ligament. Electrospun fibers are also used in drug loading and drug delivery. Drug delivery and tissue engineering have both shown a great deal of interest in electrospinning in recent years. Fibers having a core-shell shape have been developed as a result of novel nozzle configurations, and these fibers have demonstrated potential in drug delivery applications.

Tissue Engineering

The large surface areas and porosity of nanofibers offer enormous potential for use in the construction of naturally beneficial and mechanically stable tissue platforms. In order to ensure tissue platform fabric biocompatibility with body cells, careful selection is required. The fabric qualities affect the surface chemistry of the platforms, which determines biocompatibility. In recent years, researchers have electrospun natural polymers, synthetic polymers that are both biodegradable and non-degradable, and hybrid mixes of these materials, each with unique mechanical and biometric properties, fiber orientation, and pore size. Tissue engineering applications employ them in blood vessels, skins, bones, brain tissues, and muscles, supporting the regrowth of damaged or diseased cells and replacing lost extracellular matrix. Fibrous scaffolds have improved contact between the cells and matrix, as well as demonstrating an effect on cell-to-cell communication. Regenerative medicine, another name for tissue engineering, is a rapidly developing integrative field of study that uses biology, medicine, and engineering principles to create biological replacements that preserve, enhance, or restore tissue functions. In the last ten years, there has been a focus on nanofiber systems for tissue engineering scaffolds. As a result, a lot of scientists concentrate on creating scaffolds that have nanoscale characteristics akin to those of human tissue. According to a number of studies, it is possible to create large-surface-area electrospun porous nanofibrous structures that closely resemble the natural ECM network (Higuchi et al., 2012; Qian et al., 2014). According to multiple studies, an electrospun nanofiber's high surface area-to-volume ratio makes it a viable option for skin regeneration applications (Hadisi, Nourmohammadi & Nassiri 2018; Mahanty et al., 2020). Researchers claim that 3D dermal replacements based on collagen nanofibers foster a physiological environment for skin cell adhesion and expansion. Excellent cell-growing capabilities have been observed in studies using electrospun nanofiber scaffolds (Friess, 1998). Fibrous scaffolds have improved the contact between the cells and the matrix in addition to demonstrating an effect on cell-to-cell communication (Li et al., 2002). Nanofibers can stop the infiltration of external microbes, facilitate the removal of exudates, and shield injured skin tissue from losing fluid and protein. It is possible to effectively electrospun a variety of synthetic and natural polymeric biomaterials for the purpose of skin regeneration.

Drug Delivery

In medicine, delivering medications in the most physiologically feasible way is crucial. Giving a medication a smaller size and an appropriate coating substance improves its ability to absorb or digest at the intended site. The idea behind targeted drug delivery using electrospun nanofibers is that the rate at which the drug dissolves increase with both the drug's and the carrier's surface area. Numerous research articles have published the advantages of using electrospinning nanofibers as a drug delivery agent. Many medications, including antibiotics, anticancer drugs, DNA, and RNA treatments, widely use electrospun nanofibers due to their large surface area. During the treatment of wounds, electrospun nanofibers may reduce the drug's systemic absorption and negative effects (Cui, Zhou & Chang, 2010). They also preserve the integrity and bioactivity of the drug molecules during drug delivery. You can encase the medicinal compounds by mixing them with polymers, electrospinning them to form encapsulated fibers, or using coaxial spinnerets to create a core shell structure (Yang et al., 2009). Additionally, by changing the fiber diameter and mesh size throughout the electrospinning process drugs release cam be used in various cancerous treatment. Any of these techniques can be useful in delivering a controlled and prolonged release of a medication to the target spot by simply adjusting the drug-release kinetics (Sill & Von Recum, 2008). The electrospinning technology has demonstrated lower toxicity and improved therapeutic efficacy in drug release. The electrospun nanofiber can hold many medications in its fiber. Using the electrospinning method, the effects of biodegradable and non-biodegradable polymers on sustained drug delivery were also examined, however, no discernible variation in the rate of drug release was found (Kenawy, et al., 2009). *Studies on the application of PLGA electrospun nanofiber as a growth factor and calcium apatite* *medication carrier have been published. They concluded that targeted medication delivery at a target place may be accomplished successfully using PLGA electrospun nanofibers* (Haider, Gupta & Kang, 2014).

Nanofibers as Processing Aids

Originally, nanofibers were employed as filtering media and membranes for ultra- and nanofiltration. The large surface area and extremely small fiber diameter of polymeric nanofibers, which result in a high porosity and very small pore diameters, make the filtering of minuscule particles and even molecular separation possible. An especially appealing use is the use of antimicrobial nanofibrous filters to improve the microbiological safety of beverages. Here, microorganisms that would ordinarily pass through the filter are removed mechanically from the beverage system and are inactivated upon contact. The excellent efficiency of the procedure allows for the complete elimination of thermal treatment steps, protecting critical quality components like vitamins and flavors. The commercialization of nanofiber production for filtration has led to the current global production of electrospun nanofibers by over twenty businesses.

Wound Dressing

Polymer nanofibers can be designed for hemostatic devices with specific features and used to treat burns or wounds on human skin. Compared to traditional skin replacements made by freeze-drying, which are architecturally heterogeneous, scaffolds produced by electrospinning are more homogenous. An electric field can be used to create a stringy tangle dressing by directly spraying or spinning a fine fibrous mat of biodegradable polymers onto the affected area of skin. This allows wounds to heal by promoting the normal skin development pattern and preventing the formation of scar tissue, which would occur with a traditional treatment (Coffee, 1998). Researchers evaluated the effects of electrospun and freeze-dried (FD) collagen on cell dispersion, proliferation, organization, and healing of full thickness wounds in thymic mice (Powell, Supp & Boyce, 2008; Nasir & Othman, 2019). They found no significant differences for the parameters mentioned, but ES reduced wound contraction. As a result, there was less morbidity with the skin substitution of ES collagen. Similar to the extracellular matrix, these scaffolds lessen the production of scars by supporting the growth of new, healthy tissue in an injured area. Most of nonwoven nanofibrous film mats used for wound dressings have pores that range in size from 500 nm to 1 mm. A report on produced scaffolds of chitosan-based nanofibers that contain PEO, chitosan, based on the analysis of the biocompatibility data, they concluded that the electrospun composite nanofiber scaffolds encouraged the adhesion of human osteoblastic cells (*Bhattarai* et al*., 2005*).

