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TRENDS AND INNOVATIONS IN ENVIRONMENTAL SCIENCE

Editors:
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Trends and Innovations in Environmental Science

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PREFACE

In recent years, environmental science has witnessed remarkable advancements driven by innovative research and cutting-edge technologies. This book, "Trends and Innovations in Environmental Science," aims to provide a comprehensive overview of the latest developments in this dynamic field. It brings together contributions from leading experts who explore various aspects of environmental challenges and solutions.

From climate change mitigation to sustainable resource management, the chapters in this volume highlight the interconnectedness of ecosystems and the importance of multidisciplinary approaches. We delve into emerging technologies that address pollution, biodiversity conservation, and renewable energy, showcasing practical applications and theoretical advancements.

Our goal is to inspire readers by presenting pioneering research and innovative methodologies that are shaping the future of environmental science. We hope this book serves as a valuable resource for students, researchers, and professionals seeking to understand and contribute to the sustainable development of our planet.

We would like to thank all contributors for their insightful chapters and dedication to advancing environmental science. Together, we strive to foster a deeper understanding of our environment and encourage sustainable practices for a better tomorrow.

Editors

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AVIAN ECOSYSTEM SERVICES AND ECOLOGICAL ROLE IN SUSTAINABLE AGRICULTURE

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Introduction:

Birds can be found in a wide range of habitats worldwide. The significance of various ecosystem types and their associated natural resources to humanity is evident. The concept of "ecosystem services" was introduced by the Millennium Ecosystem Assessment (2005) in order to characterize the inherent natural processes that yield advantages to human populations. Ecosystem services can be categorized into four main groups, namely provisioning, regulating, sustaining, and cultural services. Birds are integral and indivisible constituents of the Earth's ecosystem, fulfilling many functions that offer several ecosystem services, hence conferring direct or indirect advantages to human beings. Ecosystem services are a reflection of society's reliance on the ecological life-support system. Birds, in particular, contribute to all four categories of ecosystem services. Provisioning and cultural services are widely recognized and assigned market values, whereas the regulating and supporting categories have potential non-market values. The ecosystem services rendered by birds are discussed below.

1. **Provisioning services:**

1.1 Food: Bird eggs and meat provide a source of food for people, medicine, tools, clothing and ornamentation. Birds have been an important source of food for humans throughout history and continue to play a significant role in many cultures and diets around the world. The importance of birds as a source of food can be understood through several key factors:

a) **Protein Source:** Birds, such as chickens, turkeys, ducks, and pigeons, are excellent sources of high-quality animal protein. Their meat is lean, and it contains essential amino acids necessary for human nutrition.

b) **Nutrient Density:** Bird meat is rich in essential nutrients, including vitamins (such as B vitamins) and minerals (such as iron and zinc). Consuming a balanced diet that includes poultry can contribute to overall health and well-being.

c) **Cultural Significance:** In many cultures, certain bird species have cultural and historical significance as sources of food. For example, turkey is a traditional centerpiece of thanksgiving meals in the United States, and roasted duck is a delicacy in many Asian cuisines.

d) **Dietary Variety:** Birds provide dietary variety. Different species have varying flavors and textures

1.2 **Medicine**: Birds themselves are not direct sources of medicinal compounds like certain plants or fungi, they have played significant roles in traditional medicine and have indirectly influenced the development of medical practices and remedies in various cultures.

a) **Use in traditional medicine:** In some traditional medicinal systems, various parts of birds, such as feathers, bones, beaks, and even entire birds, have been used in remedies. For example, bird feathers may have been used in poultices or ointments for wound healing.

b) **Symbolism and Folklore:** Birds have held symbolic and cultural significance in many societies. In some cases, the characteristics or behaviors of certain birds have inspired medicinal or healing practices. For instance, the regenerative ability of the Phoenix in mythology has been associated with healing and rejuvenation.

c) **Avian Products in Traditional Remedies:** In some cultures, bird nests, particularly those of swiftlets (like the edible bird's nest), have been used in traditional medicine. These nests are believed to have health benefits and are often used in soups and tonics.

1.3 **Tools:** Birds themselves are not typically involved in the direct creation of tools for human use, their feathers, eggs, behavior, and biological characteristics have influenced and benefited human cultures and technologies in various ways throughout history.

a) **Feathers:** Bird feathers have been used by humans for thousands of years for various practical and decorative purposes. Feathers from different species of birds have been used to create tools like arrows, quill pens, and brushes. For example, the flight feathers of large birds like eagles and vultures were used by some indigenous cultures to make arrows with improved flight characteristics.

b) **Eggs:** In some cultures, particularly in the past, bird eggs were collected and used as a source of food. Additionally, the empty shells of larger bird eggs have been used for various ornamental or artistic purposes. For instance, ostrich eggs have been carved and decorated to create intricate artworks.

c) **Behavioral Observations:** Observations of certain bird species' behaviors, such as the migration patterns of birds, have been important for navigation and tracking time for human societies. Birds have historically been used as natural indicators of changing seasons, weather patterns, and the passage of time.

d) **Aviculture:** The practice of keeping and breeding birds in captivity, known as aviculture, has been used to maintain and propagate certain species for various purposes. Some birds, like homing pigeons, have been selectively bred for their ability to return to their home loft from distant locations, making them useful as messengers in the past.

e) **Inspiration for Innovation:** Bird flight has inspired human innovations, particularly in the field of aviation. Observations of birds in flight contributed to the development of early aircraft designs. The study of bird wings and aerodynamics has played a significant role in the development of human-made flying machines.

1.4 Clothing and ornamentation: Birds play several roles in cloth and ornament making, primarily through the use of feathers and sometimes through cultural symbolism.

a) **Feather Ornaments:** Bird feathers have been used for centuries as decorative elements in clothing and ornament making. Feathers from various bird species, such as peacocks, ostriches, and birds of paradise, are prized for their vibrant colors and unique textures. These feathers are often used to create headdresses, jewelry, fans, and other ornamental accessories.

b) **Feathered Garments:** In some cultures, especially among indigenous peoples, bird feathers are incorporated into traditional clothing. Feathers may be sewn onto garments or used to create intricate patterns and designs. Feathers are also used to create elaborate ceremonial outfits for special occasions.

c) **Down and Quills:** Certain birds, such as ducks and geese, provide down feathers that are used as insulation in clothing and bedding. Down is known for its warmth and lightweight properties, making it a popular choice for winter jackets, comforters, and pillows. Bird feathers have also been used historically as quills for writing instruments.

d) **Symbolism and Embroidery:** Birds are often featured in embroidery and textile designs. Their images may be embroidered onto fabric to create intricate patterns and motifs. Birds are sometimes chosen for their symbolism, representing qualities like freedom, beauty, or grace.

e) **Featherwork Traditions:** Some indigenous cultures have a rich tradition of featherwork, where bird feathers are meticulously arranged and sewn onto clothing and accessories to create stunning works of art. For example, Native American tribes in North America have a long history of creating intricate feathered headdresses, capes, and clothing for ceremonial purposes.

f) **Feather Accessories:** Feathers are also used to adorn hats, fascinators, and hair accessories in modern fashion. These accessories add a touch of elegance and whimsy to various outfits, especially in formal and festive settings.

g) **Cultural Significance:** In many cultures, certain bird species hold cultural significance and are associated with specific rituals or traditions. For example, in some indigenous societies, the feathers of certain birds are believed to carry spiritual significance and are used in sacred ceremonies.

However, the use of bird feathers in clothing and ornament making has raised ethical and conservation concerns, particularly when it involves the use of feathers from endangered or protected species. Many countries have laws and regulations in place to protect birds and their feathers, and there is a growing awareness of the need for sustainable and ethical sourcing of feathers for these purposes.

2. Regulating services

2.1 Pollination: Birds play a vital role in pollination, although they are not as well-known pollinators as bees or butterflies. Avian pollinators, such as hummingbirds, sunbirds, honeyeaters, and some species of bats, are essential for the reproduction of numerous plant species, especially those with specific adaptations for bird pollination. The key aspects of the role of birds in pollination are as:

a) Nectar-Feeding: Many bird species are nectar-feeders. They have specialized beaks and long tongues adapted for reaching deep into flowers to extract nectar. As they feed, they come into contact with the reproductive structures of flowers, transferring pollen from one flower to another.

b) Flower Visitation: Birds are attracted to brightly colored, tubular, or trumpet-shaped flowers, which are often red or orange. These flowers have evolved to attract bird pollinators, as birds have excellent color vision and can spot these flowers from a distance.

c) Pollen Transfer: As birds probe into the flowers to access nectar, they inadvertently brush against the flower's reproductive structures, including the anthers (male parts) and stigma (female parts). Pollen adheres to their bodies, and when they visit another flower of the same species, they deposit the pollen on the stigma, facilitating fertilization.

d) Long-Distance Pollination: Birds are capable of traveling long distances, which can lead to pollination of plants that are widely spaced. This long-distance pollination can be critical for the genetic diversity and survival of certain plant species.

e) Specialized Coevolution: Many bird-pollinated plants have evolved specific adaptations to attract and accommodate bird pollinators. This coevolution has led to unique flower shapes, sizes, and colors that are well-suited for bird pollination.

f) Geographical Variation: Bird pollination is particularly prevalent in certain regions, such as tropical and subtropical areas. In these regions, numerous plant species have evolved to rely on specific bird pollinators.

g) Crop Pollination: Some economically important crops, like certain varieties of vanilla, passion fruit, and guava, rely on bird pollination. In such cases, birds can play a crucial role in agricultural production.

2.2 Pest control: Birds are an integral part of ecosystems, and their presence helps maintain ecological balance. By controlling pest populations, they prevent outbreaks that could disrupt the natural order of an ecosystem. Birds play a significant role in pest control within various ecosystems and agricultural settings. They contribute to natural pest management in several ways:

a) **Insect Predation:** Many bird species are voracious insect eaters. They feed on a wide variety of insects, including crop-damaging pests like aphids, caterpillars, grasshoppers, and beetles. By reducing insect populations, birds help protect crops and minimize the need for chemical pesticides.

b) **Rodent Control:** Some birds, such as owls, hawks, and kestrels, are skilled predators of rodents like mice and rats. Their presence can help keep rodent populations in check, reducing damage to crops and stored grain.

c) **Seed-Eating Pests:** Grainivorous birds like sparrows, finches, and doves feed on weed seeds and grains. By consuming weed seeds, they can limit the spread of invasive plants and reduce competition with crops.

Encouraging a diverse bird population can enhance overall biodiversity, which can indirectly benefit pest control. A diverse ecosystem with a range of bird species can better adapt to changes and resist pest outbreaks. To encourage the role of birds in pest control, it's essential to create habitats that support bird populations, such as providing food sources, nesting sites, and protection from predators.

2.3 Seed dispersal: Seed dispersal by birds is essential for ecosystem functioning, as it helps maintain the balance between different plant species and contributes to the overall health and stability of ecosystems. Birds play a crucial role in seed dispersal, which is a key ecological process that contributes to the survival and distribution of plant species. This role benefits both plants and birds in various ways:

a) Primary Seed Dispersers: Many plants have evolved to rely on birds as their primary seed dispersers. These plants produce fruits that are often colorful and fleshy, containing seeds. Birds consume these fruits as part of their diet. The seeds are then transported away from the parent plant when the birds move to different locations, and the seeds are later deposited through their droppings.

b) Long-Distance Dispersal: Birds can disperse seeds over long distances, allowing plants to colonize new areas. This is especially important for the survival of plant species in changing or disturbed habitats.

c) **Diverse Diet:** Birds have diverse diets, and different bird species prefer different types of fruits, seeds, and berries. This diversity in preferences means that a wide variety of plant species can benefit from bird-mediated seed dispersal.

d) **Selective Dispersal:** Birds can be selective in their choice of fruits and seeds. They often prefer ripe fruits, which may have a better chance of germination and survival. This selective behavior can enhance the plant's chances of successful seedling establishment.

e) **Enhanced Germination**: The process of passing through a bird's digestive system can benefit certain seeds. It can scarify or soften the seed coat, making it easier for the seed to germinate once it's deposited in a new location.

f) **Habitat Restoration:** Birds can contribute to habitat restoration by aiding in the natural regeneration of vegetation in degraded areas. This is especially valuable in reestablishing native plant communities.

g) **Biodiversity Maintenance:** Seed dispersal by birds helps maintain biodiversity by ensuring the distribution and survival of various plant species. This, in turn, supports diverse animal communities that depend on these plants for food and shelter.

h) **Mutualistic Relationships:** Some plants have evolved specific adaptations to attract certain bird species for seed dispersal. For example, certain flowers and fruits have shapes, colors, or nectar production that specifically target particular bird species as pollinators and seed dispersers.

However, it's important to note that the relationship between birds and seed dispersal is not one-sided. Birds also benefit from this interaction by obtaining a food source in the form of fruits, seeds, and berries. In this mutualistic relationship, both plants and birds have evolved to depend on each other for their survival and reproduction, making seed dispersal a vital ecological process.

2.4 Scavanging: Birds play an important role in scavenging within ecosystems. Scavenging is the process of feeding on dead and decaying animal matter, including carcasses and organic debris. Birds that engage in scavenging fulfill several ecological functions:

a) **Carrion Removal:** Scavenger birds help remove and decompose dead animals from the environment. This service is vital for maintaining the cleanliness and hygiene of ecosystems because it prevents the accumulation of carcasses, which could harbor diseases and attract pests.

b) **Disease Control:** By scavenging on carcasses, birds can help reduce the spread of diseases that might otherwise proliferate in dead animal remains. Their consumption of diseased animals can limit the transmission of pathogens to other wildlife and humans.

c) **Ecosystem Balance:** Scavenger birds contribute to the balance of ecosystems by preventing the over accumulation of dead biomass. This can have a cascading effect on the food web, as an abundance of carrion can attract scavengers and predators, thus indirectly influencing the populations of various species.

d) Niche Specialization: Some bird species have evolved specific adaptations for scavenging. For instance, vultures and condors have specialized digestive systems that allow them to safely consume carrion that might be contaminated with pathogens. This niche specialization reduces competition for resources within ecosystems.

e) Economic Benefits: Scavenging birds can have economic benefits by cleaning up roadkill and reducing the risk of collisions between vehicles and scavenging animals. Additionally, some birdwatching and ecotourism opportunities are scavenger species centered.

Scavenging birds can also face challenges, including habitat loss, poisoning from ingesting toxins in carrion (such as lead from ammunition), and competition with other scavengers, including mammals like hyenas and jackals. Protecting scavenger bird populations and their habitats is essential for maintaining the ecological balance and services they provide within ecosystems.

3. Supporting services

3.1 Ecosystem Engineering: Birds, through their various activities and interactions with their environment, exemplify the intricate web of connections within ecosystems. Their roles as ecosystem engineers emphasize their importance in maintaining ecological balance and diversity. Protecting bird populations and their habitats is essential for safeguarding these engineering functions and the health of ecosystems. Birds can act as ecosystem engineers, a concept that highlights their role in shaping and modifying their environments in ways that have significant impacts on ecological structure and function.

a) Nesting Activities: Many bird species construct nests for breeding and shelter. These nests can vary widely in size, location, and materials used. For example, seabirds like gulls and terns often create nests on beaches or cliffs, while woodpeckers excavate cavities in trees. These nest-building activities can modify the physical characteristics of their surroundings. Nests can provide shelter for other organisms, alter microclimates, and even change nutrient cycling.

b) Burrowing Birds: Some birds, such as burrowing owls, prairie dogs, and puffins, dig burrows in the ground. These burrows can have significant impacts on soil composition and nutrient levels. For example, burrowing activities can lead to the mixing of topsoil and subsoil, affect water infiltration rates, and increase nutrient availability in the soil. These modifications can influence plant growth and the composition of plant communities in area.

c) **Habitat Creation:** Birds can create habitats by modifying their environment to suit their needs. For example, beavers build dams that alter water flow, creating wetland habitats that support a variety of other species. Woodpeckers excavate cavities in trees, which can serve as nesting sites for themselves and other cavity-nesting birds, as well as providing shelter for mammals and insects.

3.2 Nutrient cycling: When birds consume carrion, they help recycle nutrients from dead animals back into the ecosystem. This process facilitates the transfer of energy and essential nutrients, such as nitrogen and phosphorus, from deceased organisms to living ones. Bird droppings, or guano, contain essential nutrients like nitrogen and phosphorus. In areas with large seabird colonies, guano deposition can enrich soil fertility, leading to increased plant growth and productivity. This nutrient cycling can have cascading effects on the entire ecosystem. Bird feces have significant value in agriculture. Birds contribute to nutrient cycling by redistributing nutrients through their excrement. This helps enrich soil fertility in different areas, promoting plant growth. In agriculture, bird droppings are used as fertilizer because they contain potassium, nitrogen, phosphate and other nutrients. This can easily convert to ammonia and serve as a good fertilizer for plants by contributing to the nitrogen content of the soil. The contribution of birds to increasing soil fertility on farms is very limited. Recently, it was shown that birds play a 38.0% global contribution in agriculture. The transfer of nutrients and the formation of soils are important services provided by birds in an ecosystem that allows primary producers to begin their work, which leads to the distress of primary consumers and leads to the colonization of the area by top predators and the maintenance of biodiversity.

4. **Cultural services:** Cultural services provided by birds refer to the various ways in which birds contribute to human culture, aesthetics, and our sense of place in the natural world like bird-based tourism, caged birds, falconry, art and heraldry, religion, knowledge etc. These services are often less tangible than some of the other ecosystem services provided by birds but are nonetheless significant for human well-being and cultural identity. Cultural services provided by birds encompass the myriad ways in which birds enrich human culture, art, traditions, and our overall sense of connectedness to the natural world. These intangible benefits highlight the profound influence birds have on our cultural identities and our relationship with the environment.

a) **Aesthetic Enjoyment:** Birds are appreciated for their beauty and grace in flight, as well as their striking plumage and melodious songs. Many people derive aesthetic pleasure from observing and listening to birds in their natural habitats. Birdwatching and bird photography are popular activities that connect people with nature and provide a sense of wonder and inspiration.

b) **Artistic and Cultural Symbolism:** Birds have played prominent roles in art, literature, folklore, and cultural symbolism throughout human history. They often represent themes such as freedom, transformation, and transcendence. In various cultures, specific bird species hold special meanings and are featured in myths, legends, and religious stories.

c) **Ornithology and Science:** Birds have been a source of fascination and scientific inquiry for centuries. Ornithology, the study of birds, has contributed to our understanding of biology, ecology, and evolution. Birds have also been used as model organisms for research in fields like behavior, genetics, and conservation.

d) **Bird Conservation and Education:** Birds are often used as flagship species in conservation efforts. Their popularity and cultural significance make them powerful ambassadors for raising awareness about environmental issues. Bird-related events, such as bird festivals and educational programs, promote conservation and connect people with nature.

e) **Recreation and Tourism:** Birdwatching is a popular recreational activity that attracts millions of enthusiasts worldwide. Many regions actively promote bird tourism, as birdwatchers often travel to specific destinations to observe rare or migratory species. This can boost local economies and promote the conservation of bird habitats.

f) **Bird Art and Craft:** Birds have been a subject of artistic expression for centuries. They inspire various forms of art, including paintings, sculptures, ceramics, and textiles. Bird motifs are commonly used in decorative arts and crafts.

g) **Traditional Knowledge:** Indigenous cultures often have deep knowledge of birds, including their behaviors, habitat preferences, and ecological roles. This traditional knowledge can inform conservation practices and contribute to the preservation of biodiversity.

h) **Emotional Connection:** Many people have a strong emotional connection to birds. They may associate specific bird species with personal memories, experiences, or places. Birds can evoke feelings of nostalgia, comfort, and joy.

Conclusion:

The contributions of avian fauna to ecosystem services are multifaceted and indispensable, reflecting the intricate interdependencies between natural systems and human societies. By elucidating the provisioning, regulating, sustaining, and cultural functions of birds, this paper underscores the imperative of integrating avian conservation efforts into broader ecosystem management strategies. Preserving avian biodiversity is not only essential for ecological integrity but also for sustaining the myriad benefits they confer upon humanity.

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COMBATING CLIMATE CHANGE IN ASSAM AGRICULTURE: A MULTI-STRATEGIC APPROACH BY NICRA

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Abstract:

This book chapter offers a comprehensive strategy to confront the escalating challenges posed by shifting environmental patterns. Through a synthesis of scientific research, indigenous wisdom, and practical insights, the chapter articulates the pressing need for adaptive measures to safeguard agricultural productivity and rural livelihoods. NICRA advocates for a multi-faceted approach that integrates cutting-edge technologies, policy reforms, community engagement, and sustainable farming practices to bolster the resilience of Assam's agricultural systems. Emphasizing the importance of context-specific solutions tailored to the region's socio-economic and ecological context, the chapter provides actionable recommendations for stakeholders at all levels. By fostering collaboration and knowledge exchange among diverse actors, including policymakers, researchers, farmers, and local communities, the chapter envisions a future where Assam's agriculture not only withstands the impacts of climate change but thrives in harmony with the environment. Ultimately, it serves as a roadmap for sustainable agricultural development, advocating for collective action to ensure food security, economic prosperity, and environmental sustainability in Assam and beyond.

Keywords: Climate Change, NICRA, Agriculture, Assam

Introduction:

Assam, a land characterized by its lush green valleys, mighty Brahmaputra River, and rich biodiversity, is the cradle of a vibrant agricultural heritage. Rice, the lifeblood of the state, forms the foundation of its food security and the livelihood of millions of farmers. However, this idyllic landscape is increasingly under threat due to a pressing global challenge – climate change. Climate change poses an unprecedented threat to agricultural systems worldwide, with profound implications for food security, rural livelihoods, and ecosystem stability. In regions like Assam, India, where agriculture serves as a primary source of income and sustenance for millions of people, the impacts of climate change are particularly acute. Erratic rainfall patterns, rising temperatures, and increased frequency of extreme weather events have disrupted traditional agricultural practices, undermining the resilience of farming communities and jeopardizing their ability to cope with environmental stressors.

In response to these challenges, the National Innovations on Climate Resilient Agriculture (NICRA) program has emerged as a pioneering initiative aimed at addressing the vulnerabilities of agriculture to climate change in India. Launched by the Indian Council of Agricultural Research (ICAR) in 2011, NICRA seeks to develop and promote climate-resilient agricultural practices and technologies that can enhance the adaptive capacity of farmers and improve the resilience of agricultural systems to climate-related risks.

Against the backdrop, NICRA's interventions in Assam hold immense significance in the context of climate change adaptation and agricultural resilience-building efforts. By focusing on key areas such as crop diversification, water management, soil health management, and livestock management, NICRA aims to equip farmers with the knowledge, tools, and technologies needed to mitigate the adverse effects of climate change on agriculture and improve their adaptive capacity.

Presently, NICRA project is going on four district Assam viz., Dhemaji, Darrang, Nalbari and Dhubri. Dhemaji and Darang comes under North Bank Plains Zone (NBPZ), whereas Nalbari and Dhubri in Lower Brahmaputra Valley Zone (LBVZ).

This book chapter provides a comprehensive examination of NICRA's approach to climate change adaptation in Assam's agricultural sector. Drawing on the insights, the chapter presents the NICRA interventions taken in building agricultural resilience and enhancing the adaptive capacity of farmers in the region. This book chapter seeks to contribute to the growing body of knowledge on agricultural resilience-building strategies in the face of climate change. By highlighting successful interventions, identifying areas for improvement, and offering actionable recommendations, the chapter aims to inform and inspire efforts to enhance the adaptive capacity of agricultural systems and improve the livelihoods of farming communities in Assam and beyond.