Electrospun Nanofibrous Scaffolds for Cardiac Tissue Engineering

High conductivity and flexibility heart tissue scaffolds allow them to imitate cardiac functions. The primary cardiomyocytes' spontaneous beating, cell-to-cell contacts, and proper biocompatibility were all improved by the nanofibers. Researchers have developed elastic nanofibers based on poly (glycerol sebacate) (PGS)-zein for use in cardiac engineering. According to their findings, zein improves the mechanical qualities of PGS, and the fibers have the right level of durability and biocompatibility for cardiac engineering uses. Moreover, scientists suggested using elastin to increase the flexibility of nanofibers used in heart tissue engineering. Studies on biodegradable nonwoven PLGA-based scaffolds for electrospun cardiac tissue engineering have been conducted (Dippold et al., 2016). Polyhydroxybutyrate, polycarbonate (PCL), silk, PLA, collagen, and polyamide (PA) were the basis for the synthesis of many scaffolds by Castellano et al. (2014) in order to contrast their qualities as nanofibrous electrospun scaffolds for cardiac regeneration.

Biomedical Application

Conventional electrospun fibers have garnered significant attention for their prospective uses in several fields due to their exceptional features, including their enormous surface area, complicated structure, and ease of manufacture. Almost twice as many patents exist in the fields of filtration, composites, liquid crystal devices, and electromagnetic shielding as there are in other bio- or medical-related fields. The ability of electrospinning fibers to replicate the conditions of the human body is what has drawn so much attention to them in bio-related research. Hierarchical nanofibrous structures make up the majority of human tissues, and electrospun fiber scaffolds have many characteristics in common with these biological structures. As a result, electrospinning has grown in importance in the biomedical industry. But there isn't much utility for traditional electrospun fibers in these kinds of situations. Although one can create fibers with a range of qualities by spinning different materials, these frequently fall short of requirements. As a result, ordinary fibers are frequently nanoengineered to change their characteristics or generate different morphologies. Novel features and uses, including self-healing (Lee et al., 2015) and heat storage (Chalco-Sandoval et al., 2016) have been made possible by the nanoengineering of fibers.

Filtration

In both homes and businesses, filtration is a common method for eliminating solids from liquids or the air. A high surface area to volume ratio, high porosity, and big interconnecting pores are among the characteristics of nanofibers that make them good filters. For almost a decade, polymeric nanofibers have been used in filtration applications. Because of their high porosity and connected holes, which make them highly permeable, nanofibrous membranes offer greater water filtration at reduced energy costs as compared to conventional filtration materials. Microfiltration (MF) and ultrafiltration (UF), two membrane technologies that are widely used to remove more micron-sized and other suspended solid particles from water, are examples of this. The phase inversion approach (Jeong et al., 2007) can be used to prepare these MF and UF, spun studies contrasted the filtering capabilities of an electrospun nanofiber membrane (ENM) made of the same polymeric material with a commercial MF membrane. Micron-sized particle removal may be aided by polysulfone-based nanofiber membrane (Gopal et al., 2006). Through modification of the electrospinning conditions, the pore size can be regulated. A nanofibrous membrane with a fixed pore size has been filtered for different-sized polystyrene particles under the same operation circumstances. These days, nanofiber mats are utilized for air filtering. Given their tiny size, it is clear that nanofiber mats offer superior air filtering efficiency. Up to 800 times less nanofibers are used in filtering than there are in traditional filtration media. The electrospun membranes can filter out any airborne particle with a diameter of 1 to 5 μm by means of adsorption and trapping (Islam et al., 2019). Hospitals require careful attention to air filtration since they are extremely sensitive indoor spaces and want to prevent the spread of viruses and bacteria through circulating air. Nanofiber membrane is one possible indoor air filtering method for this reason.

Nanofibers as Sensors

Because electrospun nanofibers have a large surface area, which eventually increases their sensitivity as a sensor, they offer potential for usage in the creation of sensing devices. Greater surface areas allow for the quick adsorption of analyte concentrations, which increases sensitivity compared to traditional systems. For instance, research has demonstrated that functionalized nanofibers are significantly more sensitive than films when compared to their film counterparts (Wang et al., 2003). A glucose biosensor was developed by covalently immobilizing glucose oxidase on the surface of proteins found on electrospun eggshell membranes (Choi et al., 2001). Over several months, the sensor exhibited remarkable stability. Priority is given to nanorods and nanotubes made of diverse materials, including metals, polymers, carbon, and ceramics, due to their potential applications in a wide range of sectors. Ultrafine nanofibers can be made via electrospinning, and they can then be utilized as a template to make other kinds of nanorods and nanotubes. For example, coatings of nanotube materials on an electrospun nanofiber template can be used to produce nanorods or nanotubes through solvent extraction or thermal degradation of the template. According to studies, ZnO nanowires, which can be employed as a DMS material for spin valve sensors, were prepared by electrospinning (Das & Srinivasan, 2016).

Cosmetics

Electrospun nanofiber membranes are used in face masks, deodorants, fragrances, and antiperspirants, among other cosmetic products. They have been applied as a cosmetic skin care treatment in addition to various additives to treat skin cleansing, skin healing, and other medicinal or therapeutic conditions. These skin masks have a large surface area that allows the ingredients to be transferred to the skin quickly (Huang et al., 2003). For therapeutic or maintenance purposes, electrospun cosmetic skin masks can be applied directly to the three-dimensional topography of the skin, gently, and painlessly. Mangosteen and PVA extracts combined can be electrospun to create a nanofiber membrane that is useful for a variety of cosmetic applications, including anti-aging and medicated soaps (Opanasopit et al., 2008). With or without other ingredients, electrospun polymer nanofibers have been tried as a corrective skin care solution for skin healing, skin cleansing, or other therapeutic or restorative purposes (Smith &

Reneker, 2001). In order to maximize the benefits of the added substance, this nanofibrous skin cover with its vast surface range and remarkably low interstices can promote distant, more conspicuous usage and accelerate the rate of exchange of the added substance to the skin.

Protective Clothing

Research indicates that the primary objective of soldier protection gear is to improve combat effectiveness, sustainability, and survivability in the face of inclement weather, ballistics, biological, and chemical warfare (Nurwaha, Han & Wang, 2013). Breathing apparatus that helps prevent mustard gas inhalation and absorption through the skin, as well as protective clothing with specific functions against chemical warfare agents like sarin and soman, become especially important during wartime for combatants in conflicts and civilian populations during terrorist attacks. There are restrictions on the flammability, additional weight, and air and water permeability of the protective clothes that currently use charcoal absorbents. Consequently, it is ideal to have a fabric that is breathable, light, and transparent to air and water vapor. It should also be highly reactive to deadly chemical agents and nerve gases, as well as insoluble in all solvents. Nanofiber fabrics' large surface area makes them potentially useful for counteracting chemical agents and reducing the resistance of clothing's permeability to air and water vapor (Huang et al., 2003; Sriram, Chakraborty & Prasanna, 2024). Initial studies on electrospun nanofibers have also shown that, in contrast to traditional fabrics, these garments exhibit very little resistance to the transfer of moisture vapor, are highly effective at capturing aerosol particles.