Understanding Assam's Vulnerability: A Landscape of Challenges

Assam's unique geographical location and topography make it particularly susceptible to the vagaries of climate change. The state experiences a sub-tropical monsoon climate with distinct wet and dry seasons. However, recent decades have witnessed a significant shift in these patterns. Rising global temperatures contribute to increased evaporation, leading to shorter and more intense bursts of monsoon rain followed by longer dry periods. This erratic rainfall pattern disrupts traditional sowing and harvesting cycles, often resulting in water logging during heavy monsoons and severe droughts during extended dry spells. Furthermore, the state experiences frequent floods due to overflowing rivers like the Brahmaputra, inundating vast swathes of agricultural land and causing significant economic losses.

Rising temperatures pose another significant threat. Warmer temperatures create favorable conditions for the spread of pests and diseases, leading to increased crop losses.

Additionally, higher temperatures exacerbate water scarcity, putting immense pressure on already limited water resources for irrigation. These combined challenges not only affect crop yields but also threaten the long-term sustainability of agricultural practices in Assam.

The Need for Climate-Smart Agriculture: A Paradigm Shift

The traditional agricultural practices employed in Assam, while well-adapted to the historical climatic conditions, are proving inadequate in the face of a changing climate. To ensure food security and sustainable agricultural development, a paradigm shift towards climate-smart agriculture (CSA) is essential. CSA is an approach that integrates agricultural practices, technologies, and management strategies that enhance agricultural productivity, adaptation, and mitigation of climate change. By adopting CSA principles, Assamese farmers can build resilience to climate variability and shocks, while also minimizing greenhouse gas emissions from the agricultural sector.

Mitigating Climate Change in Assam Agriculture: NICRA's Adaptation Strategies with Resilient Breeds and Crop Varieties

Assam, located in the northeastern region of India, faces significant challenges due to climate change. The state's agriculture, which is predominantly rain-fed, is highly vulnerable to the impacts of climate variability, including floods, droughts, and erratic rainfall. To address these challenges, the National Innovations in Climate Resilient Agriculture (NICRA) project has implemented various mitigation and adaptation strategies. NICRA's approach in Assam is multifaceted, focusing on empowering farmers at the grassroots level. Presently, NICRA projects covers 4 districts in Assam *viz*. Dhemaji, Darrang, Nalbari and Dhubri and its initiative employs a combination of strategies to address the specific challenges faced by the state. These strategies focus on improving the resilience of agricultural systems by introducing climate-resilient breeds and crop varieties, enhancing water management practices, and promoting sustainable agricultural practices.

Climate resilient practices and technologies demonstrated by categorizing all activities in four module *viz*.

a. **Natural Resource Management** interventions related to in-situ moisture conservation, biomass mulching, residue incorporation instead of burning, green manuring, water harvesting and efficient use, improved drainage in flood prone areas, zero tillage, artificial ground water recharge and water saving irrigation methods were demonstrated.

b. **Crop Production** technologies like introduction of drought/ temperature tolerant varieties, advancement of planting dates of rabi crops in terminal heat stress regions, water saving paddy cultivation methods (SRI, aerobic, direct seeding), frost management in horticulture through fumigation, staggered community nurseries for delayed onset of monsoon, location specific intercropping systems with high sustainable yield index, farming systems are being demonstrated.

c. **Livestock and Fisheries** interventions were fodder production in community lands which can be utilized during extreme events like droughts/floods. Augmentation of fodder production through improved planting material, improved fodder/feed storage methods, fodder enrichment, prophylaxis, improved shelters for reducing heat/cold stress in livestock, management of fish ponds/tanks during water scarcity and excess water and promotion of livestock component as a climate change adaptation strategy are being taken up.

d. **Institutional Interventions** either by strengthening the existing ones or initiating new one related to community seed bank, fodder bank, custom hiring center, village climate risk management committee, collective marketing group, commodity groups, are important interventions being taken up as part of the project.

One of the key strategies under NICRA is the introduction of climate-resilient crop varieties. Traditional rice varieties in Assam are susceptible to both flood and drought conditions. To mitigate these risks, NICRA has promoted the cultivation of flood-tolerant rice varieties such as “Bahadur Sub-1”, "Swarna Sub1" and "Ranjit Sub1." These varieties can withstand submergence for up to two weeks, thereby reducing crop loss during floods. Additionally, drought-tolerant rice varieties like "Sahbhagi Dhan" have been introduced to ensure stable yields during dry spells. These varieties are characterized by their deep root systems and efficient water use, making them ideal for regions prone to water scarcity.

In addition to rice, NICRA has focused on diversifying crops to reduce the dependency on a single crop and to spread risk. Pulses and oilseeds such as black gram, green gram, and mustard have been promoted as alternative crops. These crops not only provide nutritional benefits but also improve soil fertility through nitrogen fixation, which is crucial for maintaining soil health under changing climate conditions.

Livestock plays a vital role in the agricultural economy of Assam. To enhance the resilience of livestock systems, NICRA has introduced improved breeds of cattle, goats, and poultry. High-yielding and disease-resistant breeds such as "Gir" and "Sahiwal" cattle have been promoted. These breeds are better adapted to heat stress and have higher milk yields compared to local breeds. Similarly, the "Beetal" goat, known for its high milk production and meat quality, has been introduced to improve the livelihood of farmers. Improved poultry breeds like “Chara Chambelli”, “Rainbow Roosters”, "Vanaraja" and "Gramapriya" have been encouraged for their better growth rates and higher egg production, which are crucial for income diversification. For enhancing the adaptation to different climatic vulnerabilities in livestock the emphasis has been given to enhance the green fodder production and availability at the village at the household level. Integrated Farming Systems (IFS) like Fish+Ducks+Banana, paddy cum fish culture for efficient resource utilization. Livestock and fisheries based farming systems became more popular in the region with high returns and sustainable yields.

Water management is another critical aspect of NICRA's strategy. The project emphasizes the construction of water harvesting structures such as check dams, ponds, and rainwater harvesting systems to enhance water availability during dry periods. The adoption of micro-irrigation systems, such as drip and sprinkler irrigation, has been promoted to improve water use efficiency. These systems ensure that crops receive adequate water with minimal wastage, thereby sustaining agricultural productivity even during water-scarce periods.

NICRA also promotes sustainable agricultural practices to improve soil health and reduce greenhouse gas emissions. Practices such as conservation tillage, crop rotation, and the use of organic fertilizers are encouraged. Conservation tillage helps in retaining soil moisture and reducing soil erosion, while crop rotation breaks pest and disease cycles, improving crop health. Organic fertilizers, including compost and vermicompost, enhance soil fertility and microbial activity, leading to improved crop yields.

Furthermore, NICRA emphasizes capacity building and knowledge dissemination among farmers. Training programs, field demonstrations, and farmer field schools are conducted to educate farmers about climate-resilient practices and technologies. These initiatives empower farmers with the knowledge and skills needed to adapt to climate change and improve their livelihoods.

The following measures are taken under NICRA project to address Assam's two main vulnerabilities—the flood and the drought, and turned out to be fruitful. They are talked about below, and these actions need to be taken to address the problems of drought and flooding in other regions as well.

i. Introducing submergence-tolerant variety in the flood prone areas:

The adoption of submergence-tolerant rice varieties in flood-prone areas represents a critical strategy for ensuring food security and livelihoods in regions vulnerable to inundation events. Submergence-tolerant rice varieties such as Swarna Sub1, Ranjit Sub-1, Bahadur Sub-1, Bina-11 etc exhibit resilience to complete submergence for up to two weeks, allowing them to survive and recover from flood-induced stressors. Ciherang Sub-1 is another promising variety currently undergoing trials, offering hope for even greater resilience in the face of Assam's floods. The primary role of these varieties is to ensure crop survival and yield stability under adverse conditions, which directly contributes to food security. These varieties possess genetic traits that enable them to elongate rapidly during submergence, allowing the plants to maintain access to oxygen and prevent suffocation.

Swarna Sub1, Ranjit Sub-1, Bahadur sub-1 are having a yield potential of 5.0-5.5 t/ ha with a plant height of about 115 cm can tolerate submergence condition up to two weeks. The grain type of Swarna Sub-1 is short bold, having a maturity period of 140-145 days, whereas Ranjit sub1 is medium slender type with maturity period 150-155 days. Bahadur sub-1 is also having a maturity period of 150-155 days and grain type of medium bold. By continuing to promote and support the implementation of flood-tolerant varieties, Assam can build a more resilient agricultural sector capable of withstanding the challenges posed by climate change.

ii. Adopting Double Cropping with Rice- based cropping sequence:

Rice-based cropping sequences are an effective climate change adaptation strategy that enhances agricultural resilience and sustainability. These sequences involve integrating rice cultivation with other crops in a planned rotation throughout the year, optimizing the use of land and water resources.

Adopting rice-based cropping systems that integrate diverse crops such as pulses, vegetables, and fruits can enhance the resilience of agricultural systems by diversifying income sources, reducing pest and disease pressures, and improving soil health through crop rotation and intercropping. After the rice harvest, the fields can be prepared for dry-season crops that are less susceptible to water logging, thus making optimal use of the available water and improving overall farm productivity

Some popular rice based cropping sequences are rice-maize, rice-toria, rice-vegetables etc. For instance, a common sequence might include rice followed by wheat, legumes, or vegetables. This diversification of crops reduces the risk of total crop failure due to extreme weather events, pests, or diseases, which are becoming more frequent with climate change. Additionally, alternating between different crops can improve soil health and fertility by reducing the depletion of specific nutrients and disrupting pest and disease cycles.

In the rice-toria cropping sequence, farmers practiced growing rice during the kharif (monsoon) season and cultivating toria during the rabi (winter) season. Medium duration rice variety as Numoli could be followed by Toria (TS-38), whereas, if farmers go for long duration rice variety like Ranjit, ahadur, they should follow rice-toria cropping sequence with late sowing toria varieties like TS-67

iii. Development of fodder bank in flood affected areas:

The development of fodder banks in flood-affected areas stands as a vital intervention to mitigate the impacts of inundation events on livestock, ensure their nutritional needs are met, and enhance the resilience of communities to flooding. In regions prone to recurrent floods, traditional fodder sources are often washed away or rendered inaccessible, leaving livestock vulnerable to malnutrition and health issues. Fodder banks offer a sustainable solution by stockpiling nutritious forage crops during the dry season, which can be used to feed livestock during periods of flood-induced forage scarcity. By cultivating a diverse range of drought-tolerant forage species, such as Napier grass, sorghum, and cowpea, communities can ensure a continuous supply of nutritious feed for their animals, even in the face of extreme weather events. Additionally, fodder banks contribute to soil conservation and land restoration efforts by providing ground cover and preventing soil erosion during flooding. Studies such as those conducted by Sarker *et al.* (2020) highlight the importance of fodder banks in improving livestock productivity, enhancing food security, and promoting sustainable agriculture in flood-prone areas.

Fodder like Napier Grass (*Pennisetum purpureum* var. CO-3, CO-4, NB21), Maize (*Zea mays* var. African Tall, J 1006), Berseem (*Trifolium alexandrinum* var. Mescavi, BL 42), Hybrid Napier (*Pennisetum purpureum x Pennisetum americanum* var. BNH 10, DHN 6, Oats (*Avena sativa* var. Kent, JHO 822), Guinea Grass (*Panicum maximum* var. Hamil, PGG 101), Lucerne (*Medicago sativa* var. Siriver Anand-2) and sateria are suitable for Assam condition.

iv. Popularization of improved dual purpose breed of poultry & duck in backyard system of rearing for sustainable livelihood:

Backyard poultry rearing, particularly with improved dual-purpose poultry breeds, emerges as a sustainable livelihood option in flood-prone regions, offering resilience and economic stability for communities vulnerable to inundation events. These adaptable and resilient breeds, bred for meat and egg production, offer invaluable benefits in the face of changing climatic conditions. As climate change brings about unpredictable weather patterns, extreme temperatures, and increased frequency of extreme weather events such as droughts, floods, and storms, traditional crop cultivation becomes increasingly vulnerable to failure and damage. By diversifying agricultural practices to include poultry and duck farming alongside traditional crop cultivation, farmers can reduce their dependence on vulnerable crops while diversifying income sources. Studies such as those conducted by Mulugeta *et al.* (2019) underscore the importance of improved dual-purpose poultry breeds as a sustainable livelihood option in flood-prone areas, emphasizing their role in poverty alleviation and resilience-building efforts.

Chara chambelli, Indian runner, Khaki Campbell, Kalinga brown, Rinbow roosters, kalinga brown, kamrupa etc are some suitable dual purpose birds and already demonstrated successfully.

v. Low-cost rainwater harvesting technology (Jalkund) for cropping intensification for undulating fields in Assam:

Low-cost rainwater harvesting technology, commonly known as Jalkund, emerges as a transformative solution for cropping intensification in undulating fields of Assam's drought-prone areas. In regions characterized by undulating terrain and erratic rainfall patterns, traditional rainwater harvesting methods often prove ineffective due to land topography and limited resources. Jalkund, a simple and cost-effective technique, involves the construction of small earthen bunds or embankments along the contours of sloping fields to capture and retain rainwater runoff. These bunds trap rainwater, allowing it to infiltrate the soil and recharge groundwater resources, thus mitigating the impacts of water scarcity and enhancing soil moisture availability for crop cultivation. Additionally, Jalkund structures facilitate water storage for supplemental irrigation during dry spells, enabling farmers to sustain crop growth and mitigate yield losses during periods of drought. Studies such as those conducted by Das *et al.* (2018) highlight the effectiveness of Jalkund technology in improving crop yields, enhancing water use efficiency, and promoting sustainable intensification of agriculture in drought-prone areas of Assam. By empowering farmers with the knowledge and resources to implement Jalkund technology, communities can enhance their resilience to climate variability, improve agricultural productivity, and secure livelihoods in the face of recurring droughts and water scarcity. The capacity of Jalkund depends on water requirement of crop, runoff potential and area availability. Jalkunds can store water in various capacites from 6,000 to 60,000 litres depending on dimensions. The normal dimension of Jalkund vary from 5m x 4m x 2m to 10m x 8m x 2m etc. Approximate cost of construction of Jalkund is Rs. 11,400 per unit, with the capacity of 30,000 litres. Jalkund have been particularly useful for very small and marginal farmers of the state, provides opportunity for cropping intensification.

vi. Augmentation of community water harvesting structures to achieve resilience:

Augmenting community water harvesting structures is a crucial strategy for achieving resilience in drought-prone areas and mitigating the impacts of climate change. These structures, such as check dams, ponds, and percolation tanks, serve as vital reservoirs for capturing and storing rainwater during periods of scarcity. The community pond constructed long back have become defunct due to silting up and due to non-maintenance, resulted in loss of storage capacity of water in the pond during rainy season. Due to neglect of community ponds, excess runoff could not stored to its potential. Desilting of community pond enhance the water storage capacity and availability of water for longer period. Desilting of community ponds also help to improve the ground water level in wells located near the ponds. The ground water can be used for the life saving irrigation during dry spells in *kharif* season and also for pre-sowing and supplemental irrigation for *rabi* crops. The life saving irrigation during dry spells at critical stage of crop help to minimize the impact of drought. Desilting of community pond also provides fertile silt and when used by farmers in their fields, minimizing the fertilizer requirements.

vii. Raised bed shelter for animal:

Raised bed technology for livestock shelters is an innovative approach designed to protect animals from flooding and other adverse environmental conditions. These shelters are constructed on elevated platforms, typically 3-5 feet above ground level, using sturdy materials such as bamboo, wood, or concrete. The raised design ensures that livestock remain safe and dry above floodwaters, reducing the risk of drowning and exposure to waterborne diseases. Additionally, these shelters provide a controlled environment, making it easier for farmers to feed and care for their animals during floods. It offer a practical solution by elevating the animals above floodwaters, providing a dry and secure environment that minimizes stress and reduces the likelihood of injury or mortality. This technology not only enhances animal welfare and health by preventing conditions like foot rot but also offers significant economic benefits by minimizing livestock losses and ensuring the continuity of farming activities

viii. Raised bed vermicomposting technology:

Raised bed technology for vermicompost production is a strategic innovation tailored for flood-affected areas, ensuring the continuity and efficiency of organic waste processing even during adverse conditions. These raised beds are constructed on elevated platforms, typically using durable materials like wood, bamboo, or recycled plastic, to keep the composting units above potential floodwaters. By elevating the vermicompost beds, the technology protects the earthworms and compost material from being washed away, thereby maintaining the integrity and productivity of the composting process. This approach not only mitigates the risks associated with flooding but also enhances the aeration and drainage of the compost beds, leading to higher quality compost. Implementing raised bed vermicompost systems in flood-prone areas ensures a steady supply of nutrient-rich organic fertilizer, supporting sustainable agricultural practices and improving soil health even in challenging environments. With proper design, training, and community support, raised bed vermicompost production can significantly contribute to the resilience and sustainability of farming systems in regions vulnerable to flooding.

ix. Adopting mulching technology:

The adoption of mulching technology, encompassing both straw and plastic mulching, holds paramount importance in drought-prone areas, offering multifaceted benefits for sustainable agriculture and water conservation. In regions vulnerable to water scarcity and erratic precipitation patterns, mulching serves as a practical solution to mitigate moisture loss from the soil surface, thereby enhancing water retention and promoting efficient water use. Straw mulching, utilizing agricultural residues such as crop straw or hay, creates a protective barrier over the soil, reducing evaporation, suppressing weed growth, and moderating soil temperature fluctuations, which are particularly beneficial in drought-prone areas where water conservation is critical. Similarly, plastic mulching involves the application of polyethylene films or sheets, which form a physical barrier that minimizes water evaporation, suppresses weed growth, and promotes soil warming, thus facilitating early crop establishment and growth in adverse conditions. Moreover, plastic mulching enhances soil moisture conservation by reducing surface runoff and soil erosion, crucial aspects for sustaining crop yields and agricultural productivity under drought stress. Studies such as those conducted by Liu *et al.* (2019) underscore the significance of mulching technology, including both straw and plastic mulching, in improving soil moisture retention and enhancing crop performance in drought-prone areas. By adopting mulching practices, farmers can mitigate the adverse impacts of water scarcity, increase agricultural resilience, and improve livelihoods while promoting sustainable land management practices. Additionally, the synergistic effects of straw and plastic mulching contribute to soil health improvement, nutrient retention, and weed suppression, further enhancing the long-term sustainability of agricultural systems in drought-prone regions. Through collaborative efforts involving research institutions, extension services, and policymakers, the widespread adoption of mulching technology can be promoted, offering a promising pathway towards climate-resilient agriculture and food security in drought-prone areas.

x. Ridges and furrows in maize for moisture conservation to cope up with moisture stress in drought area

The technique of ridges and furrows is a highly effective agricultural practice for moisture conservation, particularly suited for maize cultivation in drought-prone areas. This method involves forming alternating raised ridges and lower furrows across the field. Maize plants are typically sown on the ridges, while the furrows serve as channels for water collection and distribution. This setup offers several significant advantages for managing moisture stress and enhancing crop productivity under drought conditions.

One of the primary benefits of the ridges and furrows technique is its ability to maximize water infiltration and retention. When it rains or when irrigation is applied, water accumulates in the furrows. This concentration of water in the furrows allows for more efficient absorption into the soil, ensuring that moisture reaches deeper root zones. Research indicates that this method can significantly improve soil moisture content compared to flat planting. By maintaining higher soil moisture levels around the root zone, the ridges and furrows technique helps maize plants sustain growth during dry periods.

The furrows act as barriers that slow down water movement, allowing more time for infiltration and minimizing runoff. This not only conserves water but also protects the soil structure and fertility. Studies have shown that the ridges and furrows method can reduce runoff by up to 30% and soil erosion by up to 50% compared to conventional flat planting.

xi. Green manuring with dhaincha (*sesbania aculeata*) to enhance crop productivity under the impact of climate change:

Green manuring with Dhaincha (*Sesbania aculeata*) stands out as a robust strategy to bolster crop productivity amidst the challenges posed by climate change. With its remarkable ability to fix nitrogen from the atmosphere through symbiotic relationships with rhizobia bacteria, Dhaincha enriches the soil with essential nutrients, particularly nitrogen, thereby reducing the reliance on synthetic fertilizers which contribute to greenhouse gas emissions. Its deep-rooting system enhances soil structure, fostering better water infiltration and retention, critical attributes for mitigating the impacts of erratic precipitation patterns associated with climate change. Furthermore, Dhaincha's rapid biomass production and subsequent incorporation into the soil improve soil organic matter content, thus enhancing soil fertility and microbial activity, which are vital for sustaining crop yields under changing climatic conditions. Studies such as those conducted by Sharma *et al.* (2018) provide empirical evidence supporting the efficacy of Dhaincha green manuring in enhancing soil quality and crop productivity under climate change scenarios. By integrating Dhaincha into cropping systems, farmers can not only improve soil health and crop yields but also contribute to climate change mitigation efforts by reducing greenhouse gas emissions associated with synthetic fertilizers and enhancing carbon sequestration in agricultural soils. Dhaincha green manuring thus emerges as a promising nature-based solution to enhance agricultural resilience and sustainability in the face of climate change challenges.

As climate change disrupts traditional agricultural practices, innovative solutions are needed to maintain and enhance crop productivity. Green manuring with dhaincha (*Sesbania aculeata*) emerges as a promising strategy for farmers facing these challenges. This technique not only improves soil health but also enhances crop resilience in the face of climate variability.

xii. Zero tillage for moisture conservation and cropping intensification under changing climatic scenario

Zero tillage, also known as no-till farming, is an agricultural practice that significantly contributes to moisture conservation and cropping intensification, making it an effective strategy for adapting to the changing climatic scenario. This method involves planting crops without disturbing the soil through traditional tillage practices, thus maintaining soil structure and health. The implementation of zero tillage offers numerous advantages, particularly in terms of moisture retention and soil conservation, which are critical under the pressures of climate change.

By avoiding tillage, the soil surface remains covered with crop residues from previous harvests. This residue cover acts as mulch, reducing evaporation rates and maintaining higher soil moisture levels. Research indicates that zero tillage can enhance soil moisture by up to 20% compared to conventional tillage. This is particularly advantageous in regions facing erratic rainfall patterns and prolonged dry spells, as it ensures that crops have access to the moisture necessary for growth during critical periods.

Furthermore, zero tillage contributes to carbon sequestration, helping mitigate climate change. By leaving crop residues on the field and minimizing soil disturbance, carbon stored in the soil is less likely to be released into the atmosphere. This practice enhances the soil's ability to act as a carbon sink, offsetting greenhouse gas emissions from agricultural activities.

xiii. Breed up gradation goat

Breed upgradation initiatives play a crucial role in augmenting meat production from goats in drought-prone areas of Assam, contributing significantly to food security and livelihoods in these regions. Traditionally, Assam's goat population comprises indigenous breeds like Barbari, Black Bengal, and Jamunapari. These breeds possess certain advantages, including adaptability to local climatic conditions and disease resistance. However, their meat production potential is often limited. Breed upgradation programs strategically introduce genes from high-yielding meat goat breeds like Boer or Black Bengal bucks into the local stock. This crossbreeding approach can significantly improve offspring characteristics; leading to faster growth rates, higher carcass weight, and ultimately, increased meat production. This approach not only contributes to enhanced food security but also empowers farmers with a sustainable source of income, fostering greater resilience in the face of climatic challenges.

xiv. Popularizing drought resistant crop:

Cultivating drought-resistant crops is of paramount importance for Assam as the region faces increasing challenges from climate change, particularly the rise in drought frequency and intensity. Drought-resistant crops, such as the rice variety "Sahbhagi Dhan," offer a viable solution to this pressing issue. These crops are specifically bred to thrive under water-scarce conditions, ensuring stable yields despite prolonged dry spells. One such crop is "millet," which is known for its drought tolerance and low water requirements. Millets, including varieties like pearl millet and finger millet, can thrive in arid and semi-arid conditions, making them ideal for regions with water scarcity. These crops not only ensure stable yields during droughts but also provide high nutritional value, supporting both food security and health. By integrating millet cultivation into their agricultural practices, farmers in Assam can reduce their dependence on water-intensive crops, enhance their resilience to climate variability, and sustain their livelihoods in the face of changing climatic conditions. By adopting such resilient varieties, Assam's farmers can safeguard their livelihoods, maintain agricultural productivity, and contribute to regional food security. This approach not only mitigates the adverse effects of drought but also enhances the overall resilience of the agricultural sector, making it better equipped to handle the uncertainties brought about by climate change.

xiv. Popularizing Integrated Farming System (IFS) approach

Integrated farming systems, including duck cum fish, duck cum fish cum pig, and rice cum fish, play a pivotal role in combating climate change and fostering climate-resilient agriculture. These integrated systems offer a multifaceted approach to farming by combining different components such as crops, livestock, and aquaculture in a synergistic manner. By diversifying income streams and resource utilization, these systems enhance farm resilience to climate variability and extreme weather events. They promote efficient use of land, water, and nutrients, reducing dependence on external inputs and mitigating environmental degradation. Moreover, the integration of various elements fosters biodiversity conservation and soil health improvement, while also contributing to carbon sequestration efforts. Overall, integrated farming systems represent a sustainable and holistic approach to agriculture that not only enhances farm productivity and profitability but also strengthens the resilience of farming communities in the face of climate change challenges. For eg.

Integrated Paddy-cum-Fish farming is a system of producing fish in combination with paddy cultivation using the same resources in the same unit area. Rice farming with fish culture is a type of dual culture farming system in which rice is the sole enterprise and fishes are taken to initiate additional for extra income. The Rice-cum-fish farming involves the simultaneous production of rice and fish in irrigated rice fields so as to obtain an added production of fish with rice. Flooding is the recurrent phenomenon in some areas of Assam. Though improved submergence varieties can contribute towards higher productivity, the income can be further enhanced by introducing the fish component in the rice fields. The technology was demonstrated in flood areas of Assam under NICRA project. The fish can provide balanced nutrition to the NICRA farmers can provide additional income to the community

Thus, through the innovative technologies, and incorporating scientific knowledge on agriculture with prevailing indigenous technical knowledge (ITK), farmers are empowered to effectively combat climate change while securing sustainable livelihoods for themselves and future generations.

Conclusion:

Assam's agriculture, the lifeblood of the state, faces a formidable foe in climate change. Erratic rainfall patterns, rising temperatures, and increased occurrences of floods and droughts threaten crop yields, livelihoods, and food security. However, this book chapter has illuminated a path forward – NICRA's multi-strategic approach to building resilience.

NICRA's multifaceted interventions offer a powerful counterpunch to climate challenges. From promoting drought-tolerant varieties and flood-resistant rice to advocating for climate-smart cropping practices and efficient water management, NICRA empowers Assamese farmers to adapt and thrive. By fostering innovation and knowledge dissemination, NICRA equips farmers with the tools they need to navigate a changing environment.

The journey towards a climate-resilient Assam agriculture is ongoing. Continued research on new technologies and best practices, coupled with unwavering support for farmer education and collaboration across stakeholders, is crucial. As NICRA remains steadfast in its commitment to these endeavors, a future brimming with a resilient harvest and a sustainable food system for Assam becomes a tangible reality. This future empowers farmers, safeguards the environment, and ensures food security for generations to come.

As we confront the existential threat of climate change, this chapter serves as a beacon of hope, guiding us towards a future where Assam's agriculture thrives in harmony with its natural environment. It inspires collective action and underscores the urgency of prioritizing climate resilience in agricultural development agendas. Through concerted efforts and sustained commitment, we can forge a more resilient and sustainable future for Assam's agricultural landscape, ensuring food security, economic prosperity, and environmental integrity for generations to come.

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ENVIRONMENTAL ISSUES AND SUSTAINABLE LIFESTYLE

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Our Environment - Our Treasure

Our mother planet ‘Earth’ is probably the only home for all of us and that is due the unique layer of atmosphere. The term ‘Atmosphere’ indicates the external layer over the Earth which separates us from outer space. Although no definite boundary exists between the atmosphere and space, the general accepted standard is about 100 km above the surface of the planet. Earth’s atmosphere has five major zones namely troposphere, stratosphere, mesosphere, thermosphere and exosphere in Earth's atmosphere. Among these, the Earth’s atmosphere is highly concentrated near the soil surface i.e. in the troposphere layer which hardly measures about 12 km thick. It is the troposphere area which has a conducive environment to sustain life. If we travel up, surprisingly just at an altitude of about 8 kilometers, the air does not contain enough oxygen to support human life.[1]

The above mentioned scientific data mandates us to think about a delicate layer of atmosphere or surrounding environment which is hospitable to life. The term ‘Environment’ involves living as well as non-living entities. Our surrounding environment influences the entire biotic community in multiple ways. It not only provides breathable air, potable water and food but also protects us from lethal radiations and extreme temperature-pressure effects. Similarly all non-living components like, gases, minerals, water, soil, etc. are also being recycled and replenished continuously. Thus the Earth’s environment presents a remarkably stable atmosphere in-spite of harbouring dynamic biotic and abiotic components. Undoubtedly, in the initial period of gestation, Earth was not that stable; rather it was a boiling revolving planet. Sequentially the cooling took place. It was followed by weathering of regolith (parent rock) and the early emergence of life. Further evolution of diverse kinds of flora and fauna made this plant beautiful and sustainable. One can say that, the stability of Earth’s atmosphere attained after hardship of several billion years.

If we check the history of Human existence, it is found that modern *Homo sapiens* originated from Africa 190,000 B.C.E.[2] Human is the youngest and intellectually brilliant species on the Earth. In a relatively short span of time, human species gained control over the landmasses and water resources of the globe. Initially among various tribes of almost all landmasses ‘Nature’ or ‘Natural Resources’ has a unique reputation. In India the oldest scripture i.e. in Rigveda the concept of 'Pancmahabhootas' means five elements such as Agni, Vayu, Jala, Prithvi and Aakash is mentioned. The status of five elements was equated with 'God'/ 'Goddesses'. The 'Rishi'(priest) of the historic era, used to perform certain rituals to worship five elements and requesting balance or harmony for human society in return. The rituals were also done for optimal rain, prosperity in agribusinesses, non-emergence of diseases and safe environment.[3,4] But over the period of time, across the world we humans have forgotten our responsibility towards the environment.

We started utilizing natural resources with greed by stretching all limits of mother nature. With the advent of science and technology, human species got the upper hand on continuous assured supply of food and water. Similarly successful management of livestock animals added to our food sources. These factors contributed immensely in spurt of population especially during recent two decades. Environmental problems such as deforestation, water reduction, pollution, ozone depletion, global warming, etc. have become more pronounced and apparent with increasing industrialization and urbanization.[5] There is a need to think on each of the environmental issues involving causes and probable solutions.

Environmental Issues

1. Population Explosion

The industrial revolution has benefited mankind in diverse ways by giving many unimaginable comforts. It also reduced the mortality rate of human and livestock animals due to advancement in medical facilities. There is also a noticeable change in the overall lifestyle of mankind. In general it led to sudden increase in population which invited other issues such as -

- ✓ Exploitation of natural resources
- ✓ Urban overcrowding
- ✓ Unemployability
- ✓ Rising rates of poverty
- ✓ Stress on water and food supplies

Thus all above mentioned elements are linked to each other and are byproducts of industrialization.

2. Over-exploitation of Natural Resources

The industrial revolution placed a significant deal of stress on the earth's natural resources particularly on plant and animal species through resource exploitation. Natural resources have been exploited to provide the fundamental needs of clean food, water, and shelter; this exploitation has escalated with population growth, resulting in the clearing of forest trees for fuel and habitation. In order to provide room for homes, farms, and other associated industrial projects, the verdant fields are removed. If one wants the current and future generations to be able to meet their fundamental necessities, such as clothes, food, and shelter, one must preserve our natural resources. There is upsurge need to

- ✓ Reduce dependence on fossil fuels
- ✓ Finding more eco-friendly sources of energy
- ✓ Reducing use of plastic products
- ✓ Encouraging water conservation.

3. Deforestation

Intensive commercial logging of dense forest areas severely affecting the quality of air on the planet. Due to the increasing need of agricultural land for growing food crops, rubber, fruit trees and ornamental plants, forest mass is decreasing day by day. Similarly other development projects such as dam construction, urbanization, mining, industrial plants, extended roadways, etc. put forested areas under threat of vanishing in a few decades. It is evident that deforestation would lead to global warming effect, soil erosion, climate change and variation in rain pattern.
Apart from these concerns, loss of Biodiversity is a major side-effect of deforestation activity. Valuable species of flora and fauna are becoming extinct. It is ultimately going to cause a detrimental effect on human life.

The only solution to this problem is to carry out rigorous 'Tree Plantation' activities. Farmers and citizens should be aware about severe consequences of cutting trees and should be motivated to plant more regional species of trees. In addition to this, rural people should be motivated to use renewable sources of energy for cooking such as Biogas, Solar Cooker, etc. This will also reduce pressure on adjoining forest areas near villages.

4. Pollution

Pollution is the addition of certain man-made constituents to water, air and land which in turn adversely affects the quality of the human health and ecosystems worldwide. When man-made waste products are inadequately treated, they tend to remain in nature for long time, further they may accumulate and in adverse conditions, some chemicals may become harmful/toxic substances which are called pollutants. Certain pollutants are biodegradable which can be easily decomposed naturally by biotic community. e.g. converting agriculture or kitchen waste into compost. However, non-biodegradable pollutants like plastic, mercury etc. are hazardous as they remain in the environment for a prolonged period of time.

Pollution is exhibited in major three ways; its causes and consequent effects vary from type to type.

Pollution in air is primarily caused by emissions from greenhouse gases which are mainly due to industrial exhaust gases and burning of fossil fuels. Degraded air quality causes serious threats to respiratory-cardiovascular systems and environment. Improper trash disposal, runoff from agriculture and industrial discharges all contribute to water contamination. It harms aquatic life, contaminates drinking water sources, and affects ecosystems. Soil contamination, often due to improper waste disposal processes. There is a considerable load of waste added due to industrial/ agricultural/ mining/ nuclear plant activities. It can lead to decreased agricultural productivity and pose health risks to humans and animals.

Addressing pollution requires concerted efforts at various levels, including public, industrialist, government officials and policy makers. There a need to implement and enforce regulations, promote cleaner technologies, adopt sustainable practices and increase public awareness about the importance of environmental protection.

5. Rapid Urbanization

Urbanization is a hallmark of human progress and development but can indeed contribute to environmental harm in several ways:

- Habitat destruction - It is caused by urbanization of natural habitats such as forests, un-utilized waste lands and wetlands. Habitat destruction is carried out for developing modern infrastructure, roads, dams and industries. This can disrupt existing ecosystems and threaten biodiversity
- Over exploitation of natural resources - In order to sustain the infrastructure and support growing populations, urban areas utilize enormous amount of natural resources. This high demand of energy and clean air-water-soil can lead to over exploitation; consequently result in decrease of freshwater sources and elevated levels of greenhouse gas emissions.
- Waste generation - Large amounts of solid waste, such as home trash, building debris, and industrial waste, are produced by urbanization. Inadequate waste management practices such as improper disposal, open dumping, and incineration can pollute soil, water, and air, and contribute to the proliferation of plastic pollution.
- Heat-island - Urban areas exhibit heat-absorbing properties due to buildings, roads, pavement and other infrastructure. It lead to have higher temperatures in urban areas as compared to surrounding rural areas. It is called as urban heat island effect. Due to this, there is increase in energy consumption for cooling, it can cause illnesses related to high temperature and also change weather in local areas.

Addressing the environmental challenges associated with urbanization requires integrated planning, sustainable design, and effective management strategies. These may include promoting compact and efficient urban development, investing in green infrastructure and renewable energy, enhancing public transportation and pedestrian-friendly infrastructure, implementing waste reduction and recycling programs, and fostering community engagement in environmental stewardship initiatives.

6. Global Warming

It means the gradual rise in Earth's average surface temperature brought about by human activity, particularly the atmospheric release of greenhouse gases including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Climate change is a direct result of global warming and is currently one of the most urgent environmental problems on Earth.

Rising temperatures cause melting of ice caps and glaciers, thereby leading to rising sea levels. This, in turn, pose threats to coastal habitats, exacerbates coastal erosion, and increases the frequency and magnitude of natural disasters like hurricanes, droughts, floods, and heatwaves. Moreover, global warming interrupt development of ecosystems, leading to change in habitats and loss of biodiversity. Many species try to adapt to rapid changes in temperature and climate patterns, which can result in population declines and even extinction. Global warming not only negatively affect environment but also cause dynamic changes in social and economic aspects. It affects food security, water resources, human health, and can exacerbate inequalities, disproportionately impacting vulnerable communities and regions.

In order to address the global warming issue, concerted efforts at domestic, national, and international levels are required. This involves transformation to green energy sources, increasing energy efficiency, promoting conservation and reforestation efforts, implementing sustainable activities and adopting policies to decrease greenhouse gas release. While the challenges posed by global warming are immense, there is still hope. Future generations can benefit from a more sustainable and resilient future if we act now to reduce emissions and adjust to changing conditions.

7. Ozone Depletion

Ozone layer comprised of a high amount of ozone (O3) molecules and it is situated in the stratosphere of Earth's atmosphere. It absorbs most of the sun's harmful ultraviolet (UV) rays and thus the ozone layer is essential to maintaining life on Earth. Ozone depletion refers to the thinning of the ozone layer which is a critical environmental issue.

The primary cause of ozone depletion is the release of chlorofluorocarbons (CFCs), carbon tetrachloride, and methyl chloroform into atmosphere. They are common chemicals that are used in industrial processes, refrigeration, air conditioning, and aerosol propellants. After their released into the atmosphere, these ozone-depleting substances (ODS) reach the stratosphere, where they undergo break down by UV radiation and release chlorine and bromine atoms. The halogen atoms of chlorine and bromine destroy ozone molecules and cause the thinning of the ozone layer.

Ozone depletion causes dangerous consequences and pose serious risks to human health as well as the environment. Increased exposure to UV rays can cause a variety of health problems, such as eye problem-cataracts, skin cancer and weakened immune systems. It can also damage terrestrial and aquatic ecosystems by affecting plant growth, marine life and food chains.

Adopted in 1987, the Montreal Protocol is considered by many to be one of the most successful environmental agreements in history. Its goal was to gradually restore the ozone layer by ceasing to produce and use compounds that deplete the ozone layer. There are indications of the ozone layer recovering as a result of the production and consumption of the majority of ozone-depleting compounds being drastically decreased as a result of the Montreal Protocol and its later revisions. However, challenges remain, particularly regarding the phase-out of remaining ODS and addressing new substances that may pose a threat to ozone.

Continued international cooperation and vigilance are necessary to assure protection of the ozone layer and the health of our planet in long run. Ongoing efforts to monitor ozone levels, enforce regulations, and promote alternatives to ozone-depleting substances are crucial in this regard.

8. Reduction in Water Resources

It is well known fact that only 2.5% is freshwater and remaining 97.5% of the water on our planet is salt water. The reduction of water resources is indeed a significant environmental issue that poses serious challenges globally. This issue encompasses both the quantity and quality of available water, affecting ecosystems, human health, agriculture, industry, and overall socio-economic development.

Several factors contribute to the reduction of water resources -

- Overexploitation and overuse - Many regions are withdrawing water from rivers, lakes, and aquifers at rates faster than they can be naturally replenished. This overexploitation leads to depleted water tables, reduced streamflow, and the drying up of wetlands, lakes, and rivers.
- Climate change - Shifts in patterns of rainfall, greater evaporation and increased temperature due to climate change are altering the availability of water in various regions. More frequent and severe droughts are faced by certain areas whereas some areas experience increased flooding and erratic rainfall.
- Pollution - Contamination from industrial, agricultural, and urban activities affects water quality. Polluted water is dangerous for human consumption. It also spoil aquatic ecosystems. Pollutants such as heavy metals, pesticides, fertilizers, and untreated sewage can accumulate in water bodies, posing risks to human health and biodiversity.
- Deforestation - Destruction of forest mass and conversion of landscapes for farming, urbanization, and infrastructure development can disrupt the water cycle, leading to soil erosion, reduced groundwater recharge, and altered runoff patterns.

- Population growth and urbanization - Rapid population growth and urban expansion put pressure on water resources, increasing demand for drinking water, sanitation, and industrial uses. In many urban areas, inadequate infrastructure and water management exacerbate water scarcity and pollution problems.

Addressing the reduction of water resources requires integrated and sustainable management strategies at various levels -

- Conservation and efficient use - Promoting water conservation practices, improving water use efficiency in agriculture, industry, and households, and implementing technologies for water management can help to cut down demand and alleviate pressure on water sources.
- Protecting Ecosystems - Water quality, water flow regulation, and other benefits are maintained and restored when natural ecosystems including riparian zones, wetlands, and forests are preserved. It can also enhance biodiversity and contribute to the resilience of water systems.
- Policy and Governance - Developing and enforcing water management policies, regulations, and institutional frameworks that prioritize sustainable water use, equitable allocation, and protection of water resources are essential for effective governance and stewardship.
- Infrastructure Investment - Improving water supply can be achieved by funding the construction of water infrastructure, such as reservoirs, irrigation systems, wastewater treatment facilities, and dams. It can improve water supply reliability, mitigate floods and droughts, and enhance access to safe water and sanitation services.
- Climate Resilience - Building resilience to climate change by implementing adaptation measures, such as water-efficient agricultural practices, integrated water resource management plans, and climate-smart infrastructure, helps communities cope with changing hydro-logical conditions.

A comprehensive strategy that takes into account how social, economic, and environmental variables are interconnected is needed to address the issue of depletion of water resources. Additionally the involvement of diverse stakeholders and collaboration within various sectors are necessary. By adopting sustainable water management practices and policies, we can safeguard water resources for current and future generations[6,7,8,9]

There is one term "ecological footprint," it basically compares the rate of resource utilization and waste generation by humans as against replenishing resources and absorption of waste by nature.[10] Environmental Sustainability Index is another environmental indicator. It is indicated by the range of values from 0 to 100 (from the most unsustainable to sustainable). Similarly, the Renewability and Energy The Sustainability Index is an additional metric that considers the entire flow of energy in units of aggregate and views the economic system as an open thermodynamic system inside the biosphere.[11] The Environmental Performance Index was built by combination of frontier efficiency techniques with Malmquist index approach.[12] It is reported that, currently we use more resources in the form of clean air, water and land, generating more waste which may pose serious threat to mankind.[13] It is evident from all research that, in the current modern lifestyle, we are depleting sources of energy (fossil fuel), fresh water, forests, fishes, minerals and generating pollutants, especially hazardous wastes. Our massively increasing human population is surpassing the "carrying capacity" of the mother planet.

Thus the need for sustainable development originate from the realization that our current practice of resource utilization and economic growth are not feasible for long journey. **Sustainable development is about meeting the needs of the present without compromising the ability of future generations to meet their own needs.**[14,15,16]

There are several compelling reasons why sustainable development is crucial:

- Environmental Conservation - Harmful human practices like over-harvesting of natural sources, pollution and deforestation, degrade terrestrial and aquatic ecosystems and threaten flora and fauna. Sustainable development aims to protect and conserve valuable natural resources which will assure ecosystem services like generation of clean air, water, food along with balanced climate.
- Climate change mitigation - Climate change poses a significant threat to human societies and ecosystems, with far-reaching impacts on agriculture, water resources, health, and livelihoods. Sustainable development involves transitioning to low-carbon and climate-resilient pathways, lowering greenhouse effect and adapting to dynamic climatic conditions to mitigate the worst effects of climate change.
- Social Equity - Sustainable development seeks to address inequalities and improve the well-being of all people, including marginalized and vulnerable populations. By encouraging social inclusion, literacy rate and access to education, healthcare and basic services and empowering communities to participate in decision-making processes, sustainable development aims to create more equitable societies.
- Economic stability - Unsustainable economic activities often lead to boom-and-bust cycles, resource depletion, and environmental degradation, which undermine long-term economic stability. Sustainable development emphasizes economic diversification, innovation, and investment in green technologies and infrastructure, fostering resilience and reducing vulnerability to shocks.
- Long term prosperity - Sustainable development aims to create thriving, prosperous societies that can endure over the long term. By promoting responsible stewardship of

natural resources, fostering innovation and green industries, and investing in human capital and infrastructure, sustainable development lays the foundation for lasting prosperity and well-being.

- Interconnectedness to global challenges - Many of the world's most pressing challenges, such as poverty, degradation of nature and social unrest, are interconnected and cannot be addressed in isolation. Sustainable development provides a holistic framework for addressing these complex issues by considering their interlinkages and adopting integrated approaches that balance environmental, social, and economic objectives.

Thus sustainable development is essential for safeguarding the planet's ecosystems, promoting social equity and economic stability, addressing global challenges such as climate change, and securing a prosperous future for all. It requires aggregate action, collaboration, and a dedication towards balancing the needs of people, the planet, and future generations

Concept of Sustainable Development

The word Sustainable Development is a combination of two terms i.e. ‘Sustainable’ and ‘Development’. ‘Sustainable’ means use of natural resources for a long time and ‘Development’ means economic growth. The term sustainable development can be viewed in multi-dimensional ways. According to E. Barbier, (1987) sustainable development is about reducing the absolute poverty of the world through supplying lasting and secure livelihoods that lessen resource depletion, environmental degradation, cultural disruption and social instability.”[17]

In nature, living and non living entities are interlinked with each other hence sustainable development seeks to protect and conserve natural resources, ecosystems, and biodiversity. It has been observed that the countries which follow indiscriminate over harvesting of natural resources are likely to face decline in economic growth and loss of ecosystem followed by natural disasters.[18] Hence sustainable development emphasizes on responsible management of air, water, land, and energy resources to minimize environmental degradation and assure the health of the planet for long time. At the same time it acknowledge the importance of growth in economy and prosperity but attempts to achieve these goals which are environmentally sustainable and socially inclusive.

Sustainable development is often described as having three interconnected pillars.[19, 20] They are as follows -

- Economic sustainability - This pillar emphasizes on encouraging economic growth and prosperity in such a way that is sustainable over the long term. Economic sustainability involves research promotion, productivity, and competitiveness while assuring that natural resources are used prudently and equally. It stress upon the importance of generating wealth and creating jobs while minimizing negative environmental and social impacts. Economic sustainability also involves addressing issues such as poverty, inequality, and access to basic services to ensure that economic benefits are shared by all members of society.