Conclusion

For the past few decades, the electrospinning process has been a promising continuous fiber synthesis technique. Electrospinning is a commonly used method that is easy to use, distinctive, adaptable, and economical for creating non-woven fibers. It is one of the most versatile and promising methods for creating a variety of fibrous forms. Electrospinning can be applied in various ways to blend different materials for diverse tissue engineering morphological characteristics. Several variables significantly affect the size and shape of electrospun nanofibers, including polymer content, viscosity, surface tension, molecular weight, applied voltage, tip-to-collector distance, and solvent. By adjusting these parameters, it is simple to create electrospun nanofiber scaffolds for specific purposes. Numerous potential uses for electrospun nanofiber scaffolds and membranes have been identified. Electrospun nanofibers have applications in fields such as filtration, electrical engineering, biomedical engineering, tissue engineering, textiles, drug delivery, and renewable energy, all achievable through parameter adjustments.

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Chapter 18

Sustainable Credential Management in Midwifery

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Abstract

Credentialing is the process of evaluating midwifery personnel to determine their eligibility for granting clinical authority. This paper provides a literature review on credential management, which plays a crucial role in assessing the feasibility of granting clinical authority. A literature search spanning from 2018 to December 2023 was conducted. The initial search yielded 1,196 articles, which were narrowed down to 28 for analysis based on exclusion and inclusion criteria. Using a qualitative synthesis methodology, we employed an iterative data analysis approach that combines both inductive and deductive processes to identify key themes. The studies reviewed come from a variety of disciplines. Our synthesis of the literature identifies six main themes: (1) Basic concepts of credential management, (2) Basic understanding of competency certification, (3) Competency certification and assessment, (4) Midwifery committees and credentialing

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subcommittees, (5) Credentialing process, and (6) Competence evaluation.

Keywords: midwifery, clinical authority, inductive and deductive processes

Introduction

In the current era of globalization, there have been many changes in science, technology, and people's mindsets. Public demands for high-quality, professional health service delivery is increasing. As healthcare professionals, midwives are also expected to be accountable for providing midwifery services according to their competence and authority, whether independently or in collaboration with other healthcare team members (Gershuni et al., 2023).

Midwives play an important role in achieving health development goals. The World Health Organization (WHO) states that midwives are the "backbone" of efforts to meet global, national, and regional health targets. This is because midwives represent the largest proportion of healthcare workers, continuously serving patients and being at the forefront of health service delivery to communities (Homer et al., 2023).

Achieving high-quality midwifery services requires professionals who are supported by both internal factors, such as motivation to advance their professional careers and personal goals, as well as external factors, including organizational policies, leadership, organizational structure, assignment systems, and coaching programs. To improve the quality of midwifery care and enhance the competence of midwifery personnel, the Midwifery Committee conducts ongoing evaluations and support (Chappell et al., 2021).

The Midwifery Committee is a non-structural forum within hospitals that primarily focuses on maintaining and improving the professionalism of midwifery personnel through credentialing mechanisms, ensuring professional quality, and upholding professional ethics and discipline (Pramono et al., 2022).

One of the key functions of the Midwifery Committee is to improve the professionalism of midwives in hospitals through a credentialing process for all midwifery personnel who provide services in these settings. In performing this role, the Midwifery Committee is responsible for developing the Midwife Clinical Authority initiative. Clinical authority is granted after a credentialing process conducted by the Midwifery Committee's Credential Subcommittee, in collaboration with Mitra Bestari. This clinical authority serves as the basis for the hospital director to assign clinical duties (Mckechnie & McIntyre, 2023).

Credentialing is the process of evaluating midwifery personnel to determine their eligibility for clinical authority. Recredentialing involves re-evaluating midwifery personnel who already have clinical authority to assess the continued feasibility of maintaining it.

To ensure good clinical governance, all midwifery care within the hospital should be performed in accordance with the clinical assignments issued by the hospital director. This guide is expected to be used as a reference for the credentialing and re-credentialing processes for healthcare workers (Vedam et al., 2022).

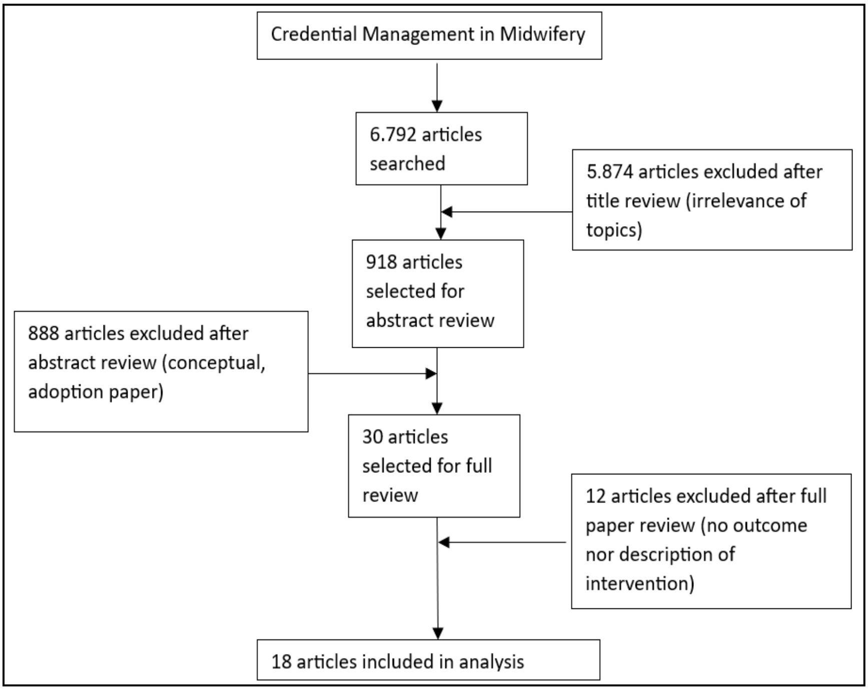

Chart 1. Inclusion and Exclusion Process.

There are some limitations to this study. First, the selection of databases, keywords, and the time frame (years) excluded research available in other databases and journals (see Chart 1). Additionally, there may be selection bias due to unpublished research that was excluded, which could have been relevant to credential management but was not accessible.

The data used in this study were based on online searches using https://app.dimensions.ai/. This database offers a wide range of scientific literature, including journal articles, books, and conference proceedings. Dimensions spans multiple fields and is well-known for its robust data analysis and visualization tools. Its purpose is to provide a comprehensive and integrated resource for academics areas across various disciplines.

Discussion

Basic Concepts of Credential Management

Credentialing, derived from the English term "credential", refers to the process of evaluating midwifery personnel to determine the appropriateness of granting clinical authority. In Indonesia, credential equates to “mandate” (Indonesian dictionary). Credentialing is a process that evaluates both new and existing midwifery personnel to assess their eligibility to perform specific clinical duties (Chaerunnisa et al., 2023).

One of the key responsibilities of a hospital in maintaining patient safety is ensuring that nursing and midwifery procedures are carried out by qualified and competent personnel. This effort involves verifying that all nursing and midwifery actions are performed only by those who have the necessary qualifications and competencies. (Alwahabi et al., 2017).

The competency requirements for midwives and nurses typically include two key components:

1. Professional competency: This includes knowledge, skills and professional behaviour.
2. Health competency: This includes both physical and mental health.

Even if a nurse or midwife holds a specialization certificate from an accredited nursing school, the hospital is responsible for re-verifing the individual’s competency to perform specific nursing actions within the scope of that specialization. This re-verification is part of the credentialing process.

There are two main reasons for conducting this process:

1. **Advances in Knowledge and Procedures**: After receiving professional qualifications, many factors can influence a nurse's or midwife's competence. The field of nursing and midwifery is continuously evolving, and procedures that were once considered standard may become outdated or unsafe. For example, certain procedures may not have been included in early education programs but may later become recognized as essential skills (Damayanti et al., 2020a). Consequently, the competency of a nurse or midwife may differ, even among those holding the same academic degrees.
2. **Changes in Health Condition**: A nurse's or midwife's physical and mental health may deteriorate over time due to aging or illness, potentially reducing the safety of the care they provide. To address this, a fitness test assessing both physical and mental health is conducted as part of the credentialing process.

The credentialing mechanism ensures that healthcare providers are competent and able to deliver safe and effective care. This verification process is not limited to nurses and midwives but applies across various professions to ensure patient and client safety. Once a nurse or midwife is deemed competent through credentialing, the hospital grants them permission to perform specific procedures within their clinical scope, known as **clinical privileges**.

Without clinical authority (clinical privileges), a nurse or midwife is not permitted to perform nursing or midwifery procedures within the hospital. The scope of clinical authority can vary among nurses and midwives, even within the same specialty, depending on the Nursing Committee's evaluation of each individual's competency. If a nursing or midwife's actions endanger patient safety, their clinical authority (clinical privileges) can be revoked, and they will no longer be permitted to perform certain procedures within the hospital. The revocation of clinical authority (clinical privilege) is strictly regulated by hospital laws and guidelines.

Credentialing and re-credentialing mechanisms are the responsibility of the Nursing Committee and are implemented by the Credentialing Subcommittee. At the end of the credentialing process, the Nursing Committee provides recommendations to the hospital director regarding the scope of clinical authority (clinical privilege) that should be granted. The Credentialing Subcommittee assesses the competencies of nursing staff seeking clinical authority and developing the necessary credentialing instruments to support this process. These instruments include: (1) a set of hospital policies regarding credentialing and clinical authority; (2) the necessary forms for credentialing; and (3) clinical competency assessment guidelines required to grant clinical authority in collaboration with Mitra Bestari. The hospital's failure to carry out the credentialing function can lead to legal liabilities for the hospital in the event of malpractice or accidents during nursing or midwifery procedures. Hospitals have a legal obligation to protect their patients by ensuring the competence of the nurses and midwives providing care, which is known as the duty of due care. It is essential that hospitals know and maintain the safety of all nursing actions carried out within their premises (Damayanti et al., 2019).

To increase the professionalism of the midwifery team, it is important to establish a management information system that supports activities related to midwifery and human resources. This system should facilitate recruitment, selection, assessment, placement, and internship processes. Additionally, the Midwifery Committee should coordinate closely with other committees, such as the Certification Subcommittee, Quality Subcommittee, Professional Ethics Subcommittee, and Nursing Discipline Committee to fulfill its role in improving midwifery professionalism (Damayanti et al., 2020b).

According to Anglin (1990), the credentialing process includes granting practice permits (licenses), registration, certification, and accreditation, all of which are integral to ensuring the competence of healthcare professionals.

Practice Permit (License)

Nursing practice permits are not a new concept for Indonesian nurses. The Indonesian National Nurses Association (PPNI) has discussed this topic on various occasions, and experts focused on developing nursing quality and practice have also contributed ideas. However, as of this writing, the issue of obtaining a nursing practice permit remains a key concern for the profession. To obtain the right to practice, three criteria must typically be met (Anglin, 1990):

1. There must be a need to protect the safety or welfare of society.
2. The work must clearly be a distinct and separate field of practice.
3. There must be an organization responsible for overseeing the licensing process.

A nursing practice permit is required for ensuring and guaranteeing the professionalism of the nursing profession. For the public, a nursing practice permit serves as a protective tool, ensuring they receive care from qualified nurses who provide high-quality nursing services. Without a nursing license, it becomes difficult to determine the quality of nursing care provided.

Registration

Registration is the inclusion of an individual's name and other relevant details in official records, whether governmental or non-governmental (Hamilton, 1995). Registered nurses are permitted to use the title "Registered Nurse". To be registered, nurses must complete an accredited nursing education program and pass an examination from the registration body with a satisfactory score.

A registered nurse is a professional who carries out nursing practice by:

1. Assessing the health status of individuals and groups.
2. Establishing nursing diagnoses.
3. Determining goals to meet healthcare needs.
4. Developing and implementing nursing interventions and strategies.
5. Authorizing nursing interventions carried out by others.
6. Maintains safe and effective care both directly and indirectly.
7. Evaluating response to interventions.
8. Teaching nursing theory and practice.
9. Managing nursing practice.
10. Collaborating with other healthcare professionals in managing care.

Certification

Certification is the process of validating that a nurse has met the minimum standards of practical competency in specialized areas such as maternal and child health, pediatrics, mental health, gerontology, and school health (Vanderlaan & Jefferson, 2023; Hamilton, 1995). Certification confirms that a nurse has the necessary skills and qualifications in a particular specialty. In the United States, the certification process is commonly used.

Certification is a process in which a certification body recognizes the competence of a professional worker after they meet the required standards for a specific health profession (Applebaum, 2022).