- Environmental sustainability - This pillar emphasizes the conservation and stewardship of natural resources and ecosystems to maintain their health, resilience, and productivity. Environmental sustainability involves reducing pollution, conserving biodiversity, protecting ecosystems, and mitigating and adapting to climate change. It aims to ascertain that human activities do not overstep the carrying capacity of the Earth and that future generations can enjoy a healthy and thriving environment. Environmental sustainability also involves promoting sustainable resource management practices, such as sustainable agriculture, forestry, fisheries, and energy production, to minimize environmental degradation and promote ecological resilience.
- Social sustainability - This pillar focuses on promoting social equity, inclusion, and justice to assure that all members of society have access to job opportunities, financial resources, and basic services needed to lead dignified and fulfilling lives. Social sustainability involves addressing issues like poverty, illiteracy, hunger, healthcare, housing, and gender inequality to promote human well-being and social cohesion. It emphasizes the importance of promoting human rights, empowering marginalized and vulnerable groups and fostering participatory decision-making processes to assure that development benefits are equally distributed and that none is left behind.

These three pillars—economic, environmental, and social sustainability—are interconnected and mutually reinforcing. Achieving sustainable development requires balancing the objectives and trade-offs between these pillars to assure that economic growth is eco-friendly, without any social unjust and equitable for all members of society. Integrating these pillars into policy-making, planning, and decision-making processes is essential for promoting holistic and trans-formative change towards a more sustainable and resilient future.

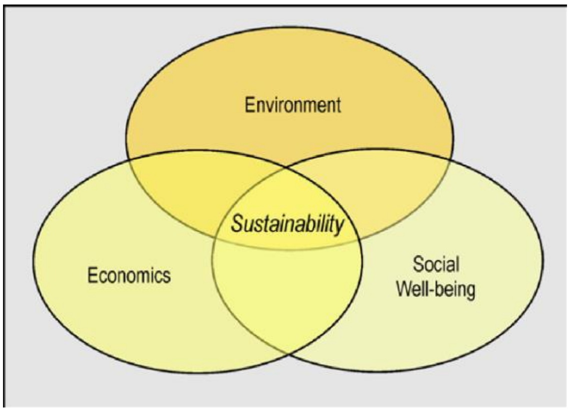

Figure 1: Three Pillars of Sustainability[20]

For a given ecosystem to be sustainable, the economic, social and environment needs to be in harmony so that it can provide a prosperous and healthy life to one and all of present and future generations. In order to achieve this common goal, it encourages innovation, entrepreneurship, and investment in green technologies and industries that generate wealth, at the same time taking care that it will not harm the environment and society. Thus sustainable development takes a holistic approach involving the interconnections and inter-dependencies between environment, society and economy. It tries to address complex challenges such as climate change, poverty, and biodiversity loss through integrated strategies that balance multiple objectives and promote synergies between different sectors.

Sustainable development emphasizes building resilience towards natural disasters, climate change, societal disturbances and economic crises. It encourages adaptive management practices, preparedness, and capacity-building to cope with uncertainty and change.

Sustainable development acknowledges the rights of upcoming generations to receive a healthy and thriving nature. It calls for responsible decision-making and resource management that considers the long-term consequences of present actions, ensuring that natural resources are used wisely and ecosystems are preserved for future generations. It also promotes democratic governance, transparency, and citizen engagement in decision-making processes. It recognizes the value of local knowledge, community involvement, and stakeholder collaboration towards shaping policies and initiatives that affect the environment and society.

Overall, sustainable development represents a vision for a better future, where human well-being is achieved within the limits of the Earth's carrying capacity, and where the needs of existing and future generations are met with a fair, equitable and environmentally responsible manner. Achieving sustainable development requires collective action, collaboration, and a commitment to trans-formative change at domestic, national and international levels.

Sustainable Development Goals (SDGs)

Sustainable development emphasizes to strive for economic growth using all natural resources prudently without affecting the ability of the future generation from meeting their needs. It’s a shared global responsibility. In order to achieve sustainability, responsible proactive decisions and innovations are required towards minimizing hazardous impact on the nature and conservation of valuable resources. At the same time economic prosperity, public health-education and political justice should not be compromised.

With respect to this, 2015 was a landmark year in which the 17 Sustainable Development Goals (SDGs) were adopted by General Assembly of the UN (United Nations) which need to attain by year 2030. These SDGs are as follows –

1. No Poverty 2. Zero Hunger 3. Good Health and Well-being 4. Quality Education 5. Gender Equality 6. Clean Water and Sanitation 7. Affordable and Clean Energy 8. Decent work and

economic growth 9. Industry, Innovation and Infrastructure 10. Reduced Inequalities 11. Sustainable Cities and Communities 12. Responsible Production and Consumption 13. Climate Action 14. Life Below Water 15. Life on Land 16. Peace, Justice and Strong Institutions and 17. Partnerships for the Goals [21]

Sustainable Lifestyle

A sustainable lifestyle is one that prioritizes actions that minimize destructive impacts on the environment, encourage social equity and assist economic prosperity in a way that can be retained over the long period of time. Certain practically workable solutions related to a sustainable lifestyle are discussed below -

- Reduce Consumption - Opt for a minimalist approach by consuming less and prioritizing quality over quantity. Avoid unnecessary purchases, choose durable and long-lasting products, and consider borrowing, sharing, or renting items instead of buying new ones.
- Choose sustainable Products - Make wise choices by selecting products that are eco-friendly, ethically produced, and have minimal environmental impact throughout their lifecycle. Look for certifications like Forest Stewardship Council (FSC) and organic or fair trade to ensure sustainability standards are met.
- Practice Energy Efficiency - Reduce energy consumption by installing energy-efficient home appliances, lighting, and heating/cooling systems. Turn off electronic devices and lights whenever not in use, disconnect chargers and think of investing in green energy sources such as solar or wind energy.
- Conserve Water - Use water wisely by repairing leaking taps, installing water-efficient articles and following water-saving habits such as taking shorter showers, using a dishwasher with a full load, and collecting rainwater for outdoor use.
- Minimize Waste - Reduce waste generation by avoiding single-use plastics, choosing reusable alternatives, composting organic waste, and recycling materials like paper, glass,

plastic, metal, etc. Embrace a zero-waste lifestyle by adopting strategies to reduce, reuse, and recycle resources.

- Support Sustainable Food Selection - Opt for domestic organic and seasonal farm fresh foods in order to cut down the carbon footprint associated with transport. Support sustainable agriculture practices. Choose plant-based meals more often, support organic farm markets, reduce food waste and help to agriculture programs which are community-supported.
- Embrace eco-friendly transportation - Reduce carbon emissions by walking for short distances. Whenever possible do carpooling or use public transportation for long distance journey Choose fuel-efficient or green vehicles which are driven by electric energy and do consider cycling as healthy way of transport.
- Cultivate sustainable habits - Incorporate eco-friendly habits into daily routines such as choosing reusable containers or bags, recycled plastic articles; eco-friendly cleaning and personal care products. Support companies or organizations that follow sustainable ways of manufacture and product services.
- Engage sustainable leisure activities - Enjoy outdoor activities such as hiking, camping, and nature exploration while respecting natural habitats and ecosystems. Choose eco-friendly travel options, support ecotourism initiatives, and engage in activities that promote environmental stewardship and conservation.
- Educate and advocate - Raise awareness of sustainability issues and promote others to follow sustainable lifestyle. Advocate the plan of action and initiatives that encourage sustainability, conservation, and climate action at national and international levels.

By embracing a sustainable lifestyle and making conscious choices in daily needs, people can build a resilient and sustainable future for present community as well as future generations.[22,23,24]

Environment-Friendly Practices - 4R principle (Reduce, Reuse, Recycle & Recover)

Waste is an un-utilizable indispensable component generated in various activities which take place at domestic areas, agriculture fields and industrial plants. The chemical nature of waste depends upon the source of raw materials and the processes which are involved in production of commodities. The biodegradable waste originated from nature (e.g. paper, wood, agriculture and kitchen wastes) and can be degraded by microbial activities in a short period without causing toxic effects on the environment. However the non-biodegradable wastes are man-made products, such as plastic which remain in nature for substantial periods and e-waste/ industrial wastes which can be converted into hazardous materials. The presence of persistent and hazardous materials is a serious matter of concern because it may lead to detrimental effects on nature. Undeniably, the production of waste is inevitable. But one can strategically follow effective waste management at individual level on the basis of 4R principle where **4'R' represents Reuse, Reduce, Recycle and Recover.**

Reuse *– Use of various durable articles is an effective way to reduce amount of solid waste as well as reduce unnecessary spending on one-use throw articles. Examples -*

- One-sided printed papers can be reused for rough work at home and in offices.
- Old clothes can be donated to charitable trusts.
- Plastic containers can be re-utilized for plantation/ storage after use.
- Electronic devices should be reused after repairing
- Rain water harvesting and storage can be done for gardening and other purposes

Reduce *– approach demands a smart way of buying/ using articles which will lead to less production of waste. Examples -*

- Minimizing usage of plastic carry bags/ containers in all day to day activities
- Incorporating usage of washable items like cotton napkins instead of paper towels
- Cotton/Jute shopping bags can be preferred for marketing.
- Cotton diapers can be used instead of disposable ones.
- Saving paper by promoting paperless practices in administration of offices

Recycle *– offers the added advantage of reducing the burden of extraction of raw materials from nature. Examples -*

- Kitchen waste can be managed at home scale for preparation of compost
- Domestic waste water can be treated by Municipal Corporations and used for plantation purpose in cities
- Domestic and agricultural waste can be treated to produce biogas in rural areas.
- Debris of construction should be used for the formation of bricks.

Recover *– provides an opportunity to extract valuable metal ions from waste such as gold, copper, lead, etc. Example -*

- Certain plants are known as 'Hyper-accumulators' as they absorb selective metals and store it in their tissues. Such plants can be cultivated on waste lands which are contaminated by heavy metals. Such plants further can be used in 'Phyto-Mining'.
- Similarly 'Rhizofiltration' is a promising process to recover valuable metals using aquatic plants from wastewater.

Thus the 4R approach is stressed upon prudent use of articles which are durable and degradable commodities. It is useful in minimizing pollution and restoring the environmental health.[23]

Sustainable Cities -

Sustainable cities are urban areas that are planned, developed and managed in such a way that they can attain harmony in environment, society and economy. These cities aim to create vibrant, inclusive, and resilient communities that fulfill the needs of present and future generations at the same time minimizing harmful impacts on the environment. Here are some key features and strategies of sustainable cities-

- Compact and Mixed-use development - Sustainable cities promote compact and mixed-use development patterns that reduce urban sprawl, minimize land consumption, and enhance walkability. By locating residential, commercial, and recreational areas close together, sustainable cities encourage active transportation, reduce car dependency, and promote social interaction.
- Public transportation and active mobility - Sustainable cities prioritize public transport systems such as buses, railways and metro to provide affordable, efficient, and accessible mobility options for residents. They also invest in infrastructure and amenities that support walking, cycling, and other forms of active transportation, reducing congestion, air pollution, and greenhouse gas emissions.
- Green infrastructure and urban green spaces - Sustainable cities involves development of green infrastructure inform of gardens/parks, green roofs, urban forests, terrace gardens and vertical gardens to enhance air quality, improve biodiversity, regulate temperatures, and manage storm-water runoff. Green spaces provide recreational opportunities, promote mental and physical health, and enhance the overall quality of life for residents.
- Energy efficient buildings and green energy - Sustainable cities prioritize energy efficiency measures in buildings. It mainly includes installation of energy efficient appliances for heating/cooling systems and lighting. In order to make energy sufficient and mitigate climate change, the use of green energy obtained from Sun, water, wind and geothermal power plants is promoted.
- Waste management and circular economy - Sustainable cities implement waste management strategies through which waste generation is minimized, recycling and composting is promoted and landfill disposal is reduced. They also embrace the principles of the circular economy, which focuses on maximizing resource efficiency, reusing materials, and minimizing waste throughout the product life cycle.
- Water conservation and sustainable water management - Sustainable cities prioritize conservation of water by means of gathering rainwater, recycling grey-water and water-efficient landscaping to mitigate water scarcity. They also implement sustainable water management practices to protect water quality, manage stormwater runoff, and restore natural water systems such as rivers and wetlands.

- Social inclusion and affordable housing - Sustainable cities promote social equity and inclusion by providing affordable housing options, supporting mixed-income neighborhoods, and addressing homelessness and housing insecurity. They also prioritize access to education, healthcare, social services, and cultural amenities to ensure that all residents have the opportunity to thrive.
- Community engagement and participation - Sustainable cities engage residents, businesses, and other stakeholders in decision-making processes, planning initiatives, and community projects. They foster a culture of collaboration, transparency, and accountability to ensure that the policies are framed vigilantly and programs reflect the necessity and priorities of the community.
- Resilience and climate adaptation - Sustainable cities build resilience to climate change and other environmental hazards by incorporating climate adaptation measures into urban planning and infrastructure design. They assess vulnerability, identify risks, and implement strategies to protect critical infrastructure, enhance disaster preparedness, and promote adaptive capacity among residents.
- Smart and innovative technologies - Sustainable cities leverage smart and innovative technologies to improve efficiency, enhance service delivery, and optimize resource management. They use data-driven approaches, digital platforms, and sensor technologies to monitor air quality, manage traffic congestion, optimize energy use, and enhance urban governance.

By adopting these strategies and principles, sustainable cities strive to create livable, healthy, and prosperous urban environments that balance the needs of people, the planet, and the economy. They serve as models of sustainability and innovation, inspiring positive change and driving progress towards a resilient future.

Examples of Smart Cities -

There are several cities around the world that are leading the way in sustainability and are often cited as examples of sustainable urban development.[25,26,27] Here are a few notable examples -

- **Freiburg, Germany -** Freiburg is recognized as a pioneer in sustainable urban planning and renewable energy. The city has embraced solar power and sustainable building practices, with over 5000 solar installations and numerous energy-efficient buildings such as the Vauban Eco-district. Freiburg also prioritizes public transportation, cycling infrastructure, and car-free zones, making it a model for sustainable mobility and livable communities
- **Copenhagen, Denmark -** Copenhagen is often considered one of the greenest cities in the world. It is famous for its dedication towards sustainability and It has set ambitious

targets to become carbon-neutral by 2025 and is investing heavily in renewable energy, energy-efficient buildings, and sustainable transportation. Copenhagen boasts an extended network of bike lanes, pedestrian friendly streets and green spaces, making it a model for sustainable urban mobility

- **Stockholm, Sweden -** Stockholm is recognized for its commitment to environmental stewardship and quality of life. The city has implemented comprehensive waste management and recycling programs, invested in renewable energy and energy-efficient buildings, and promoted sustainable transportation options such as cycling and public transit. Stockholm's green spaces, clean waterways, and eco-friendly neighborhoods contribute to its reputation as one of the world's most sustainable cities.
- **Curitiba, Brazil** - City is celebrated for its unique innovative urban planning as well as public transport system. It has pioneered the Bus Rapid Transit (BRT) system, which efficiently moves large numbers of passengers while reducing congestion and air pollution. Curitiba also prioritizes green spaces, recycling initiatives, and social inclusion programs, making it a model for sustainable development in emerging economies.
- **Portland, USA -** Portland is celebrated for its strong environmental ethos and commitment to sustainability. The city has invested in public transportation, cycling infrastructure, and green spaces, earning it a reputation as bike-friendly and walk-able city of United States. Portland's focus on urban density, green building design, and local food systems reflects its dedication to sustainable living and community resilience
- **Vancouver, Canada -** Vancouver is known for its stunning natural surroundings and progressive sustainability initiatives. The city has set ambitious goals to become the greenest city in the world by 2020 and has implemented measures to drop down temperature effect of greenhouse gases, promote active transportation, and improve energy efficiency of buildings. Vancouver's focus on urban density, green building design, and renewable energy sources exemplifies sustainable urban development in a North American context.

These cities demonstrate that sustainable urban development is achievable through visionary leadership, innovative planning, and collaboration between government, businesses, and communities. By adopting holistic approaches to sustainability that integrate environmental, social, and economic considerations, these cities serve as models for creating thriving, resilient, and equitable urban environments.

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THE ROLE OF VESSEL MONITORING SYSTEMS (VMS) IN PROMOTING SUSTAINABLE FISHERIES MANAGEMENT: CHALLENGES, OPPORTUNITIES, AND FUTURE DIRECTIONS

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Abstract:

The global fisheries industry faces multifaceted challenges, prominently driven by overfishing, necessitating urgent international cooperation for sustainable resource management. Vessel Monitoring Systems (VMS) emerge as pivotal tools in this endeavour, facilitating compliance with regulations and enhancing data collection efficiency. This paper explores the role of VMS in fisheries management, emphasizing its functions, components, and applications, alongside potential advancements such as integrating artificial intelligence and satellite surveillance. Additionally, it addresses operational requirements and challenges, particularly in developing countries, proposing strategies to overcome barriers to VMS implementation. By fostering international consensus and innovative solutions, VMS can catalyze coordinated efforts towards sustainable fisheries management on a global scale.

Keywords: Fisheries management, Vessel Monitoring Systems (VMS), Sustainability, Overfishing and International cooperation.

Introduction:

The global fisheries industry faces significant challenges across various regions, including the North Sea, the Northwest Atlantic, the Northeast Pacific, the Bering Sea, the Mediterranean, and coastlines in Africa and South America (FAO, 2020). These regions are grappling with fisheries in varying states of difficulty, highlighting the urgent need for international cooperation to restore and ensure the health and sustainability of this vital natural resource, which plays a crucial role in our food supply (Costello *et al.*, 2016). The widespread threat to world fisheries largely stems from the well-documented issue of overfishing (Pauly & Zeller, 2016). The ability to locate and catch fish stocks has increased significantly, leading to overexploitation even under sound management practices affected by environmental factors (Worm *et al.*, 2009). Fisheries managers primarily rely on tools like quotas and fishing effort limitations to counter overfishing and protect stocks (Hilborn *et al.*, 2020). However, the effectiveness of these measures is hindered by inadequate resources for enforcement, including personnel, patrol vessels, and aircraft (Agnew *et al.*, 2009). Addressing these challenges requires innovative solutions, with Vessel Monitoring Systems (VMS) emerging as a key tool in fisheries management (Deng *et al.*, 2005). Timely and accurate information on fishing vessel movements enhances operational efficiency and resource management (Mazor *et al.,* 2013). While national and regional VMS initiatives are commendable, the global nature of fishing fleets necessitates a coordinated international approach (McCauley *et al.,* 2016). There is a growing consensus among fisheries managers worldwide on the need to harmonize efforts to save fish stocks that transcend national boundaries (Pons *et al.,* 2018). Achieving this requires detailed agreements on VMS implementation standards to facilitate seamless operations across different fisheries (Kroodsma *et al.,* 2018). Establishing a broad international consultation platform where fisheries protection officials can express their needs, preferences, and concerns regarding VMS implementation is crucial for developing a universal standard (Mora *et al.,* 2009). While the establishment of a global VMS standard remains a complex endeavour due to logistical, political, and economic challenges, fostering some level of consensus on VMS implementation could provide temporary guidance (Österblom *et al.,* 2015). This shared direction, albeit temporary, could serve as a stepping stone towards aligning fisheries managers globally and moving towards sustainable fisheries management practices Garcia on an international scale (Garcia & Charles, 2007).

1. Enhancing Fisheries Management with Vessel Monitoring Systems

Vessel Monitoring Systems (VMS) play a vital role in fisheries management by fulfilling two key functions:

1.1. Ensuring Compliance with Fisheries Management Rules

Fisheries management rules aim to promote sustainable and profitable fishing practices by regulating vessel access, gear types, fishing time, and catch quotas. VMS is instrumental in enforcing these rules by providing real-time vessel position data to monitoring agencies. This data transmission allows for effective tracking of vessel activities, ensuring adherence to regulations and enhancing the overall management of fish stocks (Sumaila *et al.,* 2019).

1.2 Streamlining Collection of Fishing Catch and Effort Data

Accurate catch and effort data are essential for assessing the status of fisheries. VMS offers significant advantages in data collection by improving the timeliness of information delivery, reducing data entry costs, and enhancing data accuracy through streamlined processes (Deng *et al.,* 2005). Direct interaction between vessel operators and data entry/editing programs facilitated by VMS contributes to more efficient data handling and reporting (Mazor *et al.,* 2013). VMS systems typically consist of mobile transceiver units on vessels, a communication service provider for data transmission, and secure monitoring facilities for compliance oversight. The confidentiality of collected data is maintained, accessible only to authorized personnel. The application of VMS has shown promise in fisheries like the commercial snapper grouper fishery in the South Atlantic region of the United States. By enhancing data collection, ensuring compliance, and serving as a safety tool, VMS can significantly improve fisheries management practices. However, the costs associated with VMS implementation, including installation, maintenance, and communication expenses, are typically the responsibility of vessel owners. Catch data and other fishing activity data such as reports about a vessel's intentions, may also have a compliance-related function. For example, catch reports may be used to monitor a catch quota. Catch and effort reporting has not been a major focus of VMS implementation to date, the major exception being the VMS implemented by Japan. Further catch and effort reporting via VMS can be expected to develop around the world but this document will only deal with catch and effort reporting as it relates to MCS in keeping with the purpose of the document.

2. Understanding Vessel Monitoring Systems (VMS)

Vessel Monitoring Systems (VMS) are a crucial tool in the Monitoring, Control, and Surveillance (MCS) toolkit for fisheries management. VMS provides fisheries management agencies with accurate and timely information about the location and activity of regulated fishing vessels.

Vessel Monitoring Systems (VMS): What They Do vs. What They Do Not Do

What VMS Does

- **Accurate Vessel Location:** VMS provides precise data on the location of regulated fishing vessels, allowing fisheries management agencies to monitor and manage fishing activities effectively (Deng *et al.,* 2005).
- **Near Real-Time Data:** VMS delivers near real-time information on vessel positions, enhancing the ability of authorities to respond swiftly to potential violations or emergencies.
- **Vessel Speed and Heading:** VMS tracks and reports on the speed and heading of vessels, contributing to a better understanding of fishing patterns and potential illegal activities.
- **Catch and Effort Data:** VMS systems can collect data on fishing effort, such as the time spent fishing and the areas covered, which is crucial for stock assessment and management (Mazor *et al.,* 2013).
- **Communication Capabilities:** VMS can facilitate communication between vessels and management authorities, improving the coordination and response to at-sea incidents (McCauley *et al.,* 2016).

What VMS Does Not Do

- **Does Not Replace Conventional MCS Measures:** VMS does not eliminate the need for traditional MCS methods such as aerial surveillance, at-sea boarding, landing inspections, and documentary investigations (Agnew *et al.,* 2009).
- **May Not Provide Sufficient Evidence for Court Proceedings:** VMS data alone might not be enough for legal actions in criminal courts but can be the basis for further investigations using other MCS methods.
- **Does Not Intervene in Vessel Operations:** VMS itself does not enforce regulations or directly intervene in the operations of fishing vessels; it is primarily a monitoring tool.

- **Does Not Guarantee Accuracy of Catch and Effort Reporting:** The accuracy of catch and effort data reported via VMS needs to be verified through other means, such as observer programs, to ensure reliability (Pauly & Zeller, 2016).
- **Does Not Ensure Complete Coverage:** VMS does not guarantee that all vessels are monitored, as some vessels may not be equipped with VMS systems or may operate in areas with limited connectivity (Kroodsma *et al.,* 2018).