Accreditation

Accreditation is a process through which organizations or government bodies evaluate and grant accreditation status to institutions, programs or services (Hamilton, 1995). Accreditation is awarded after institutions undergo supervision and evaluation, meeting various established criteria.

The accreditation status of an institution reflects its performance and quality. It indicates the effectiveness, efficiency and relevance of the programs it offers. The factors measured in accreditation include structure elements, process and outcomes (Sakit, 2017).

Basic Understanding of Competency Certification

Certification is a process by which individuals, products, or organizations are officially recognized for meeting certain standards. For example, ownership certification may be issued for land ownership, while product certification may grant a halal label for certain food products. Likewise, information certification can be issued for recognition of events such as a birth or adoption (Rusydiana & Marlina, 2020; Nuryuniarti & Nurmahmudah, 2019).

In the context of healthcare, competency certification is issued to individuals who have demonstrated proficiency in a specific task, job, or position. This process is known as **competency certification**. Once an individual is recognized for their competencies, they receive certification that validates their qualifications (Widjaja, 2022).

The activities involved in competency certification, include: registration, assessment, certification decision, surveillance, recertification, and use of certificates.

Competency Certification and Assessment

Assessment is a systematic process of collecting evidence, and comparing it against competency standards to determine whether an individual has achieved the required competencies. The process is conducted by qualified assessors based on existing evidence and criteria (Gosal et al., 2022). The assessment process typically involves: (1) collecting the evidence(s), (2) comparing the evidence(s) to established benchmarks, and (3) recommending further actions based on the results.

In order to guarantee the quality of the evidence collected during the assessment, the evidence must meet the 4 principles of evidence collection:

- **Validity**: The evidence must accurately represent the competencies being assessed.
- **Authenticity**: The evidence must be original and genuine.
- **Currency**: The evidence must be up-to-date and relevant.
- **Sufficiency**: The evidence must be adequate to make a valid assessment.

The competency assessor must meet specific requirements, including:

1. Familiarity with relevant certification schemes.
2. Sufficient knowledge of testing methods and the specific areas being tested.
3. Competence in the field of practice being assessed.
4. Effective communication skills, both orally and in writing, in the language used for the assessment.
5. Independence from any conflicts of interest to ensure impartial and unbiased assessments (Wardani, 2021).

Midwifery Committee and Credential Subcommittee

The Midwifery Committee is a non-structural institution within hospitals whose main function is to maintain and improve the professionalism of the midwifery staff This is achieved through credentialing mechanisms, maintaining the quality of the midwifery profession, as well as maintaining ethics and discipline, so that midwifery care services to patients are provided correctly (scientifically) according to good standards, (ethically) in accordance with the professional code of ethics, and only given by competent midwifery staff with clear authority (Nurhikmah et al., 2023).

The Midwifery Committee assists the hospital director in implementing credentialing processes, fostering professional discipline and ethics, and supporting the ongoing professional development of midwifery.

Relationship with Hospital Management

The Midwifery Committee is under and responds directly to the hospital director. They collaborate and coordinate with the head of midwifery and provide input regarding the development of the midwifery profession. The midwifery committee is assisted in its functions by an ad hoc committee composed of bestari partners according to the discipline (specifications/SPF) and specialization of the midwifery staff based on the needs of the hospital.

The credentialing process aims to ensure that midwifery staff are competent in delivering services that align with professional standards.

The **Credentialing Subcommittee** has several key responsibilities: (1) compile a detailed list of clinical authorities and midwifery qualifications, (2) prepare a white paper outlining the requirements related to the competencies needed to perform each type of midwifery service, (3) receive and verify credential requirements from the HR department, (4) recommend the stages of the credentialing process, (5) prepare and submit a report on the entire credentialing process to the chair of the midwifery committee for approval by the hospital director, (6) recommend the restoration of clinical authority for midwifery staff, and (7) conduct re-credentialing periodically.

Credentialing Process

The credentialing process involves several stages, starting with the acquisition of clinical authority. The first step requires the nurse to submit an application to the Head of the Midwifery Division, which is provided by the head of the department. The applicant must also complete various forms provided by the hospital and submit all required documents to the Head of the Midwifery Division for review. Once the application is submitted, the nurse receives written proof of their authority to practice across Indonesia, known as the SIP (Surat Izin Praktik). This license is issued to newly graduated nurses, those currently working, and those undergoing formal education. The SIP is valid for 5 years and must be renewed six months before its expiration. It is issued by the provincial health service, granting nurses official permission to carry out nursing practices. Nurses must obtain this work permit within one month of starting employment, or no later than two years for those already employed.

The second stage of the process is the Mitra Bestari study. The Midwifery Committee assigns a credentials subcommittee to process the application. This subcommittee prepares a group of bestari partners, typically consisting of four to six experts, who review the proposed midwifery care or actions based on a white paper. The white paper outlines the competency criteria for midwives, such as educational qualifications, training, and handling a specific number of cases within a set period. Based on this document, the bestari partners either recommend or reject the request for clinical authority to perform midwifery care and procedures. Additionally, they assess the applicant's physical and mental health, consulting with a doctor if necessary. Once the evaluations are completed the bestari partners make their final recommendations on which midwifery care and actions the applicant may undertake, which are referred to as clinical previleges. In some cases, practical tests, interviews, or written tests may be required. Afterward, the Midwifery Committee reviews the recommendations and may make modifications before moving forward.

The final stage of the credentialing process involves the issuance of a clinical assignment letter by the hospital directorThis letter is issued based on the recommendations from the Chair of the Midwifery Committee and outlines the specific clinical authorities the midwife is authorized to perform. This assignment letter is valid for a set period, and it formalizes the clinical responsibilities assigned to the nurse or midwife.

The credentialing process itself is designed to ensure that nurses and midwives possess the necessary skills and authority to perform detailed clinical actions. The credentialing process typically involves three main stages. First, nurses and midwives apply for clinical authority through the self-assessment method. Second, bestari partners review and provide recommendations on the proposed nursing actions. Finally, the hospital director issues assignment letters (clinical appointments) based on the recommendations from the bestari partners, specifying which clincal privileges the nurse or midwife can perform. These letters are valid for a fixed period, after which the recredentialing process is initiated, repeating the same three stages.

New nurses and midwives, after completing at least one year of work, are required to undergo a competency assessment to confirm their qualifications for Clinical Nurse (PKI) status. The competency assessment is managed by the head of the nursing section, who evaluates whether the nurse or midwife has mastered the necessary competencies. Once deemed competent the new nurse or midwife can apply for clinical authority using the self-assessment method. This involves submitting an application to the hospital director through the nursing section, along with the necessary documents. The nursing section then forwards the application to the nursing committee, which assigns a credentialing subcommittee to process the request.

The subcommittee forms a team of bestari partners, typically four to six experts in the relevant field, to evaluate the application. The bestari partners do not have to be a member of the credentialing subcommittee and can even come from outside the hospital if necessary. The bestari partners may be from different specialties, in accordance with the clinical authority requested. Thus, the group of bestari partners can be different for each nurse or midwife who applies for clinical authority. Mitra Bestari reviews each nursing and midwifery action proposed by the applicant, following a white paper that sets out the competency standards for specific procedures.

In addition to evaluating clincal competence, the bestari partners also assess the applicant's physical and mental health, ensuring that they are fit to perform their duties. If necessary, the hospital conducts relevant exams or consultations with medical or mental health professionals. After completing their evaluation, the bestari partners recommend the nursing or midwifery actions that the applicant is qualified to perform. The nursing committee then reviews these recommendations and makes any necessary modifications before submitting them to the hospital director (Azhari et al., 2022), who ultimately issues the assignment letter outlining the nurse’s or midwife’s clinical privileges.

The hospital director may ask the nursing committee to review a recommendation with hospital management if deemed necessary. The assignment letter provided to each nurse and midwife outlines the specific clinical authorities they are allowed to perform, which may vary depending on their specilization. Nurses and midwives within the same field may have different lists of clinical authority, reflecting their individual qualifications and areas of expertise. Certain nursing and midwifery procedures can only be performed by those who have received an official letter of clinical authority, ensuring that only qualified personnel carry out these tasks. (Munir & Parinduri, 2021).

Nurses and midwives may request additional clinical privileges at any time by submitting a request to the hospital director. If the request is approved, the nursing committee will initiate a special credentialing process to assess the new actions and provide recommendations to the hospital director. On the other hand, clinical privileges may be revoked, if a nurse or midwife is found to be incompetent or has violated ethical or professional standards. This will be further explained in the section on ending clinical authority.

In accordance with the time conditions set for each long-serving nurse, the nurse has the right to submit an application for career advancement and participate in the credentialing process. Upon successful credentialing, the nurse can then take on duties at a new, higher level. Similarly, experienced nurses are eligible for promotion to a new position based on their qualifications and performance. However, midwives who have not met the required criteria for promotion within two to three years will face sanctions, as outlined by the hospital's provisions.

The assignment letter for each nurse and midwife is valid for a period of three years from the date of issue. Clinical authority is automatically revoked if the assignment letter expires or is rescinded by the hospital director under certain conditions, such as when the individual is deemed incompetent, has violated ethical or disciplinary standards, or if their physical or mental health is compromised. Additionally, if an accident occurs due to perceived incompetence, the clinical authority may also be revoked. At the end of the assignment letter's validity period, the hospital must conduct a recredentialing process, which is generally simpler than the initial credentialing process (Idhan, 2023).

If clinical authority is terminated due to incompetence, it may be reinstated once the nurse or midwife has regained their competency. In such cases, the nursing committee may request the professional quality sub-committee to provide coaching and support to restore the individual's skills. Following this coaching, the nursing committee can recommend to the hospital director the reinstatement of the nurse's or midwife's clinical authority, provided they are deemed competent. Ultimately, the credentialing process is designed to ensure patient safety while fostering the ongoing development of nursing and midwifery competence. This highlights the significant role the nursing committee plays in the credentialing process, as it is responsible for assessing and granting clinical authority to each nurse and midwife in the hospital (Miranda & Hidayat, 2021).

Competence Attachment

Midwife Medical-Surgery Clinic

In clinical midwifery practice in medical surgery, an assessment is carried out to evaluate professional, ethical, legal and culturally sensitive practices. This assessment focuses on responsible behaviour towards professional practice, such as being accountable for professional decisions and actions. Midwives nust be able to scientifically explain the reasons for every action they take, know the limits of their roles and competencies, and refer or consult with more experienced colleagues when necessary. Midwives must practice in accordance with the Indonesian Midwifery Code of Ethics, respecting clients' privacy and cultural rights. For example, this includes practices such as separating male and female patients, explaining patients' rights to information, ensuring confidentiality, and respecting the dignity and cultural practices of clients and patients. Midwives also need to ensure that their actions comply with national and local policies, and they must demonstrate professionalism and adherence to the midwifery code of ethics (Khakbazan et al., 2019).

The provision and management of midwifery care includes reviewing basic midwifery data and performing fundamental tasks such as ensuring proper breathing, balanced nutrition, urinary and fecal elimination, mobility, body positioning, rest and sleep, body temperature regulation, personal hygiene, and injury prevention. Midwives must also provide therapeutic communication, address spiritual needs, fulfill activity and recreational needs, conduct health education and promotion, administer simple medications, and implement infection control measures. Additionally, midwifery care management involves collaborating with other healthcare professionals, documenting actions, and providing continuous evaluation of the care provided. Midwives are expected to engage in continuous professional development by improving their practice, applying research findings, participating in continuing education, and evaluating their own performance. Clinical midwives must actively engage in scientific activities, mentoring, and professional improvement efforts to maintain high standards in midwifery practice.

The assessment of Clinical Midwives II in medical surgery involves evaluating their professional, ethical, legal and culturally sensitive practices. This includes demonstrating responsible behaviour in professional practice, in line with the competence of Clinical Midwives I. Midwives at this level must perform their duties based on the Indonesian Midwifery Code of Ethics while being mindful of culture considerations. They are also expected to advocate for the protection of human rights, as outlined in the Indonesian Nursing Code of Ethics, ensuring that clients/patients are protected from actions that could cause physical or material harm. Furthermore, Clinical Midwives II must practice in accordance with their competence level, adhering to applicable regulations related to midwifery practice and the midwifery code of ethics.

Clinical Midwives II are responsible for the management of obstetric care, including understanding biomedical concepts related to medical-surgical procedures, reviewing basic surgical-medical obstetric data, diagnosising obstetric issues, and developing an obstetric care plan for patients without complications. They are expected to perform basic obstetric procedures across the 12 body systems, including immune, respiratory, cardiovascular, hematological, sensory, neurological, digestive, musculoscletal, urinary, endocrine, integumentary, and reproductive systems. This involves performing diagnostic preparations, post-surgical care, therapeutic actions, health education, and midwifery documentation. Clinical midwives at level II also mentor and guide other midwives and students in these areas.

Professional development is achieved through continuous efforts to improve midwifery practice, including enhancing the competence of Clinical Midwives II, maintaining the professional image of midwifery, and contributing to the overall development of the profession. Additionally, Clinical Midwives II are expected to engage in continuing education as a part of their professional responsibility, ensuring their competence aligns with the standards for this level. They also take on roles as supervisors and mentors for other Clinical Midwives II, helping to guide and support their professional growth.