3. The Role of VMS in Fisheries Management

Vessel Monitoring Systems (VMS) are a key component of effective fisheries management, providing monitoring agencies with valuable information to ensure compliance with regulations and support sustainable fishing practices. By tracking vessel movements and activities, VMS enables fisheries managers to make informed decisions and respond to potential issues in a timely manner (Deng *et al.,* 2005). The implementation of VMS varies across regions and countries, with specific requirements and approved equipment depending on the fishery and vessel type. However, the core principles of VMS remain consistent: to enhance monitoring and control of fishing activities, promote sustainable resource use, and protect the livelihoods of fishermen (Mazor *et al.,* 2013).

4. Suitable Applications of Vessel Monitoring Systems (VMS) in Fisheries Management

Vessel Monitoring Systems (VMS) can be effectively applied in various fisheries management scenarios, particularly those involving restrictions related to specific geographic areas. Some examples of suitable applications include:

- ❖ Monitoring areas closed for fishing, navigation, or other activities like transhipment
- ❖ Enforcing temporal closures of certain areas
- ❖ Restricting access to specific areas based on vessel characteristics (nationality, type, size, license status, etc.)
- ❖ Controlling the amount of access to an area by timing or counting vessel entries
- ❖ Enforcing catch quotas or other restrictions in a particular area
- ❖ *In situ*ations where catch restrictions apply, it may be necessary to modify management rules to fully leverage VMS capabilities. For instance, requiring vessels to operate in a single area during a voyage can make it easier for VMS to detect fishing activity outside the designated area and facilitate port inspections to verify catch sizes.

4.1 Deterrent Effect of VMS

One of the significant impacts of VMS in Monitoring, Control, and Surveillance (MCS) is its deterrent effect. When fishing vessel operators are aware of being monitored and the likelihood of enforcement action for illegal activities, they are less likely to engage in such practices (Agnew *et al.,* 2009). This preventive aspect of VMS is crucial for maintaining the credibility of the system in the eyes of vessel operators. To sustain the deterrent effect, all operational issues, particularly those affecting vessels (e.g., failure to report on schedule), must be followed up (Mazor *et al.,* 2013). The presence of VMS equipment on vessels and its use for direct communication between vessels and monitoring agencies further reinforces the monitoring function (Deng *et al.,* 2005).

4.2 Targeted Investigations and Inspections

VMS can assist in establishing "probable cause" for investigations in some jurisdictions, such as obtaining search warrants. While VMS data alone may not be sufficient evidence for convictions, it can provide enough information to lead officers to believe that an illegal act has occurred. VMS also enables targeted at-sea or landing inspections of vessels, allowing monitoring officers to determine a vessel's location and potential port entry time. This capability can result in significant savings in time and resources compared to conducting random inspections.

4.3 Enhancing Surveillance Patrols and Catch Reporting

Even with an effective VMS, patrols by sea and air remain necessary for fully effective MCS, as unlicensed vessels may not participate in VMS or their position data may not be available to a particular nation's monitoring agency (McCauley *et al.,* 2016). Providing VMS data to patrol craft can minimize the time spent confirming legitimate fishing vessels detected by radar (Kroodsma *et al.,* 2018). Additionally, VMS's communication capabilities can help assure that vessel operators accurately declare each catch as it is made, increasing the risk of detection for under-reporting or misreporting catches. This is particularly useful in fisheries with catch restrictions or quotas for specific species in certain areas (Mazor *et al.,* 2013).

5. VMS Components

Vessel Monitoring Systems (VMS) consist of several essential components that collectively facilitate efficient fisheries management. At its core, VMS operates as a cooperative system, where participating vessels are equipped with transmitters or transceivers capable of fixing their positions (Deng *et al.,* 2005). These devices, often erroneously referred to as transponders, utilize the Global Positioning System (GPS) due to its accuracy, widespread availability, and cost-effectiveness (Deng *et al.,* 2005). The automated reporting system, governed by programmed instructions within the transmitters and the communications infrastructure, ensures timely transmission of position data to fisheries monitoring stations (Agnew *et al.,* 2009). Communication between vessels and monitoring agencies typically occurs through satellite-based systems, offering global coverage and high reliability. Alternative methods like cellular phone and HF radio are also utilized in some cases, such as in China's trial of VMS using Single Side Band radio (Kroodsma *et al.,* 2018). Satellite-based communication involves data transfer from the vessel to a satellite, then to an earth station, and finally to the monitoring agency via secure public data networks or telephone networks, adhering to international data communication protocols like X25 (Mazor *et al.,* 2013). Within monitoring agencies, computerized stations play a pivotal role, collecting, storing, and analyzing data received from vessels (McCauley *et al.*, 2016). This analysis includes detecting and highlighting exceptional conditions relevant to monitoring officers and presenting data in a meaningful format, often against geographical backgrounds. Additionally, the integration of specialized Geographical Information Systems (GIS) further enhances the monitoring station's capabilities, facilitating historical and statistical analyses of both position and catch data (Mazor *et al.*, 2013). Together, these components form a robust VMS infrastructure crucial for effective fisheries management and conservation efforts (Pauly & Zeller, 2016).

6. The Potential Impact of Artificial Intelligence on Fisheries Management

Satellite surveillance technology is gradually emerging as a potential component for monitoring and controlling fishing vessel activities, although it's not yet fully integrated into existing systems. This technology, commonly associated with non-cooperative targets, employs satellites too visually or radar detect vessels without their active participation in the monitoring process. While traditionally utilized by military intelligence agencies, satellite imagery has become more accessible for commercial and governmental applications.

Two primary types of satellite imagery exist: optical/infrared and Synthetic Aperture Radar (SAR). SAR, in particular, shows promise for fisheries Monitoring, Control, and Surveillance (MCS) due to its capability to penetrate cloud cover and operate in darkness. Service providers now offer software packages that analyze SAR data, pinpointing vessels within SAR images.

Despite ongoing trials in countries like Norway and Canada, the widespread adoption of satellite surveillance for fisheries MCS remains uncertain. Several challenges hinder its effectiveness:

- Varying success rates: SAR systems' effectiveness in detecting vessels fluctuates depending on sea state and satellite angles, necessitating enhancements in image processing and satellite technology.
- Lack of vessel identification: Vessels detected by SAR remain unidentified, and further confirmation through conventional means such as patrol boats or aircraft is necessary.
- Limited coverage and revisit intervals: SAR satellites have limited coverage in equatorial regions and revisit geographical locations intermittently, potentially delaying detection and response to vessel activities.
- Cost considerations: SAR imagery is relatively expensive, with a single scene costing thousands of dollars.

Despite these limitations, SAR-equipped satellites hold potential for fisheries MCS, particularly in monitoring areas where conventional surveillance is impractical. When combined with existing VMS technology, SAR systems could enhance monitoring efforts by complementing VMS's vessel tracking capabilities with SAR's vessel detection capabilities. However, further development is needed to address the current limitations of SAR technology and make it economically viable for widespread use in fisheries MCS initiatives.

While satellite MCS initiatives primarily focus on VMS due to its commercial availability and cost-effectiveness, satellite surveillance technologies like SAR offer valuable additional tools for monitoring and controlling fishing activities. As technology advances and challenges are addressed, the integration of satellite surveillance with existing MCS systems may become more feasible, potentially revolutionizing fisheries management practices.

7. VMS Operational and Performance Requirements

Table 1: Major VMS Operation Requirements

Requirement	Description
Position Report Accuracy	VMS equipment, known as Vessel Location Devices (VLDs), must provide vessel positions with a specified accuracy, typically within ±100 meters. The European Commission and the U.S. National Marine Fisheries Service have set accuracy requirements at ±500 meters to accommodate certain terminal systems.
Vessel Speed and Course	GPS-equipped VMS receivers provide vessel speed and course data, aiding in determining fishing activity. Speed and course information, along with vessel type and gear used, can indicate non-fishing activities.
Frequency of Position Reports	Vessels are typically required to report positions up to hourly, with more frequent reporting (e.g., every 15 minutes) in cases of suspected illegal activity. Dynamic reprogramming capabilities are essential for varying reporting frequencies based on management needs.
International Data Exchange Formats	Standardized formats and protocols for exchanging VMS data between national monitoring agencies are crucial. Agreed standards would facilitate data exchange and software development for seamless communication.
Catch and Effort Data Formats	Standardizing catch and effort data transmission via VMS is essential to avoid confusion and ensure data consistency. A universal format and protocol are needed to support data transmission across jurisdictions.
Other Data Transmission	VMS can transmit additional data from sensors onboard, such as water temperature or equipment operation details. Consideration should be given to standardizing intention messages and sensor data for clarity and ease of use.
Beginning and End of Operation Messages	VLDs should send special messages when entering or exiting service to avoid anomalies in position reporting. Emergency operation messages are crucial in case of power interruptions to maintain data integrity.
Two-way Messaging Capability	Systems with two-way messaging enable fisheries managers to communicate operational messages to vessels. Manual input devices onboard vessels enhance catch reporting capabilities, a key aspiration for fisheries managers.

8. Challenges and Opportunities of Implementing Vessel Monitoring Systems (VMS) in Developing Countries

In developing countries, the implementation of Vessel Monitoring Systems (VMS) faces significant challenges due to limitations in economic and telecommunications infrastructure. The primary obstacles include ensuring the installation and functionality of necessary hardware on each vessel, establishing base stations capable of receiving and processing data, and accessing telecommunications networks with adequate performance levels, all at a cost acceptable in the developing world. Normalization of Vessel Location Devices (VLDs) could address the hardware issue by standardizing equipment requirements. Despite cost concerns, mandating certified VLDs for foreign vessels fishing in their waters could be a feasible condition for access, given the value of fishing grounds in developing countries. Additionally, base stations for VMS need not be highly sophisticated; a simple PC with appropriate software can meet most operational needs at a moderate cost. While telecommunications infrastructure remains a significant challenge, increasing internet access in developing countries offers potential for utilizing internet-based VMS systems, albeit with some performance limitations compared to dedicated satellite links. Overall, despite these challenges, VMS can be a valuable tool for fisheries management in developing countries, provided appropriate strategies are employed to overcome logistical and cost barriers.

Conclusion:

Henceforth, the global fisheries industry faces a pressing need for sustainable management practices to combat the pervasive threat of overfishing. Vessel Monitoring Systems (VMS) emerge as indispensable tools in this endeavors, facilitating compliance with regulations, enhancing data collection efficiency, and promoting international cooperation. By addressing key challenges and leveraging innovative solutions such as artificial intelligence and satellite surveillance, VMS can play a pivotal role in safeguarding fish stocks and ensuring the long-term viability of the fisheries sector. With concerted efforts and collaboration among stakeholders, including governments, fisheries managers, and industry players, the adoption and integration of VMS can pave the way for a more sustainable and resilient future for fisheries worldwide

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CITIZENS' PERCEPTIONS OF CLIMATE CHANGE AND SUSTAINABLE CITIES IN MUMBAI'S METROPOLITAN REGION

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Abstract:

i. **Aim**: The aim of this survey was to study the perceptions on climate change, natural disasters and sustainable cities and sustainable development of Mumbai's metropolitan residents, to be used to call for better climate action and to ensure better and greater citizen participation in environmental movements.

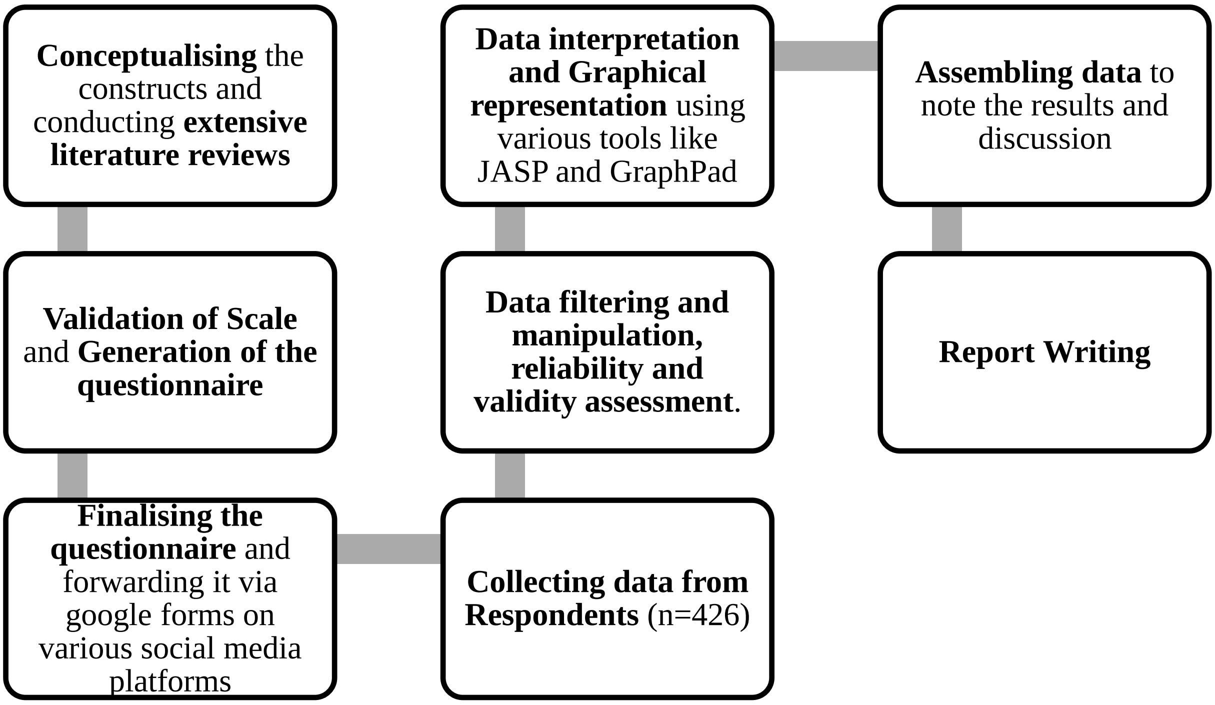
ii. **Methodology**: The survey was administered and circulated via Google Forms via various social media platforms, targeting an audience above 16 years of age. Statistical analysis tools like JASP version 0.18.3 and GraphPad were used.

iii. **Results**: The results indicate that citizens of Mumbai's metropolitan region are extremely concerned regarding climate change. Substantial links between climate change concern levels and the perceived impact of individual lifestyle choices on climate change were discovered, but no significant connection between the levels of climate change concern and the involvement of households in recycling initiatives or endeavours aimed at combating climate change was found.

iv. **Interpretation**: Climate change perceptions among the public must be understood. Awareness campaigns are the need of the hour to ensure that residents are aware of the negative impact of climate change and global warming and begin taking up more sustainable practices to ensure that the city thrives in the future.

Keywords: Climate Change, Mumbai, Sustainable Cities and Development

Graphical Abstract:



Introduction:

India is a peninsular country with a long coastline of around 7,000- 8,000 km, encircled by the Indian Ocean, the Bay of Bengal, and the Arabian Sea. It is a rapidly developing nation whose economy has seen a rapid transformation, not necessarily sustainable or inclusive since the 1990s (Sharma and Chaturvedi, 2020). Previous studies have reported an association between intense weather events and anthropogenic climate change (Estrada *et al.*, 2023). This suggests that coastal residents are vulnerable to the repercussions of climate change, including elevated sea levels (Chauhan, 2009).

The current population in India 2024 is 1.44 billion (Projected Population - Census of India https://censusindia.gov.in). To serve the growing population, there has been tremendous growth associated with consumption. Since India is one of the fastest growing global economies (developing country) large-scale migration has been observed into urban cities.

Urban areas present a dual role in climate change, serving as a primary source of worry due to their substantial carbon emissions, while also holding promise for climate adaptation, mitigation, and sustainable growth (Chandni Singh *et al.*, 2021).

Mumbai is one among twenty other cities considered to be at the greatest risk from coastal flooding by 2050 (Ghosh, 2015). Due to the growing pressure on the infrastructure along with quick unplanned expansion, Mumbai has an increased vulnerability to climate change shifts. Factors such as overcrowding, old buildings and mangrove degradation further make it imperative to incorporate sustainable changes to the city. Before this, it is important to understand more about sustainable behaviour, climate change knowledge and climate change perceptions among the citizens of Mumbai.

a) **Approaches to climate change adaptations.**

Preliminary scientific literature reviews and surveys indicate that anthropogenic greenhouse gases have been responsible for the warming of the Earth since the 20^{th} century, due to increased production and consumption of crucial resources in urban/ developing cities. Therefore, it is vital that such cities prepare for the forthcoming climatic impacts and also take necessary steps to lower their anthropogenic contributions towards greenhouse gas emissions (Alankar, 2015)

b) **Planning, implementation and adaptation.**

In this century, global warming has been accelerating and climate change has been reaching levels that will affect future generations. Owing to the high density, increasing urban population and the amount of pollution in the cities, it has led to a focus on climate change and sustainability adaptations in cities (Chandni Singh *et al.*, 2021).

Efforts have to be taken by policymakers to combat climate change and determine strategies to alleviate and accommodate the impending issues. Climate change policies alone are insufficient to sensitise individuals about the consequences.

To raise public awareness of climate change, it is imperative to put extra efforts into place for media outreach initiatives. Such steps will promote public awareness regarding climate change and its associated impacts among a larger proportion of the public. (Korkmaz, 2018).

Hence, knowledge about climate change is important and necessary so that people adapt appropriately. Climate adaptation strategies must be established with both long-term and short-term objectives. However, these adaptation strategies cannot have the same approach, since each city is different (Cortekar *et al.*, 2016).

c) **Forthcoming consequences in developing cities.**

One of the nation’s highly vulnerable to the climate crisis is India. According to a study by Revi, 2008, in Indian cities, the populations most vulnerable to climate change are the slum, squatter and migrant populations whereas the most vulnerable structures are public and private infrastructure as well as informal or traditional housing. Climate change can hit these populations and disrupt structures causing a cascade of problems.

However, it is crucial to comprehend the collective cognizance regarding environmental shifts and more importantly, sustainable strategies which can be enacted to mitigate the effects of climate variability on a wide scale. Recognising the societal views regarding climatic change can ultimately boost the collective action taken to tackle the same. Key stakeholders would be able to bring about awareness and frame appropriate policies and strategies (Korkmaz, 2018).

Mumbai, a highly populated megacity, is exceptionally susceptible to the impacts of climatic fluctuations and its effects including a rise in sea level, coastal erosion and flooding (de Sherbinin *et al.,* 2007). In addition to this, a large proportion of vulnerable communities, increased migration and poor infrastructure make it essential to formulate strategies to mitigate and prevent climate change in Mumbai (Patankar *et al.,* 2010).

Considering these aspects, it is very important that as the city continues to expand, it does so in a more sustainable manner.

In reaction to the climate catastrophe and to maintain a high standard of living for their residents, many cities worldwide are currently transforming into sustainable or climate-resilient communities. Examples include Masdar City in Abu Dhabi (D'Eramo, 2021), which was designed with a traditional Arab layout, to make it waste-free and carbon-neutral, and help the city adapt to the severe climate (Ibrahim, 2016). Semarang, Indonesia, a city highly susceptible to climate change-related risks (Findayani *et al.,* 2024), which include rising sea levels, coastal erosion and regular flooding, is adopting strategies like extensive afforestation, and mangrove reforestation (United Nations Environment Programme, 2017). Mangroves act as coastal defences and improve fisheries- which benefit local communities dependent on the same. Mumbai, however, has lost large swathes of mangroves (Everard *et al.*, 2014) and should therefore take steps toward harnessing the multi-pronged benefits offered by mangroves to build climate change resilience.

Toronto, witness to several climate change-induced disasters, is focussing on making infrastructural changes to make the city more resilient- by using methods like Green Roof infrastructure- which the government hopes will improve the air purity (United Nations Environment Programme, 2017), support 'urban biodiversity', and reduce a building's energy use requirements (Blackhurst *et al.,* 2010; Köhler and Clements, 2013).

Johannesburg, grappling with the effects of climate change and facing issues like freshwater supply and flooding, has turned to 're-planning' initiatives like reducing the dependence on private transport and flood hazard control to turn around its position (United Nations Environment Programme, 2017). Mumbai's public transport systems must be expanded to cope with the growing population. A review by Loggia *et al.,* 2012, found that certain elements like high-resolution data, mitigation plans, and better infrastructure, among others are required for flood mitigation. These elements must be incorporated in Mumbai, due to its propensity of monsoon flooding.

It is of utmost importance that stakeholders are involved in the implementation of the strategies and measures to build climate-resilient cities, as they often have first-hand experience with the problems being addressed. This will allow for scientific suggestions to be seamlessly integrated and tailored to experiences faced by local communities. Participation of stakeholders employing self-mobilisation, interactivity, and consultation through a questionnaire or an interview could result in efficient stakeholder participation (Conde *et al.*, 2005).

Materials and Methods:

Participants

The criteria for inclusion were as follows-

- Being a resident of the Mumbai Metropolitan Region
- Above the age of 16 years
- Ability to read English
- A device with access to the internet
- Willingness to participate in the study

Survey

The survey was administered through Google Forms and was circulated via email, WhatsApp, Facebook and Twitter. Participants were provided with information regarding the survey objectives; informed consent of the participants was obtained and it was emphasized that participation was voluntary. The survey was conducted over 2 years, from 2020- 2022, and 426 responses were obtained.

Respondent anonymity was prioritised- the survey did not collect names, email IDs or mobile numbers.

The survey had three sections and the data collected through the survey was as follows-

- The initial part of the survey gathered demographic information, such as age, gender, highest educational attainment, and highest educational attainment in a science-related field
- The second section of the survey collected data on climate change knowledge (one question), concern levels (general and about specific problems in Mumbai) and sustainable behaviour and perceptions regarding sustainable behaviour and their impact on climate change. A 1-5 Likert scale was employed to gauge concern levels (1- No concern whatsoever, 2- Slight concern, 3- Indifferent, 4- Moderate concern, 5- Intense concern) (Joshi *et al.*, 2015).
- The third and final section collected data on the perceived impact of climate change on natural disasters. Statements on the same were given and the perceived impact was measured using the 1-5 Likert scale.

Statistical Analysis

The demographic data and data on sustainable behaviour and perceptions regarding the same were summarised using descriptive statistics. The education level indicated by the respondents was classified as 'Grade 10 or lower', 'Grade 12 or higher' and 'Postgraduate'.

To obtain the total climate change concern level scores for problems in Mumbai, the scores indicated by the respondents on the Likert scale (with a score of '1' corresponding to 'Not at all concerned', a score of '2' being 'Not very concerned', '3' corresponding to 'Neutral', a score of '4' corresponding to 'concerned' and '5' being 'very concerned') were added up to get a score out of a total of 25. The scores were subsequently categorized as extremely low (1-5), low (6-10), moderate (11-15), high (16-20), and extremely high (21-25). Similarly, the cumulative score for the perceived influence of the specified action on climate change as well as the aggregate points for the perceived significance of climate change on natural disasters were obtained. Chi-square analysis was used to check for the association between various factors, such as the association between climate change concern levels and gender, age and the observed consequences of climate change on natural disasters etc.

The statistical analysis was executed via JASP 0.18.3 (JASP Team, 2024). Statistical significance was defined at $p<0.05$. The Cramér's phi (ϕc) value indicating the strength of the relationship between two variables was interpreted following Akoglu, 2018. Graphical representation was performed using software GraphPad Prism Version 10.

Results and Discussion:

The present study sample consisted of a total of 426 respondents. The mean age of the sample was 31.972 (±16.099) years. The ages ranged from a minimum of 16 years (as specified by the survey) to a maximum of 78 years (Figure 1).