The assessment of Clinical Midwives III focuses on evaluating their professional, ethical, legal and culturally sensitive practice in medical-surgical settings. Midwives are expected to demonstrate responsible behaviour in accordance with the Indonesian Midwifery Code of Ethics, ensuring that their actions adhere to ethical decision-making guidelines, respect patient rights, and maintain professionalism in all aspects of care. In addition, midwives must exhibit cultural sensitivity by providing care that is not only clinically effective but also respectful of the diverse cultural values, beliefs, and practices of patients. This includes an understanding of cultural differences and the ability to incorporate these values into the delivery of midwifery care. Midwives are also required to engage actively in ethical decision-making, prioritizing the well-being of their patients. They must make morally sound decisions, rejecting unethical actions proposed by peers or other healthcare workers. This is especially critical in situations of crisis or conflict, such as during war, violence, or natural disasters, where midwives are faced with high-pressure environments that challenge their ethical judgment. In these situations, midwives must make decisions that safeguard patient welfare while adhering to ethical principles, even when others may suggest harmful actions.

The provision and management of midwifery care requires comprehensive understanding of advanced medical-surgical biomedicine and the ability to apply this knowledge to clinical practice. Midwives must be capable of conducting midwifery assessments for medical-surgical clients with risks or complications across all 12 body systems, working independently to evaluate patient conditions. They must also be able to analyse data, determine obstetric diagnoses, develop care plans for clients with complications, perform obstetric procedures, and manage perioperative care (pre-surgical, intra-surgical and post-surgical). This involves performing diagnostic examinations, conducting health education, and observing patients. Midwives must also engage in collaborative actions with other healthcare professionals, make appropriate midwifery referrals, provide counseling to clients, and ensure comprehensive obstetric documentation is maintained. Additionally, the provision and management of midwifery care is assessed in terms of effective therapeutic communication. Clinical Midwives III are also expected to guide Clinical Midwives II and students, supporting their learning and clinical development. Finally, they must identify areas that require further research.

Professional development at this level requires clinical midwives to use valid evidence in evaluating care quality, participate in quality assurance procedures, and actively contribute to continuing education. Clinical midwives at level III also mentor and guide students and junior midwives.

The assessment of Clinical Midwives IV focuses on evaluating their professional, ethical, legal and culturally sensitive practice in medical-surgical settings. Midwives are expected to demonstrate responsible behaviour in accordance with the Indonesian Midwifery Code of Ethics, ensuring that their actions adhere to cultural and legal practice competence of Clinical Midwives III. The provision and management of midwifery care requires understanding of advanced surgical-medical biomedicine, and the ability to practice independently in specialized areas of medical-surgical midwifery, including managing complex obstetric care or sub-specialties within the 12 body systems, including immune, respiratory, cardiovascular, hematological, sensory, neurological, digestive, musculoscletal, urinary, endocrine, integumentary, and reproductive systems. They must be capable of providing specialized midwifery care, guiding other clinical midwives, and conducting health education for patients, families, and students. Collaboration with other healthcare professionals is essential in this role. Clinical Midwives IV must be able to provide specialized midwifery care, guide other clinical midwives, document care, collaborate with other professionals, and provide health education for patients and families. Clinical midwives at level IV must also take on the role of consultants within their area of expertise and engage in research activities. Professional development at level IV includes continued improvement of midwifery practice, maintaining competence, participating in continuing education, and mentoring clinical midwives at lower levels. Clinical midwives at this stage are expected to demonstrate a high level of professional responsibility, contribute to the development of the midwifery field, and maintain lifelong learning.

The assessment of Clinic Midwives V focuses on evaluating their professional, ethical, legal and culturally sensitive practice in medical-surgical settings. Midwives are expected to demonstrate responsible behaviour in accordance with the Indonesian Midwifery Code of Ethics, ensuring that their actions adhere to cultural and legal practice competence of Clinical Midwives IV. The provision and management of midwifery care requires the ability to independently provide specialized or sub-specialized midwifery care within the scope of medical surgery. This includes making independent decisions, guiding other midwives at level IV, collaborating with other healthcare professionals, and providing counseling and education to patients and families. Clinical Midwives V must be capable of providing specialized midwifery care, documenting care, guiding midwifery students, and acting as a consultant in the scope of their field. Clinical midwives at level V also have responsibilities in research and quality improvement initiatives. Professional development at this level requires active participation in continuing education, mentoring and supervising clinical midwives, and contributing to the overall development of the midwifery profession. Midwives at this level should be recognized as leaders in their field, with expertise in both practice and education.

Competence of Maternity Clinic Midwives

The competence of maternity clinic midwives is assessed based on a combination of professional, ethical, legal and culturally sensitive practices. At all levels, from Clinical Midwife I to Clinical Midwife V, midwives are expected to demonstrate responsible behaviour in their professional practice, which includes making informed decisions and taking actions that are scientifically sound. Midwives must be able to explain the rationale behind their clinical decisions and know their professional limits, ensuring they do not exceed the scope of their capabilities. When necessary, they should refer clients to midwives with higher expertise or consult with other professionals. Midwives must also adhere to the Indonesian Midwifery Code of Ethics, respecting the privacy rights of clients, explaining patients' rights to information, maintaining confidentiality, and providing care that aligns with both legal and cultural norms.

The assessment of midwifery care provision and management involves a holistic approach, guided by the fundamental principles of midwifery care. This includes the implementation of health promotion efforts in midwifery services, the implementation of basic nursing care, conducting midwifery assessments, conducting data analysis, determining midwifery diagnoses, formulating midwifery plans with an emphasis on efforts to stimulate growth and development, and implementing midwifery actions. These actions include providing health education, observing and fulfilling basic needs such as: (1) the need to breathe, (2) the need for balanced eating and drinking, (3) the need to eliminate urine, (4) the need to eliminate feces, (5) the need to mobilize and maintain body position, (6) the need for rest and sleep, (7) the need to choose and wear clothing appropriate to the situation and conditions, (8) the need to maintain normal body temperature, (9) the need to maintain body and personal hygiene, (10) the need to avoid environmental hazards and injury, (11) the need to communicate, (12) spiritual needs, (13) the need to work, (14) the need for recreational activities, (15) the need to learn, (16) the administration of medication, (17) the maintenance of clean techniques and sterile body positions, and (18) wound care.