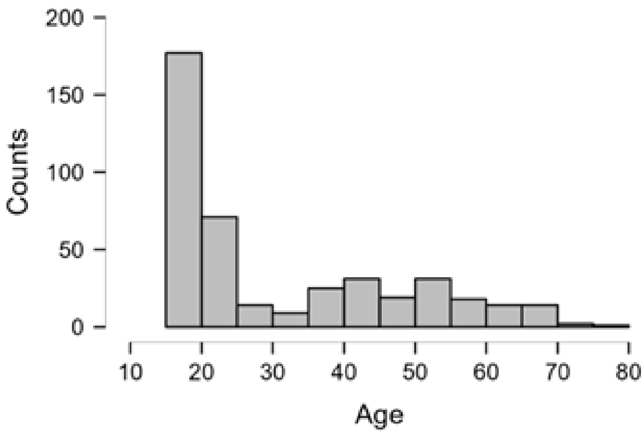


Figure 1: The age distribution of the respondents

A majority of the respondents were female (63.4%). Males accounted for 35.4% of the sample and five respondents preferred to keep their gender undisclosed (1.2%) (Figure 2).

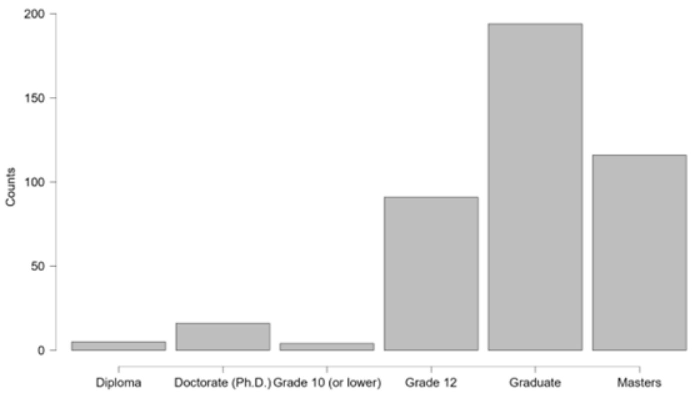


Figure 2: The gender of the respondents

The majority of the respondents (45.5%), had completed or were completing their graduate education, while 116 respondents were pursuing/ had completed their Masters. The other 27.3% of the respondents were a mixed group comprising school students, to a higher level, i.e., PhD level academics. (Figure 3).

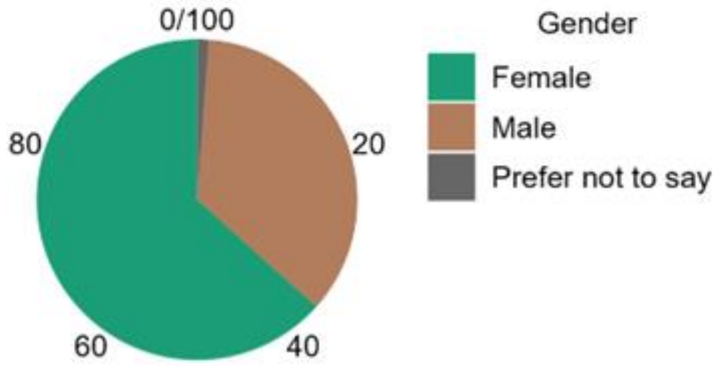


Figure 3: Highest education level of the respondents

Among the participants of the current study, about 135 respondents had completed or were completing their graduate education in a science-related field. There were a smaller number of respondents who were pursuing or had completed their postgraduate education in a science-related subject (Figure 4).

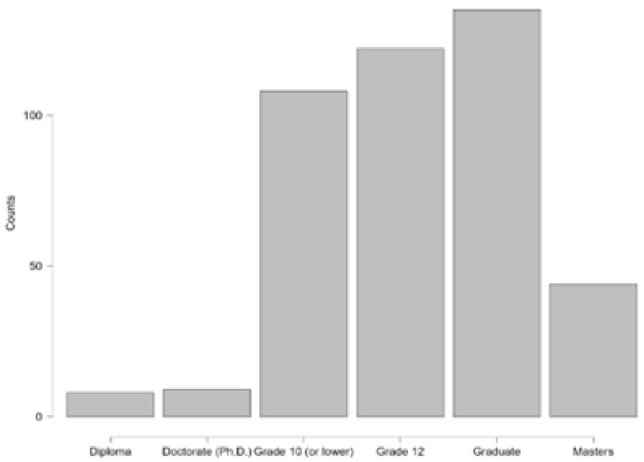


Figure 4: Highest education level of the respondents in a science- related subject

The second section of our study collected information regarding Climate change concerns, perceptions and thoughts on sustainable lifestyles. This was based on the 1-5 Likert scale.

47.2% of the respondents were 'extremely concerned' regarding climate change. Our data indicated that most respondents were 'Extremely concerned' about Plastic Pollution (52.1%), followed by Air Pollution (47.1%). Conversely, the fewest respondents were 'Extremely Concerned' regarding erratic rainfall causing floods (37.0%) and Mangrove degradation and deforestation (38.0%) (Figure 5).

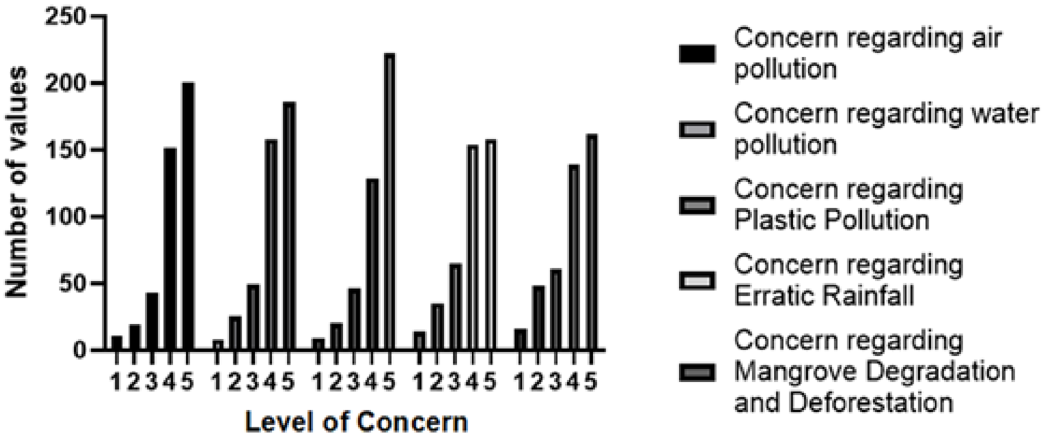


Figure 5: Concern levels for air pollution, water pollution, plastic pollution, erratic rainfall patterns causing floods and mangrove degradation in Mumbai.

Our survey also tested the respondents on their knowledge of climate change through the question- "Are you aware that several countries have declared Climate Emergencies in the recent past?". A large proportion of the respondents (72.1%) indicated that they were aware of the same (Figure 6).

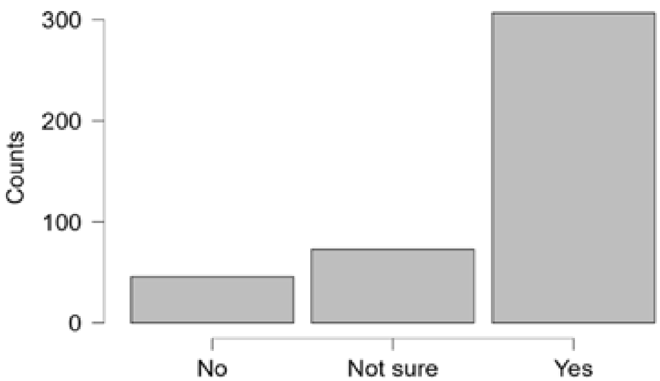


Figure 6: Responses to "Are you aware that several countries have declared climate emergencies in the recent past."

The study surveyed individuals to determine their thoughts on personal choices contributing positively to the fight against climate change. 61.5% of the respondents answered

'Yes', and nearly 27.3% were unsure whether their choices would have a positive impact (Figure 7).

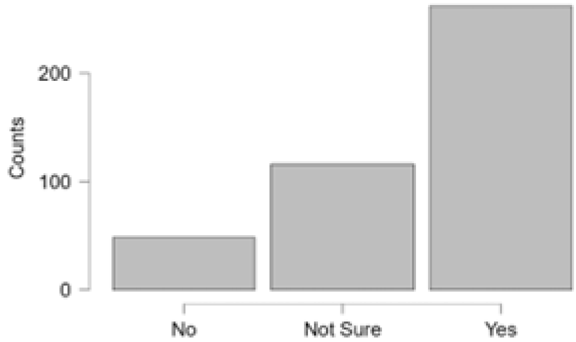


Figure 7: Responses to individual lifestyle choices having a positive impact on climate change and its effects.

To assess whether the respondents in our study were undertaking any sustainable practices, respondents were asked whether their households were engaged in any recycling practices. More than half of the participants said that their households were engaged in the aforementioned practices (58.7%). (Figure 8).

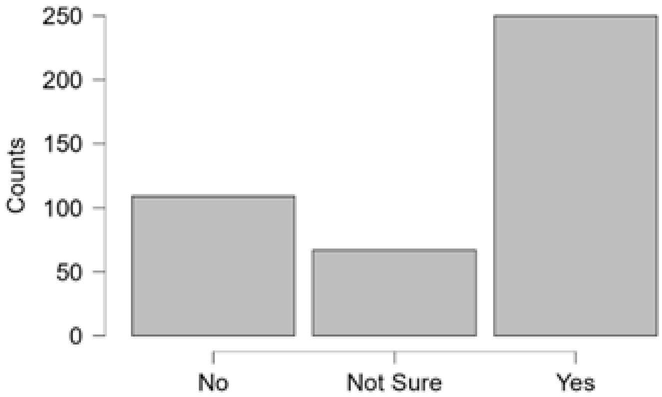


Figure 8: Responses to "Is your household involved in any recycling initiatives (Paper, Plastic, E-Waste etc.)?"

We subsequently asked respondents to quantify the extent to which certain practices, namely, using public transport, walking, recycling, using less packaging, shopping from organic farms, composting and reducing the use of plastic, could impact climate change or its effects. This was again based on the Likert scale.

Our results revealed that the largest proportion of respondents (61.27%) believed that reducing the use of plastic would have an 'Extremely significant' impact on climate change, followed by recycling (55.16%). Using public transportation and purchasing from organic farms were perceived by the fewest respondents as having an 'Extremely Significant' effect on climate change (Figure 9).

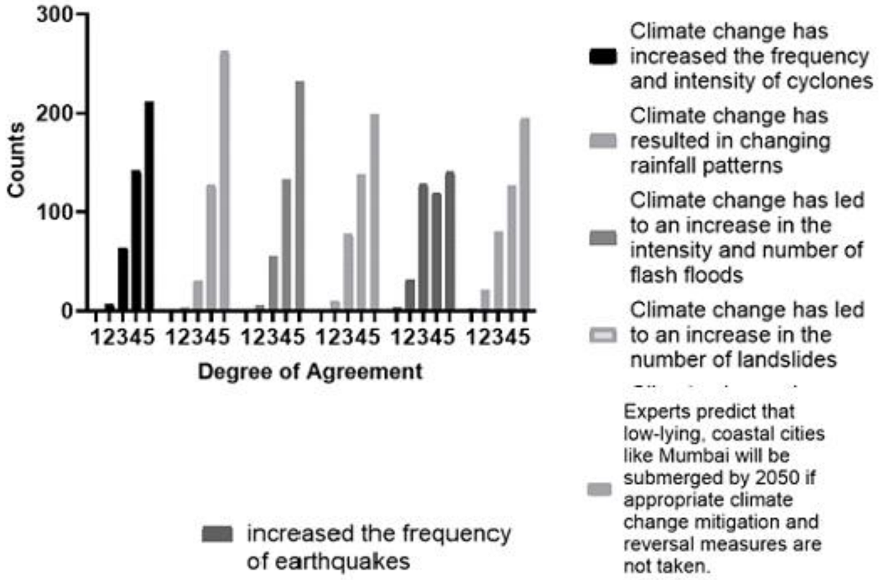


Figure 9: The perceived effect of certain actions on climate variability

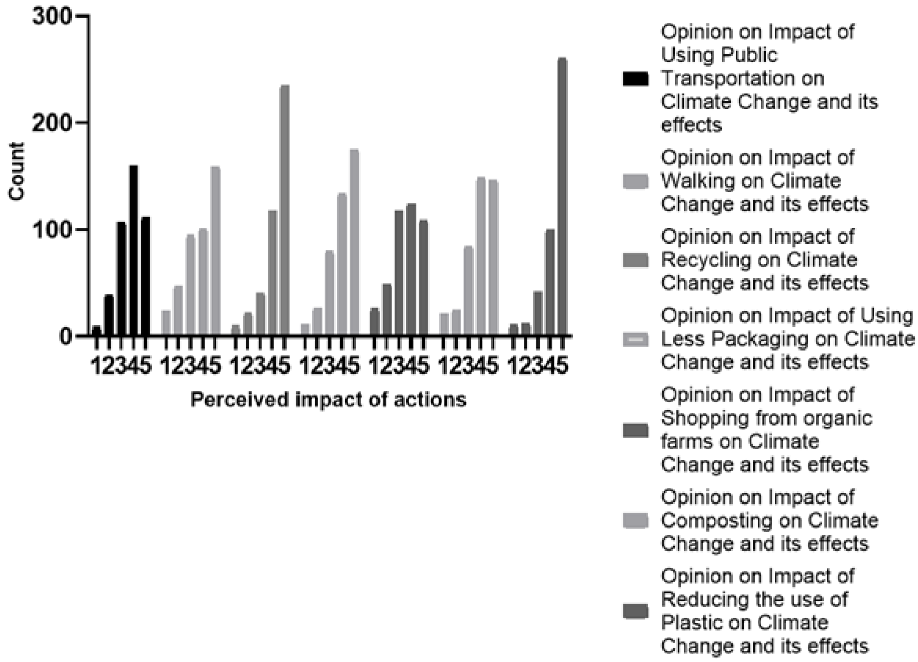


Figure 10: The perceived impact of climate change on natural disasters

In the concluding segment of the survey, respondents were tasked with evaluating the perceived impact of climate change on a range of natural disasters, including Earthquakes, Shifting Rainfall Patterns, Landslides, Flash Floods, Cyclones, and the consequences of climate change on low-lying coastal urban areas.

Data was obtained through a 1-5 Likert Scale, where each score represented the levels ranging from Strongly Disagree to Strongly Agree, respectively. The largest number of respondents (263) strongly agreed that climate change caused a shift in rainfall patterns, while only 141 respondents 'Strongly Agreed' that Earthquakes were a result of climate variability (Figure 10).

To investigate the potential relationship between age and climatic change concern levels within the context of climate variation-related matters in Mumbai, a Pearson's correlation test was conducted. To accomplish this, the sum of the individual scores (for air pollution, water pollution, plastic pollution, erratic rainfall patterns and mangrove degradation) based on the Likert scale were added up to get a total score out of 25. The test revealed a very weak negative correlation (r= -0.067) in our study (Figure 11).

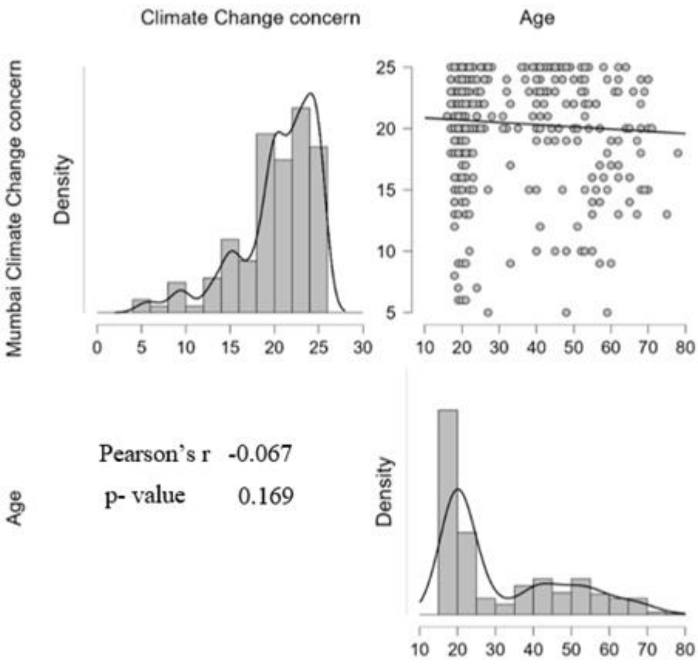


Figure 11: The correlation between age and climate change concern levels for issues faced by Mumbai

Similarly, a Pearson's correlation test was also performed to check whether there was any correlation between climatic change concern levels and concern levels about mangrove degradation in Mumbai. A moderate positive correlation was observed (Figure 12).

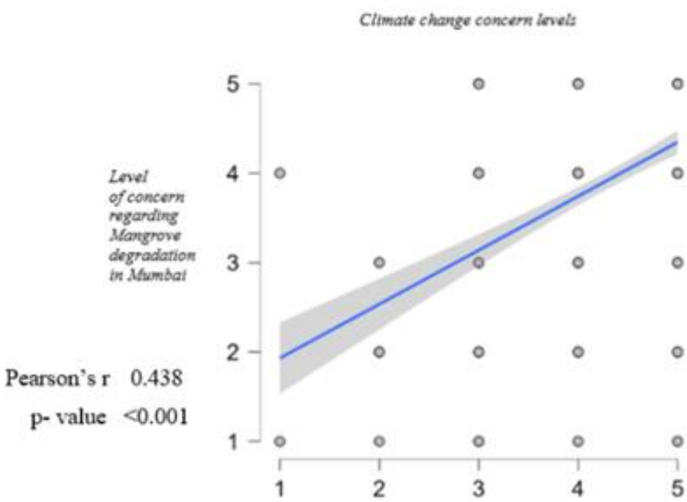


Figure 12: The relationship between degree of concern regarding climatic change and Mangrove degradation

To further examine whether there was a correlation between age and people's opinions on the impact of different methods to combat climate change, a Pearson's correlation analysis was carried out. To accomplish this, the sum of the individual scores, based on the Likert scale of 1-5, was added to get a total score out of 35. The test revealed a very weak negative correlation (r= -0.173) (Figure 13).

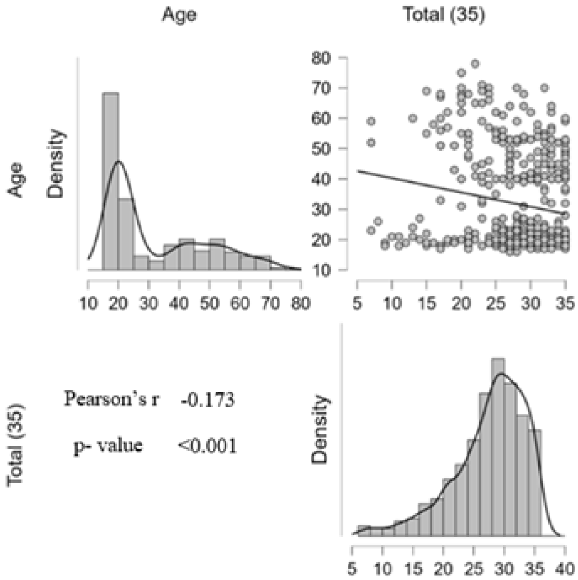


Figure 13: The correlation between age and People's opinions on impact of different methods on climate change and its effects by residents of Mumbai

A feeble positive correlation (r= 0.107) was observed between climate change concern levels and the perceived impact of climate change on natural disasters (Figure 14). The cumulative score out of 30 for the perceived influence of climate change on natural calamities was obtained by adding the individual scores (of the impact of climate variations on cyclones, changing rainfall patterns, flash floods, landslides, earthquakes and finally, sea-level rise in coastal cities).

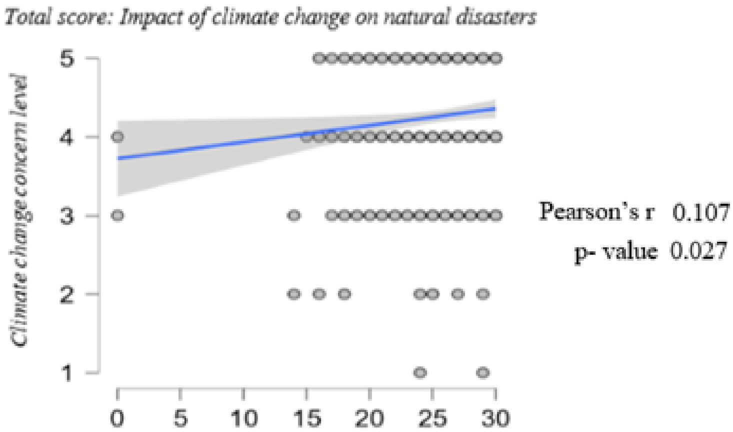


Figure 14: The relationship between levels of concern regarding climate change and the perceived influence of climatic variation on natural disasters

As mentioned previously, we added up the scores based on the Likert scale for each category to get a score out of a total of 25. Upon applying the aforementioned score classification, an examination of the relationship between gender and levels of concern regarding climate change in Mumbai through a chi-square test revealed a lack of statistically significant association (p=0.160) (Figure 15).

Climate change concern levels for issues specific to Mumbai		Gender: Female	Male	Prefer not to say	Total
Very Low	Count	1.000	1.000	0.000	2.000
	Expected count	1.268	0.709	0.023	2.000
Low	Count	4.000	5.000	0.000	9.000
	Expected count	5.704	3.190	0.106	9.000
Medium	Count	39.000	24.000	3.000	66.000
	Expected count	41.831	23.394	0.775	66.000
High	Count	99.000	47.000	2.000	148.000
	Expected count	93.803	52.460	1.737	148.000
Very High	Count	127.000	74.000	0.000	201.000
	Expected count	127.394	71.246	2.359	201.000
Total	Count	270.000	151.000	5.000	426.000
	Expected count	270.000	151.000	5.000	426.000

Chi-Squared Tests

	Value		p
X^2	11.804	8	0.160
N	426		
Cramer's V	0.118		

Figure 15: The association between level of concern regarding climatic change issues in Mumbai, and Gender

What is your level of concern regarding climate change?		Do you think that individual lifestyle choices (e.g. Going Vegetarian, or using electric cars) will have a positive impact on climate change and its effects?: No	Not Sure	Yes	Total
1	Count	0.000	0.000	2.000	2.000
	Expected count	0.225	0.545	1.230	2.000
2	Count	6.000	3.000	0.000	9.000
	Expected count	1.014	2.451	5.535	9.000
3	Count	9.000	23.000	34.000	66.000
	Expected count	7.437	17.972	40.592	66.000
4	Count	18.000	47.000	83.000	148.000
	Expected count	16.676	40.300	91.023	148.000
5	Count	15.000	43.000	143.000	201.000
	Expected count	22.648	54.732	123.620	201.000
Total	Count	48.000	116.000	262.000	426.000
	Expected count	48.000	116.000	262.000	426.000

Chi-Squared Tests

	Value	df	p
X^2	44.292	8	< .001
N	426		
Cramer's V	0.228		

Figure 16: The relation between climatic variation concern levels and the perceived impact of individual lifestyle choices

To explore the connection between levels of climate change concern and the perceived impact of individual lifestyle choices on climate change, a chi-square test was performed. The results indicated a significant association between the two factors ($p<0.001$) (Figure 16).

The chi-square test employed to examine the association between levels of climate change concern and individuals' participation in efforts to combat climate change revealed a statistically insignificant connection between these variables ($p=0.152$), $\varphi c= 0.119$. (Figure 17).