The provision and management of midwifery care are assessed through various critical processes. One of the key aspects of this assessment is consulting with more competent professionals when necessary. Another important component of the assessment process is the evaluation of actions carried out during midwifery care. In addition, documenting midwifery care is a fundamental responsibility that serves as both a record of care and a means of ensuring accountability. The use of therapeutic and interpersonal communication as well as interpersonal relationships are central to the provision of high-quality midwifery care.

In terms of professional development, midwives are encouraged to continually improve their practice through ongoing education, research, and participation in scientific activities. This professional growth is essential for advancing both personal competence and the overall quality of midwifery care.

A Clinical Midwife II plays a critical role in the provision of maternity care operating with professionalism, ethics, legality and cultural sensitivity. This role is grounded in the fundamental principles of the Indonesian Midwifery Code of Ethics, which guides the midwives' behavior in a manner that upholds human rights, client safety, and the dignity of the individual. In this capacity, the midwife demonstrates responsible behavior by consistently adhering to professional standards and providing care that is not only clinically effective but also ethically sound.

The assessment of midwifery care provision and management for Clinical Midwives II focuses on (1) competence, (2) understanding the complexities of maternity care and reproductive system disorders, (3) collecting data, (4) analysing the data and establishing obstetric diagnoses, (5) developing a midwifery plan that describes intervention in uncomplicated maternity clients, (6) assisting in childbirth with limited supervision, (7) performing basic obstetric interventions on: prenatal, intranatal, postnatal, pregnancy disorders, reproductive system disorders, with the following activities: (a) helping clients/patients in meeting their basic needs, (b) making observations, (c) preparing clients for normal delivery, (d) managing infants immediately after birth, (e) managing newborns, (f) preparing for diagnostic examinations, (g) performing obstetric interventions on pre- and post-surgical clients, (h) managing family planning services, (i) conducting referrals, (j) advocating for clients/patients and their families, (k) providing recommendations to the health team on nosocomial infection prevention measures, (l) conducting assessments, (m) conducting health education, (n) conducting obstetric documentation, (o) supervising Clinical Midwives I.

Professional development in midwifery is a continuous process that involves ongoing improvement of skills. For Clinical Midwives II the assessment of professional development includes a range of activities aimed at enhancing competence, improving and maintaining the professional image of midwifery, and contributing to the broader development of the midwifery profession. Another important aspect of professional development is participating in continuing education and guiding and mentoring junior midwives.

Clinical Midwives III play a critical role in the provision of maternity care operating with professionalism, ethics, legality and cultural sensitivity. This role is grounded in the fundamental principles of the Indonesian Midwifery Code of Ethics, which guides the midwives' behavior in a manner that upholds human rights, client safety, and the dignity of the individual. In addition, midwives must exhibit cultural sensitivity by providing care that is not only clinically effective but also respectful of the diverse cultural values, beliefs, and practices of the patients. Midwives are also required to engage actively in ethical decision-making, prioritizing the well-being of their patients. They must make morally sound decisions, rejecting unethical actions proposed by peers or other healthcare workers. This is especially critical in situations of crisis or conflict, such as during war, violence, or natural disasters, where midwives are faced with high-pressure environments that challenge their ethical judgment. In these situations, midwives must make decisions that safeguard patient welfare while adhering to ethical principles, even when others may suggest harmful actions.

The assessment of provision and management for Clinical Midwives III focuses on their competence, the ability to perform basic obstetric interventions within the scope of midwifery maternity with complications, consulting with higher clinical midwives on: prenatal, intranatal, postnatal, pregnancy disorders, disorders of the reproductive system, with the following activities: (1) helping clients/patients in meeting their basic needs, (2) making observations, (3) preparing clients for normal labor, (4) assisting in normal delivery, (5) managing infants immediately after birth from mothers with complications, (6) managing newborns with complications, (7) preparing for diagnostic examinations, (8) providing nursing care to pre- and post-surgical clients, (9) managing family planning services, (10) conducting referrals, (11) advocating for clients, patients and their families, and (12) providing recommendations to the health care team on preventive measures for nosocomial infections and the modification of the supportive environment, (13) conducting assessments, (14) conducting health education, (15) providing midwifery documentation, (16) mentoring Clinical Midwives II, (17) performing special midwifery actions with risks, and (18) identifying areas that need further research.

For Clinical Midwives III the assessment of professional development focuses on activities aimed at enhancing and maintaining competence, using valid evidence to evaluate the quality of the midwifery practice, and participating in improving the quality assurance procedures. Another important aspect of professional development is participating in continuing education and guiding and mentoring junior midwives.

As midwives progress to Clinical Midwife IV (maternitas), they are assessed on their professional, ethical, legal and culturally sensitive practices. Clinical Midwives IV must demonstrate responsible behaviour in their professional practice and adhere to the Indonesian Midwifery Code of Ethics while respecting culture diversity and legal norms. This level of practice also involves the delivery of specialized obstetric care or sub-specialties within maternity care, including areas such as infertility, endocrine disorders, and oncology. Clinical Midwives IV are expected to make independent decisions in their specialized roles, while collaborating with other professionals to ensure comprehensive patient care. In addition to providing specialized care, Clinical Midwives IV are responsible for counseling patients in the field of women's health, delivering health education to patients and their families and contributing to the development of midwifery programs. They also play a significant role in mentoring midwifery learners, providing consultation on maternity care and nursing, conducting research in groups, and developing new programs related to midwifery practice. This level also involves acting as a supervisor for lower-level midwives and participates in continuing education, ensuring that best practices and ethical standards are maintained.

Clinical Midwives V are assessed based on their professional, ethical, legal, and culturally sensitive practices. Clinical Midwives V must demonstrate responsible behaviour in their professional practice and adhere to the Indonesian Midwifery Code of Ethics while respecting culture diversity and legal norms. This level of practice also involves the delivery of specialized obstetric care or sub-specialties within maternity care, including areas such as infertility, endocrine disorders, and oncology. Clinical Midwives V are expected to make independent decisions in their specialized roles, collaborate with multidisciplinary teams, provide counseling and health education for patients and their families, and serve as mentors and consultants in maternity care. They are also involved in research, program development, and the ongoing improvement of midwifery practice. Professional development at this level involves developing professional improvement efforts in midwifery practice and participating in continuing education.

Conclusion

The process of assessing midwifery staff to decide who is eligible to receive clinical authority is known as credentialing. Recredentialing is the process of reassessing midwifery professionals who already hold clinical authority in order to ensure that midwives continue to meet the necessary standards and competencies to maintain their clinical authority In order to ensure appropriate clinical governance, all midwifery care is provided by hospital midwifery staff in accordance with the clinical assignments designated by the hospital's director. It is anticipated that health workers would use this credentialing handbook as a reference when applying for and renewing their credentials.

Disclaimer

None.

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