Level of Concern Regarding Climate Change on a scale of 1-5		Is your household involved in any recycling initiatives? (Paper, Plastic, E-Waste etc)			
		No	Not Sure	Yes	Total
1	Count	0.000	0.000	2.000	2.000
	Expected count	0.512	0.315	1.174	2.000
2	Count	4.000	2.000	3.000	9.000
	Expected count	2.303	1.415	5.282	9.000
3	Count	15.000	18.000	33.000	66.000
	Expected count	16.887	10.380	38.732	66.000
4	Count	39.000	20.000	89.000	148.000
	Expected count	37.869	23.277	86.854	148.000
5	Count	51.000	27.000	123.000	201.000
	Expected count	51.430	31.613	117.958	201.000
Total	Count	109.000	67.000	250.000	426.000
	Expected count	109.000	67.000	250.000	426.000

	Value	df	p
X^2	11.979	8	0.152
N	426		
Cramer's V	0.119		

Figure 17: The association between climate change concern levels and the respondent's household being involved in activities combating climate change

Climate change is the enduring alteration and fluctuations in worldwide weather patterns and temperature due human activities (Shivanna, 2022).

India, with its vast coastline (*Profile - Know India: National Portal of India*, n.d.), has a climate that is intricately connected and tied to its geographical features, and understanding these dependencies is essential for the country, as a vast population depends on the various sectors that are dependent and sensitive to the climate- such as forestry, agriculture and fishery for their livelihood. Climate change has led to a rise in the severity of livelihood challenges faced by the country (Balasubramanian *et al.,* 2012). Climate change is one of the most significant threats faced by coastal megacities such as Mumbai and may have several impacts such as a rise in sea level, a rise in infectious diseases and so on (Pandve, 2010). A study regarding sustainable consumption of the South Indian population has been attempted earlier (Kavitha and Kumar, 2023).

A general constraint faced concerning the number of responses received could have been the limited access to the internet, and the survey being only in English.

Our study aimed at uncovering the perceptions of the residents of Mumbai towards climate change and sustainable behavioural practices primarily to facilitate community engagement in sustainable practices and of course, in building climate change resilience. Our study finds that a majority of the respondents were very apprehensive regarding the issue of climate change (Figure 5). Thus, climate change perceptions among the public must be understood to get a better understanding of its various facets.

In a research investigation conducted by Korkmaz in 2018, it was observed that there existed no substantial association between age and climate change. Our study aligns with this discovery and reveals a lack of correlation (Pearson's r value= -0.076) between age and climate change (Figure 12). This result, however, could have been influenced by the age limitation of the study- where only respondents above the age of 16 were asked to answer the survey. Additionally, it was noticed that there were a lower number of responses from respondents above the age of 65- which was expected due to their limited access/ interest in social media platforms.

Our study found that there was a negligible negative correlation between age and people's opinions on the impact of individual choices to combat climate change, which is supported by studies showing that there has been a diminished generational gap concerning people's opinions regarding climate change (Poortinga *et al.*, 2023)

India's extensive coastline is susceptible to the consequences of climate change. It is widely recognised that mangroves play a crucial role in shielding out coastlines from erosion (United Nations Environment Programme, 2017). According to a study by Zahran 2006, coastal residents appeared less subjectively threatened by a host of ecological risks. The research conducted revealed a moderate positive relationship between the levels of worry about climate change and the levels of worry regarding mangrove degradation (Figure 12). Given the crucial role that mangroves play in preserving the well-being of coastlines, it is imperative to emphasize the significance of mangroves and implement enhanced conservation strategies to enhance public awareness of their importance (Everard *et al.,* 2014).

The existence of a mild positive correlation between the levels of concern regarding climatic change and the ratings of the perceived impact of climate variation on natural disasters suggests that individuals living in coastal areas who were vulnerable to such events also exhibited a heightened perception of subjective immunity, mirroring findings from a separate research study (Zahran, 2006).

A study by Korkmaz, 2018 in the Western Mediterranean locale of Turkey found that there were no statistically substantial variances between how the two genders perceived climate change. Our study yielded comparable outcomes, indicating that there was no statistically significant variation in the perception of climate change between males and females. McCright's 2010 study delved into the influence of gender on climate change knowledge and concern within the American population. The results indicated that women display a marginal but discernible higher level of concern regarding climate change when compared to men. Notably, this gender discrepancy cannot be accounted for by variations in fundamental principles, beliefs, or societal roles. The observed disparity in the number of male and female respondents who participated in the survey could be attributed as the underlying cause for this phenomenon. It was noted that a higher proportion of female respondents were recorded in comparison to their male counterparts.

In our research, we discovered a substantial link between the levels of concern regarding climate change and the perceived impact of individual lifestyle choices on climate change. Nevertheless, we found no significant connection between the levels of climate change concern and the involvement of households in recycling initiatives or endeavours aimed at combating climate change. This indicates that while respondents and residents of Mumbai are aware that individual actions do impact climate change, and a portion of the respondents are engaged in activities like recycling, upcycling, using public transport, there is a percentage of those who are unable to do so due to various factors, including lack of time, space, and adequate knowledge regarding the same.

The conclusion of the survey saw the unveiling of Mumbai's Climate Action Plan, a document formulated by the Municipal Corporation of Greater Mumbai (MCGM) in collaboration with WRI India, acting as a knowledge partner, and endorsed by the Government of Maharashtra. This plan, currently in the drafting phase, is the result of extensive consultations with various stakeholders. It encompasses a range of activities, such as presenting demographic information and outlining the socio-economic and ecological characteristics of the city, establishing a comprehensive 'climate profile' for Mumbai, conducting detailed analyses of six key sectors, setting clear targets for reducing emissions in Mumbai, and formulating strategies for their implementation.

To ensure a greater spread of awareness among all respondents and residents of Mumbai, awareness campaigns can be started in schools, colleges, and housing societies to ensure that all residents are aware of the negative impact of climate change and global warming and begin taking up more sustainable practices to ensure that the city thrives in the future. Additionally, cities need to take various steps toward being sustainable in response to the emerging climate crisis through collaborative efforts. This will ensure better adaptation to global warming and climate change.

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AGRICULTURAL WASTE AND ITS MANAGEMENT

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Introduction:

The increase in the global population resulted in massive production of waste. Waste can be defined as any unwanted material which is discarded/rejected from different sources. It could be by-product of industries, domestic, commercial, institutional, municipal, ashes, agricultural, mining, and from other activities. There are various definitions of waste. (Gilpin, 1976) defined waste as material of solid or semi-solid character that the possessor no longer considers of sufficient value to retain. Waste is any material that is unwanted or worthless and rejected (Post & Mihelcic, 2010). Waste can be categorized depending on its origin, composition, and environmental impact. Large amounts of waste in the form of liquids, slurries, or solids have inevitably been produced as agricultural production has expanded. Domestic wastes are those produced by household activities; commercial wastes are those produced in offices, wholesalers, restaurants, hotels, markets, warehouses, and other commercial establishments. Municipal wastes (produced as a result of municipal operations and services, including street litter, animal carcasses, market trash, and abandoned automobiles), Ashes (residues from burning wood, charcoal, and coke for heating and cooking in homes, institutions, and small businesses), industrial wastes include discarded solid materials from production processes and industrial operations, such as red mud and tailings produced by the aluminum, zinc, and copper industries, press mud produced by the sugar industry, lime and fertilizer produced by the pulp and paper industry, and gypsum by related industries.

The residues from the production of crops (rice, corn, wheat, palm oil, rubber, coconut, sugarcane bagasse, cotton, mustard, sesame, castor seed, sunflower, tobacco stalks), bovine husbandry, animal manure, agricultural chemicals and agro-industrial by-products are referred to as agricultural wastes or agro-waste. Agricultural waste may be formed from organic and inorganic material. Based on their source of origin, agricultural waste can be grouped into two categories; waste originates from the agricultural output and by-products of the agricultural output and waste originates from the residual input of agricultural activities (Al Seadi & Holm-Nielsen, 2004). The intensification of the cropping system leads to an increase in agricultural waste. Mishandling of agricultural waste can lead to environmental problems and can be hazardous to human and animal health. But most of the agricultural wastes can be recycled and can be used for industrial purposes. Agricultural waste has potential to produce sustainable energy (FAO and UNEP, 2010), and other uses, some are discussed in this chapter.

Agricultural waste

A vast variety of organic and inorganic materials that are left over from agricultural activities like crop production or livestock farming are referred to as agricultural waste. Consider agricultural chemicals, waste feed, animal manure, crop residues (stalks, rice straw, leaves, or husks), and all the packaging used during the production and supply chain. In the course of their daily operations, agricultural activities generate a variety of wastes, including biological, solid, hazardous, and wastewater wastes. To keep the environment and the community's residents safe, it is essential that these wastes are recognized and appropriately managed.

Agricultural waste may be nutrient-rich and biodegradable, and with proper management, it has enormous potential. Thus, it can be composted, converted into biofuels, or processed into biogas to become a valuable resource. However, the consequences of agricultural waste can devastate ecosystems and have an adverse effect on life quality. Poor management of agricultural residues may result in contaminated water, adverse effects on soil fertility and climate, and depletion of essential organic matter. Furthermore, it may have a major impact on human health. Therefore, there is a need for affordable agriculture waste management systems to meet the challenges of food production. The growing global population necessitates higher agricultural productivity and food security. Large amounts of waste from farming operations will still be produced, and this waste cannot be dumped in landfills. To create a more resource-efficient world, farmers must learn to appreciate the potential of agricultural waste and implement eco-friendly practices.

Agricultural waste management

The coordination, handling, and control of all waste resulting from agricultural activities is referred to as agricultural waste management. Preventing risks to human and animal health, greenhouse gas emissions and pollution of soil and water are the main objectives.

Agricultural waste can be managed by physical, biochemical, and thermochemical processes. Physical methods include in-situ management of field residue, composting, use of waste as animal feed, use as substrate in mushroom cultivation etc. While, thermochemical method includes combustion, hydrothermal and pyrolysis and biochemical methods includes fermentation and biomethanation (Babu *et al.,* 2022). In addition to the techniques mentioned above, waste reduction, recycling, and reuse techniques can be used to manage agricultural waste. By using these techniques, waste can be converted into useful materials like biogas or organic fertilizers.

Different countries, industries, and organizations have adopted different waste management options at different times, and all of these have applied varying degrees of technology, depending on what is available and accessible at a given time in terms of available technology, which is also defined by the availability of financial and other resources as well as the level of education and knowledge of operators.

There are many problems with waste management that, if left unchecked, could lead to major environmental issues that could become serious in extent. Due to the hazardous nature of waste and the urgent need to find solutions, recycling and waste minimization strategies were suggested as viable solutions for agricultural and food processing wastes.

Waste recycling

It is the process of creating useful products out of what was previously thought to be waste. Reducing the amount of waste that is released into the environment and the resulting health risks is the main goal of recycling. A variety of fertilizers, fungicides, herbicides, and other pesticides are used in modern agriculture. Using these chemicals in modern agriculture has the advantage of increasing agricultural output while lowering crop losses. An increase in agricultural output is accompanied by an increase in agricultural wastes, which may pollute the environment. The production and generation of agricultural wastes result from agricultural activities like food production, animal husbandry, kitchen waste, etc. Conversely, industrial wastes originate from various industrial processes. The two main types of wastes produced by agricultural processes are solid and liquid wastes.

Large amounts of vegetal wastes as a result of their intensive field crop or livestock production. Waste generation has significantly increased over time as a result of population growth, consumerism, urbanization, industrialization, higher agricultural output, and other associated factors. Waste generated from agricultural products is richer in Lignocellulosic wastes which contain cellulose, hemicelluloses and lignin. Wastes in this class typically contain roughly 50% cellulose by dry weight, with hemicellulose and lignin making up the remaining nearly equal portion (Pandey *et al.*, 2000).

Even though lignocellulosic wastes have been used extensively as sources of energy (heat and electricity), it is thought that using these wastes for animal nutrition could result in a significant value addition (Pandey *et al.*, 2000). Unfortunately, their extremely low protein, vitamin, oil, and other nutrient content, as well as their limited digestibility and palatability to ruminants, limit their use in animal feeding. On the other hand, they could be used for animal nutrition after protein enrichment. Solid substrate fermentation has been the focus of most efforts made in this direction (Ezejiofor *et al.*, 2014).

Composting

Composting is the process by which a variety of microorganisms, such as actinomycetes, bacteria, and fungi, convert organic waste from plants and animals into a fertile matrix in the presence of oxygen. When various microorganisms are added to solid waste, it can be transformed into compost or a variety of byproducts (Żukowska *et al.*, 2019). Following the microbiological process, humus is a solid and stable matrix that can be effectively applied to land as an organic fertilizer to improve soil fertility and structure.

The four stages of the composting process are mesophilic, thermophilic, cooling, and compost maturation. These stages can occur simultaneously rather than sequentially (Belyaeva & Haynes, 2009). The duration of each stage depends on numerous factors such as microbiological composition, water content, air circulation, and inceptive framework (Smith *et al.,* 2010). A mix of bacteria, fungi, and actinomycetes causes the fast metabolism of substrates that are abundant in carbon dioxide during the mesophilic phase. Additionally, since aerobic metabolism generates heat, this is achieved by choosing acceptable temperatures, which are typically between 15 and 40 ˚C. Temporarily lowering the temperature through matter transformation and air circulation slows down the rate at which other organic matter degrades. The temperature rises during the 2nd phase (thermophilic phase) to about 40 ˚C which is favourable to most thermophilic bacteria, such as Bacillus. Fungi breakdown lignin and other complex compounds. Actinomycetes also plays an important role in the degradation of waste and formation of humus (Smith *et al.*, 2010). The last stage of compost formation is characterized by the lower uptake of oxygen and also lowers the temperature below 25 ˚C. Compost quality is also improved during the final stage of compost formation (Hadar & Papadopoulou, 2012). The final product of composting has lower C:N ratio as compared to the initial product.

Numerous studies demonstrated the benefits of using Agricultural Waste Management in the field through composting, which improved the soil's structure and texture in addition to having many other positive effects. As approaches and green development advanced, researchers concentrated on improving the structure of composting, supplying bioavailable components, improving product consistency, and the effects on the environment and economy.

1. Vermicomposting

The formation of compost using organic waste from various earthworm species is known as Vermicompost and the process is known as Vermicomposting (Huang *et al.,* 2020). Waste is placed in different layers to make the compost and earthworms are added to the pit or container. Water is added regularly during the process and after leaching down of compost tea, it can be collected in a separate container. Compost tea is a nutrient-rich liquid fertilizer that can be used to promote plant growth. Earthworms can decay various types of wastes (crop waste, kitchen waste, sewage waste, industrial waste etc.) into compost.

For *Eisena Fetida*, the ideal temperature, moisture content, and pH were 25 °C, 75%, and 6.5 respectively, for the best growth of earthworm species. The time it took for compost to break down was reduced when earthworms and microorganisms (bacteria that fix nitrogen, potassium, and magnesium) were combined, and the resulting compost had a higher concentration of nutrients (N, P, K, Ca, Mg, and Zn) than regular compost (Busato *et al.,* 2012).

The most effective way to speed up root growth was to apply prepared vermicompost as fertilizer since it increases nutrient uptake and boosts overall yield (Padmavathiamma *et al.*, 2008).

2. Aerobic composting

Aerobic composting is the degradation of organic matter with the help of micro-organisms in the presence of oxygen (Zhang *et al.*, 2020). For example, to aid in quick decomposition, green and brown materials are chopped into pieces that are no larger than 2-3 cm using a chopper. Following that, the material that has been shredded is stacked or arranged in a row with a particular moisture content. To ensure the survival of microorganisms, frequent turnings are used along with enough moisture to allow for adequate mixing and aeration.

When there is enough water and oxygen present in organic material, microorganisms grow and break it down. Depending on the material being composted, the material becomes fine and turns dark brown after seven to eight turns. It also has a diminished odor. Temperature, biological, physical, and chemical parameter changes occur at the same temporal intervals during composting processes.

During the process of compost formation, several changes occurred such as an increase in temperature brought on by mesophilic and thermophilic microorganisms and a shift in the levels of OM, N, P, and K even in aerated piles (Waqas *et al.*, 2023). Compared to non-composted poultry litter, composted litter had noticeably higher Organic matter. Thus, crop fields are less vulnerable to loss when Organic matter is available (Tiquia & Tam, 2002).

Biochar accelerated the process and improved the quality of the final compost by increasing porosity and stabilizing the composting rate. Reduced GHG emissions, improved looseness, and improved material degradation are all provided by biochar (CO_2, N_2O, NH_3, CH_4) (Liu *et al.*, 2017). Perforated PVC pipes can be laid under waste for pressured air circulation to aid in waste degradation. The temperature rise during thermophilic and mesophilic phases can also be lowered in forced air composting (Waqas *et al.*, 2023). The moisture content requirement is also higher in this method of composting due to rapid evaporation.

3. Anaerobic composting

Anaerobic composting is the degradation of Organic matter with the help of micro-organisms in the absence of oxygen (Meng *et al.*, 2020). It occurs in two steps. To generate biogas for use in the first step, cow dung was fed into a digester on a daily basis. All greenhouse gases were removed from the digested slurry, which was a byproduct of the digester. The product decreased environmental pollution and was effectively used for composting. To carry out additional decomposition, the slurry was combined with shredded browns. The process of anaerobic composting takes more time as compared to the aerobic composting (Obersky *et al.*, 2018). There are various greenhouse gases produced during this composting process. Methane produced during decomposition can contribute to the greenhouse effect but this gas can be utilized as a source of energy either for combustion or electricity generation. Anaerobic composting requires Nitrogen rich waste and high amount of moisture for the successful generation of the end product. Due to high moisture content, compost tea is also formed which can be used as a liquid fertilizer to enhance soil fertility (Smet *et al.,* 1999). This process of compost generation is time-consuming and another drawback of this method is the production of bad odor and the final product after anaerobic decomposition contains *E.coli* which is harmful for human health (Zhang *et al.,* 2020).

***In situ* crop residue management**

Burning of crop residues has negative effect on the microbial population, organic matter content, plant micro- and macronutrients, and soil health (Nyanga *et al.,* 2020). Using sustainable methods for managing crop residues is one of the cleaner ways to produce crops (Raza *et al.,* 2019). A significant challenge is managing crop residues sustainably to reduce negative effects on both the environment and humans. Because sensible crop residue management practices do not immediately boost farm income, farmers are frequently reluctant to implement any corrective measures. Thus, choosing appropriate crop residue management techniques that boost farm income while being environmentally friendly is crucial. Various crop residue management technologies, such as conservation tillage, nutrient cycling, soil conversation practices, zero-tillage and residue mulching, use in animal feed, and vermicompost preparation, are being used in various parts of the world under real-world field conditions (Humphreys *et al.,* 2016; Valkama *et al.,* 2020).

1. Impact of *In situ* Crop residue management on soil physical properties

It has been demonstrated that adding leguminous crop residues improves the physical characteristics of the soil, including its permeability and ability to hold water. The incorporation of residues from leguminous crops boosts crop growth and productivity by improving the availability of nutrients for the crop's root zone (Smitha *et al.,* 2019). Modern input-intensive agriculture frequently uses heavy machinery and farm implements such as planters, reapers, combine harvesters, and zero-tillage implements. However, improper usage of these heavy equipment can compact the soil and negatively impact its physical qualities, such as its ability to hold water, infiltration rate. The addition of mixed litter and crop residues from ryegrass and straw can greatly increase the soil's porosity and water-holding ability, which will ultimately increase the soil's productivity (Carlesso *et al.,* 2019). In rice-based cropping systems, the application of crop residues in conjunction with conservation tillage has been shown to improve soil aggregate and carbon storage (Wang *et al.,* 2019).

Mulching is the process of covering the topmost soil with any type of material such as crop residue, leaves, straw etc. Mulch made from agricultural solid waste improves nutrient retention, inhibits weed growth, and preserves soil moisture. Mulching enhances crop health and productivity by shielding the soil from temperature changes and erosion. Mulching under conservation agriculture helps in the improvement of the soil ecosystem, nutrient availability and soil physical properties (improve water holding capacity of soil, decreased bulk density) (Malgaya *et al.,* 2023).

2. Impact of *In situ* Crop residue management on soil chemical properties

Sustainable crop management can effectively enhance the transformation of various primary and secondary plant nutrients as well as the chemical properties of the soil, such as pH, electrical conductivity, and cation exchange capacity (CEC). Crop residue application is positively correlated with the soil carbon pool (total and labile pool). The total and labile carbon pool of an irrigated maize production system can be considerably increased by applying 75 kg N ha^{-1} in addition to 10 Mg ha^{-1} of wheat residue mulching (Chatterjee *et al.,* 2018). It is possible to increase system productivity, K use efficiency, and apparent K balance by implementing conservation tillage in a rice-maize cropping system with residue management (Singh *et al.,* 2018). Residue incorporation also helps reduce the need for external K supplies by recycling up to 15% of the K available in the soil (Singh *et al.,* 2018). The SOC and soil macronutrient availability were greatly increased by applying cluster bean crop residue before sacred basil (*Ocimum sanctum Linn*) transplanting (Smitha *et al.,* 2019).

3. Impact of *In situ* Crop residue management on soil biological properties

Crop residues has been demonstrated to have a significant impact on governing the microbial biomass in the soil. Applying crop residue mulching results in increased microbial activity in the upper soil layer (Samui *et al.,* 2020). The application of wheat crop residue led to a significant increase in soil microbial biomass carbon (SMBC) (Chatterjee *et al.,* 2018). It has been observed that adding leguminous crop residues, such as cluster beans, to the soil before planting crops increases soil microbial biomass and dehydrogenase activity (DHA) in comparison to the control treatment, which applied crop residue (Smitha *et al.,* 2019). In a wheat-soybean cropping system, residue retention under Conservation practices has also been shown to be advantageous for lowering the population of soil nematodes (Escalante *et al.,* 2021).

Use of agricultural waste as animal feed

Agri-waste, which is primarily made up of straw and stover that are collected after the crop is harvested and used as an abundant feedstock for ruminant grazing, can be very helpful in meeting the need for fodder. During the lean season, the feed material made from agricultural waste can be stored and utilized for animals (Patil *et al.,* 2020). Crop residue of wheat, maize, pearl millet, and rice stover can be used as animal feed (He *et al.,* 2020). Rice straw can be utilized as animal feed when there is a shortage of green fodder, but it has low protein content (3-5%) while rich in silica content (12-16%) and crude fiber (26-34%). Cereals are low in nutritional quality and need to improve the feed quality with the addition of supplements and enriched crop residues (Sethupathy *et al.,* 2022). The intake and digestibility of rice straw are increased when it is chopped and then soaked in water before feeding. The intake and digestibility of rice straw were further enhanced by adding chopped straw to molasses, fermented edible oil cakes, and leaves of Leucaena and Gliricidia.

There are various methods to convert agricultural waste into valuable animal feed. The most promising method for producing animal fodder that is high in protein is solid-state fermentation since it eliminates the components that are detrimental to animals from agricultural waste (Wang *et al.*, 2022).

Industrial use of agricultural waste

Agri-waste has enormous potential in the production of cardboard and paper pulp industries. Nowadays, wood pulp is being used in the cardboard industry which is not an eco-friendly method as it results in ecological imbalance due to deforestation (Patil *et al.*, 2017). Agri-waste should be used in place of wood pulp as a green effort and choice to prevent deforestation and manage open-field residue burning. Bioplastic made from agri-waste has the potential to be a viable and sustainable alternative to synthetic plastic. Rice straw yields bioplastic with good mechanical, tensile, and elongation qualities (Bilo *et al.*, 2018).

Agricultural waste as a fuel material

It is possible to use agri-waste as a source of renewable energy. Biofuel can be classified into four types based on the feedstock used: first-generation biofuel, which is made from sugar, starch, and edible oils; and second-generation biofuels are made from waste biomass. While third-generation biofuel is produced from algae, and fourth-generation biofuel is produced from modified cyanobacteria (Babu *et al.*, 2022). Biofuels are liquid fuels made from biomass that are used for transportation, such as ethanol and biodiesel.

Biomass from agriculture may be used as a precursor to create sustainable energy. The type of crop species influences the biomass's energy content. For instance, the energy content of hay is approximately 3738 kcal/kg (15.639 MJ/kg) and rice straw is approximately 3015 kcal/kg (12.614 MJ/kg) (Timbers & Downing, 1977). Many developing nations find agriculture biomass to be appealing because of its affordability and accessibility (Bharthare *et al.*, 2014). The amount of biomass energy used in developed and developing nations varies significantly, with estimates indicating 4% and 22%, respectively. This situation is mostly the result of restrictions set in place in developed nations to protect the environment (Saleem, 2022).

Agriculture biomass is a common primary fuel source in many Asian and African nations, despite its bulk and low calorific value. Still, it lags behind the amount of wood consumed for heating and cooking (Saleem, 2022). Numerous nations, including Denmark, Poland, Nigeria, China, India, and Denmark, have looked into the potential of agricultural biomass as a source of energy (Biegańska & Barański, 2022). Depending on its availability, physical and chemical characteristics, and other factors, agricultural biomass can be used in a variety of ways as an energy source. More than 30% of household energy used for cooking, heating, and lighting comes from biomass produced in agriculture worldwide. Any biomass, whether processed or raw, produced during agricultural operations can be used to produce heat and electricity on a commercial scale (Baum *et al.,* 2013). To generate energy, 4.9 million tons of cereal and rape straw were utilized. Combustion processes can produce approximately 1.5 billion m^3 of biogas (Gospodarki, 2010). Approximately 37% of China's agricultural biomass is reportedly used for direct combustion fuel, in addition to other domestic uses, such as cooking and heating (Saeed *et al.,* 2015). Asia uses more than 2500 Tg of agricultural biomass as fuel (Saeed *et al.,* 2015).

Pyrolysis is a process of thermal decomposition at high temperature for the production of bio-oil (Bian *et al.,* 2016). Additional processing of bio-oil yields diesel, kerosene oil, gasoline, and gasoline. Bio-char is another byproduct of the pyrolysis process; it is a solid residue that contains a high concentration of carbon and light hydrocarbon gases (Liu *et al.,* 2017).

Conclusion:

The incorporation of crop residue and animal waste into the soil can improve the physical, chemical, and biological properties of the soil. The waste has potential for biofuel and energy generation. Agri waste can also be utilized as a by-product of various industries with a very low impact on the environment. Supplementation of crop residue and fodder can be used to feed the animals. Agri waste can be easily managed by waste reduction, recycling, and reuse techniques.

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BIODEGRADATION OF HAZARDOUS CONTAMINANTS AND PESTICIDES

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Introduction:

Biodegradation is a process through which organic substances are broken down by living organisms, typically microorganisms. This natural process is crucial for the detoxification and removal of hazardous contaminants and pesticides from the environment. The biodegradation of hazardous substances, including pesticides, has gained significant attention due to its potential to mitigate pollution and restore environmental health. This essay explores the mechanisms, challenges, and advances in the biodegradation of hazardous contaminants and pesticides. One promising treatment method is to exploit the ability of microorganisms to remove pollutants from contaminated sites, an alternative treatment strategy that is effective, minimally hazardous, economical, versatile and environment-friendly, is the process known as bioremediation (Finley *et al.*, 2010).

Thereafter, it was discovered that microbes have the ability to transform and/or degrade xenobiotics, scientists have been exploring the microbial diversity, particularly of contaminated areas in search of organisms that can degrade a wide range of pollutants. Hence, biotransformation of organic contaminants in the natural environment has been extensively studied to understand microbial ecology, physiology and evolution due to their bioremediation potential (Mishra *et al.*, 2001). The biochemical and genetic basis of microbial degradation has received considerable attention. Several genes/enzymes, which provide microorganisms with the ability to degrade organopesticides, have been identified and characterized. Thus, microorganisms provide a potential wealth in biodegradation. The ability of these organisms to reduce the concentration of xenobiotics is directly linked to their long-term adaptation to environments where these compounds exist. Moreover, genetic engineering may be used to enhance the performance of such microorganisms that have the preferred properties, essential for biodegradation (Schroll *et al.*, 2004).

Biodegradation

Biodegradation is defined as "A substance's breakdown catalyzed by enzymes in vitro or in vivo" by the International Union of Pure and Applied Chemistry. For the purpose of hazard assessment, this could be described as: First, primary. modification of a substance's chemical structure that causes the loss of a particular property.

Compliant with the environment. biodegradation to the point that the compound's unwanted qualities are eliminated. This usually relates to primary biodegradation, however it varies depending on the environmental conditions under which the products are released.

Microbial degradation of chemical compounds in the environment is an important route for the removal of these compounds. The biodegradation of these compounds, i.e., pesticides, is often complex and involves a series of biochemical reactions. Although many enzymes efficiently catalyze the biodegradation of pesticides, the full understanding of the biodegradation pathway often requires new investigations. Several pesticide biodegradation studies have shown only the total of degraded pesticide, but have not investigated in depth the new bio-transformed products and their fate in the environment.

Mechanisms of biodegradation

Biodegradation involves several biological and chemical processes that convert hazardous substances into less harmful or non-toxic forms. The primary mechanisms include enzymatic degradation, co-metabolism, and microbial consortia.

1. **Enzymatic degradation:** Enzymes produced by microorganisms play a critical role in breaking down complex molecules. For example, the enzyme dehalogenase can remove halogen atoms from organic compounds, which is essential for the degradation of many pesticides and chlorinated solvents.
2. **Co-metabolism:** Some microorganisms degrade contaminants incidentally while metabolizing other compounds. This process, known as co-metabolism, often requires the presence of a primary substrate to induce the necessary enzymes.
3. **Microbial consortia:** Mixed microbial communities or consortia can be more effective than single strains in degrading complex pollutants. Different microorganisms may degrade different parts of a contaminant molecule or sequentially transform it into non-toxic end products.

Factors influencing biodegradation

Several factors influence the rate and efficiency of biodegradation, including the chemical structure of the contaminant, environmental conditions, and the presence of suitable microorganisms.

1. **Chemical structure:** The complexity and stability of a contaminant's molecular structure affect its biodegradability. For example, pesticides with simple, less halogenated structures are generally more amenable to biodegradation than those with complex, highly chlorinated structures.
2. **Environmental conditions:** Temperature, pH, oxygen levels, and nutrient availability are critical environmental factors that influence microbial activity and, consequently, the

biodegradation process. Optimal conditions can significantly enhance the degradation rate.

3. **Microbial presence:** The presence and diversity of microbial populations capable of degrading specific contaminants are crucial. Indigenous microorganisms may adapt to degrade pollutants over time, while bioaugmentation (adding specialized microbes) can enhance degradation rates in contaminated sites.

Biodegradation of pesticides

Pesticides are among the most widespread hazardous contaminants due to their extensive use in agriculture. Their persistence in the environment poses significant risks to ecosystems and human health. Biodegradation offers a sustainable approach to mitigating these risks.

1. **Types of pesticides and their biodegradation:**
   - **Organochlorines:** The organochlorine pesticides are known to be highly persistant in the environment. This class of pesticides includes the chlorinated derivatives of diphenyl ethane (dichlorodiphenyltrichloroethane - DDT, its metabolites dichlorodiphenyldichloroethylene - DDE, dichlorodiphenyldichloroethane - DDD, and methoxychlor), hexachlorobenzene (HCB), the group of hexachlorocyclohexane (α-HCH, β-HCH, ϒ-HCH, δ-HCH, or lindane), the group of cyclodiene (aldrin, dieldrin, endrin, chlordane, nonachlor, heptachlor and heptachlor-epoxide), and chlorinated hydrocarbons (dodecachlorine, toxaphene, and chlordecone), (Menone *et al.,* 2001; Patnaik, 2003). Unlike the organophosphate and the carbamate pesticides, the toxic properties of the organochlorine pesticides are not very similar (Matolcsy *et al.*, 1988). Although the toxicological properties are analogous to organochlorines with similar structures, like heptachlor and chlordane, the toxicological degree can vary by substituting a chlorine in the molecule. For instance, the substitution of chlorine atoms in the DDT ring for a methoxide group decreases the toxicity (Patnaik, 2003).
   - DDT is the most well known pesticide from the organochlorine group. The use of organochlorine pesticides started in 1939, when Paul Hermann Müller realized that the DDT, first synthesized by Othmar Zeidler in 1874, was an efficient insecticide (Matolcsy *et al.,* 1988). The DDT's high efficiency, its low water solubility, its high persistence in the environment and its mode of action, unknown until that moment, contributed to the increasing use of DDT (Konradsen *et al.,* 2004). These pesticides, such as DDT and lindane, are known for their persistence and bioaccumulation. Microorganisms like *Pseudomonas* and

Alcaligenes species have been reported to degrade these compounds under aerobic and anaerobic conditions.

- **Organophosphates:** Currently, among the various groups of pesticides that are used worldwide, organophosphorus pesticides form the major and most widely used group that accounts for more than 36% of the total world market. The most used among these is methyl parathion. Its accumulation has many health hazards associated to it, hence, its degradation is very important (Ghosh *et al.*, 2010). The organophosphorus pesticides (OP) are all esters of phosphoric acid and are also called organophosphates, which include aliphatic, phenyl and heterocyclic derivatives. Owing to large-scale use of OP compounds, contaminations of soil and water systems have been reported from all parts of the world. In light of this, bioremediation provides a suitable way to remove contaminants from the environment as, in most cases, OP compounds are totally mineralized by the microorganisms. Most OP compounds are degraded by microorganisms in the environment as a source of phosphorus and /or carbon. Classification of Pesticides. Thus, the OP pesticides can be hydrolyzed and detoxified by carboxylesterase and phosphotriesterase enzymes. Organophosphates are used to control a variety of sucking, chewing and boring insects, spider mites, aphids, and pests that attack crops like cotton, sugarcane, peanuts, tobacco, vegetables, fruits and ornamentals. OP pesticides are marketed by many of the world‘s major agrochemical companies. Some of the main agricultural products are parathion, methyl parathion, chlorpyriphos, malathion, monochrotophos, diazinon, fenitrothion and dimethoate. Commonly used organophosphate pesticides include parathion and malathion. Bacteria such as *Flavobacterium* and *Arthrobacter* species can hydrolyze these pesticides, breaking down the phosphate ester bonds.
- **Carbamates:** Carbamate pesticides like carbofuran and carbaryl are degraded by microorganisms such as *Pseudomonas* species, which utilize carbamates as a nitrogen source. Carbamates were introduced as pesticides in the early 1950s and are still used extensively in pest control due to their effectiveness and broad spectrum of biological activity (insecticides, fungicides, herbicides). High polarity and solubility in water and thermal instability are typical characteristics of carbamate pesticides, as well as high acute toxicity. The carbamates are transformed into various products in consequence of several processes such as hydrolysis, biodegradation, oxidation, photolysis, biotransformation and metabolic reactions in living organisms (Soriano *et al.*, 2001). Chemically, the carbamate pesticides are esters of carbamates and organic compounds derived

from carbamic acid. This group of pesticides can be divided into benzimidazole-, N-methyl-, N-phenyl-, and thiocarbamates. The compounds derived from carbamic acid are probably the insecticides with the widest range of biocide activities (Sogorb & Vilanova, 2002). The biodegradation of carbamates has been investigated by different microorganisms that metabolize carbamate pesticides. In most cases, the studies did not eliminate the possibility that abiotic processes are involved in the degradation. A number of bacteria capable of degrading carbofuran (Pseudomonas, Flavobacterium, Achromobacterium, Sphingomonas, Arthrobacter) have been isolated and characterized in an effort to better understand the bacterial role to remove carbofuran from the environment. Carbofuran is one of the pesticides belonging to the N-methylcarbamate class used extensively in agriculture. It exhibits high mammalian toxicity and has been classified as highly hazardous. Carbofuran was degraded first to carbofuran phenol and the result was degraded to 2-hydroxy-3-(3-methylpropan-2-ol) phenol by Sphingomonas sp. (Kim *et al.*, 2004).

2. **Microbial degradation pathways:** The biodegradation of pesticides often involves specific metabolic pathways where enzymes such as hydrolases, oxygenases, and reductases play vital roles. These pathways can lead to complete mineralization (conversion to CO_2 and water).
3. **Microbial community engineering:** The engineering of microbial communities tailored to specific contaminants holds great promise. This involves designing synthetic consortia with complementary metabolic pathways that can degrade complex pollutant mixtures more effectively than individual strains. Research into the interactions between different microbial species and their collective metabolism can lead to the development of robust and efficient biodegradation systems.
4. **Enhanced bioavailability techniques:** Improving the bioavailability of contaminants to degrading microorganisms is a critical area of research. Techniques such as the use of biosurfactants, which can solubilize hydrophobic pollutants, and the application of physical methods like ultrasound to break down soil aggregates, can enhance the accessibility of contaminants to microbes.
5. **Metabolic pathway optimization:** Optimizing the metabolic pathways of microorganisms through genetic engineering can increase their efficiency in degrading specific contaminants. This can be achieved by introducing genes that encode for more efficient degradation enzymes or by knocking out genes that divert metabolic flux away from the desired degradation pathway.

6. **Field-scale applications and trials:** Translating laboratory successes to field-scale applications remains a significant challenge. Pilot projects and field trials are essential for testing the scalability and effectiveness of biodegradation technologies under real-world conditions. These trials can provide valuable data on the operational challenges and inform the development of best practices for large-scale bioremediation projects.
7. **Economic feasibility and cost-benefit analysis:** Assessing the economic feasibility of biodegradation technologies is crucial for their adoption. Cost-benefit analyses that compare biodegradation with other remediation methods can highlight the long-term economic and environmental benefits, promoting wider acceptance among stakeholders and policymakers.

Biological pesticides:

Synthetic chemical pesticides provide many benefits to agriculture and food production, however, as previously discussed, they also present toxicity to non-target organisms and cause environmental pollution, therefore efforts to find new pest control alternatives have been studied, essentially due to the increasing concern about the effects of these compounds on human health and on the environment. Biodegradation and bioremediation of synthetic pesticides have been used as alternative green technologies to solve the problems related to the accumulation of these contaminants in soil and water. Another proposal to reduce the environmental impact of pesticides is the use of biological-derived products also known as biopesticides. According to the Environmental Protection Agency (EPA), biopesticides are defined as naturally occurring pest control substances. They are classified into three groups (Joshi, 2006):

A. Microbial pesticides: in which a microbial living organisms (bacteria, fungi, viruses, protozoans) is the active control agent.

B. Plant pesticides: pesticidal substances produced by plants from introduced genetic material (plant incorporated protectants)

C. Biochemical pesticides: naturally occurring substances that control pests by nontoxic mechanisms. These include substances that interfere with growth or mating such as pheromones. The main advantage of biopesticides is their safety to non-target organism, biodegradability and their specificity, which permits the use of small dosages and power exposure, hence avoiding pollution caused by conventional pesticides (Rosell *et al.,* 2008). In addition to being less harmful than chemicals, biopesticides have been of great value in integrated pest management (IPM) strategies where the use of biopesticides greatly decreases the use of chemicals, maintaining crop yields. The specificity of biopesticides contrasts with the broad spectrum of chemical counterparts. In contrast, biopesticides are also slow acting, have relatively critical application times, most suppress rather than eliminate the target population, have limited field persistence and short-shelf life. Despite the range of biopesticides that have been described, our discussion focuses on microbial pesticides.

Microbial pesticides:

Microbiological control is sustained by beneficial interactions resulting from competition, antagonism and parasitism of microorganisms against plant pathogens, insects and weeds (Montesinos, 2003). In general, microorganisms are able to suppress pests by producing a toxin, causing a disease or preventing the establishment of other organisms. Currently, several microorganisms involved in such processes are the active ingredient of microbial pesticides.

1. Bacteria: Most biopesticides available in the market are bacterial-based products. The well-known and widely used bacterial biopesticide comprises the gram-positive, spore-forming bacteria belonging to the genus Bacillus that are commonly found in soil. The majority of commercial microbial insecticides are preparations based on strains of Bacillus thuringiensis (Bt) that produces a crystalline inclusion body during sporulation (Frankenhuyzen, 2009). The crystal proteins (Cry proteins) are toxic to many insects and are defined as endotoxins (Bt toxin) that are generally encoded by bacterial plasmids (Gonzales & Carlton, 1980). Both spores and inclusion bodies are released upon lysis of the parent bacterium at the end of the sporulation cycle and if ingested, the spores and crystals act as poisons in certain insects. The protein is activated by alkaline conditions and enzyme activity of insect's gut hence, Bt is referred as a stomach poison (Chattopadhyay *et al.*, 2004). The toxicity of the activate protein is dependent on the presence of receptor sites on the insects gut wall. This match between toxin and receptor sites determines the range of insect species killed by each Bt subspecies and isolates (Frankenhuyzen, 2009).
2. Fungi: Fungi often act as important natural control agents against insects, pathogenic fungi, nematodes and as herbicide. Many fungi utilized as biopesticides are pathogenic to insect hosts, therefore they are referred as entomopathogenic fungi; among them, members of Entomophtorales (Zygomycota) and Hyphomycetes are currently under research (Srivastava *et al.*, 2009). Fungal strains are considered suitable for biopesticide development because, unlike other microorganisms, the infectious propagules (conidia) do not need to be ingested and contact with cuticle permits the fungi to penetrate the insect body (Thomas & Read, 2007).
3. Viruses: Virus-based biopesticides have been used as insect control agents. The larvae of many insect species are vulnerable to viral diseases. Baculoviruses are a large virus group belonging to the family Baculoviridae and can infect different insect orders, particularly Lepidoptera and Diptera (Theilmann *et al.*, 2005). Baculoviruses are classified into two genera: nuclear polyhedrovirus (NPV) and granulovirus (GV), (Cory & Hails, 1997;

McCutchen & Flexner, 1999). Two morphologically distinct forms of infectious particles are generated in the baculovirus cycle, the occlusion derived virus (ODVs), comprising enveloped virions embedded within a crystalline matrix of protein (polyhedrin for NPVs and granulin for GVs), and budded virus (BVs), consisting of a single virion enveloped by a plasma membrane. Due to their specificity and high virulence to a number of insect pest species, they have been used worldwide to control lepidopteran pests in many crops (Moscardi, 1999). BVs are responsible for the systemic or cell-to-cell spread of the virus within an infected insect. OVs, in turn, are responsible for the larva-to-larva transmission of the virus (Inceoglu *et al.,* 2006).

4. Protozoa: Some protozoan pathogens can kill insect hosts; however, many of them cause chronic infections with debilitating effects (Lacey & Goettel, 1995). One important consequence of protozoan infection is the reduction in the number of offsprings by the infected insects. Species of the genera Nosema sp. and Vairimorpha necatrix offer the greatest biopesticide potential. Nosema locustae is a specie of Microsporidium commercially available to control grasshoppers and crickets. It is most effective when ingested by immature grasshoppers (early nymphal stages). The spore formed by the protozoan is the infection stage in susceptible insects; it germinates in the midgut and causes a slow progress infection where the pathogen causes death three to six weeks after initial infection (Rosell *et al.,* 2008). Ostrinia nubilalis that causes important damages to corn was controlled by Nosema pyrausta infection, which reduced the egg production per female 53 and 11% at the 16 and 27°C temperature, respectively (Bruck *et al.,* 2001). Nosema locustae has been used to reduce grasshopper population in rangeland areas; although not all insects are killed, the infected grasshoppers consume less forage and the females produce fewer eggs. However, the utility of N. locustae as biopesticide remains questionable because of the difficulty to determine the treatment efficacy in this highly mobile insect.

Case studies:

1. **Biodegradation of Polycyclic Aromatic Hydrocarbons (PAHs):** PAHs are a group of hazardous organic pollutants commonly found in oil spills, industrial discharges, and urban runoff. Microbial degradation of PAHs, such as benzo[a]pyrene, has been successfully demonstrated in various environmental matrices. Studies have shown that bacteria like *Mycobacterium* and fungi such as *Phanerochaete chrysosporium* can degrade high-molecular-weight PAHs through oxidative and reductive pathways.
2. **Biodegradation in marine environments:** Marine environments present unique challenges for biodegradation due to factors like salinity, pressure, and low temperatures. However, certain marine microorganisms, such as *Alcanivorax borkumensis* and

Thalassolituus oleivorans, have shown remarkable capabilities in degrading hydrocarbons and other marine pollutants. Biostimulation, which involves the addition of nutrients to enhance microbial activity, has been effective in promoting biodegradation in marine oil spill scenarios.

3. **Pharmaceutical contaminants:** The presence of pharmaceutical compounds in the environment, particularly in water bodies, is an emerging concern. Biodegradation of pharmaceuticals, such as antibiotics and endocrine-disrupting compounds, has been explored using bacteria like *Pseudomonas putida* and *Bacillus subtilis*. Advanced bioreactor systems, such as membrane bioreactors and constructed wetlands, have been developed to treat pharmaceutical-laden wastewater effectively.

Advances in biodegradation research

1. Application of Omics Technologies: Omics technologies, including genomics, transcriptomics, proteomics, and metabolomics, provide comprehensive insights into the functional capabilities and adaptive responses of microbial communities during biodegradation. Metagenomics, for example, allows for the identification of microbial genes involved in contaminant degradation without the need for culturing. These technologies facilitate the discovery of novel biodegradation pathways and the optimization of microbial consortia for enhanced performance.
2. Bioinformatics and Computational Biology: Bioinformatics tools and computational models are increasingly used to predict the biodegradation potential of contaminants and to design effective bioremediation strategies. Computational approaches can simulate the interactions between contaminants and microbial enzymes, identify key metabolic bottlenecks, and optimize the conditions for maximal biodegradation efficiency. These models are invaluable for scaling up laboratory findings to field applications.

Conclusion:

Biodegradation remains a vital and promising strategy for addressing the environmental and health impacts of hazardous contaminants and pesticides. The integration of advanced biotechnological techniques, comprehensive environmental monitoring, and interdisciplinary research can overcome existing challenges and enhance the effectiveness of biodegradation processes. Future efforts should focus on optimizing microbial consortia, improving contaminant bioavailability, and implementing field-scale applications to achieve sustainable and efficient bioremediation. The commitment of researchers, policymakers, and communities to advancing biodegradation technologies will be essential in ensuring cleaner and healthier environments. Continued investment in research and development, coupled with supportive regulatory frameworks, can unlock the full potential of biodegradation in mitigating environmental pollution and safeguarding public health. The pollution of the environment by pesticides is a consequence of the continuous agricultural expansion, combined with the population increase. Pesticides are used in sizeable areas and applied to soil surfaces and accumulate beneath the ground surface, reaching rivers and seas. The natural microbiota is continuously exposed to pesticides therefore, it is no surprise that these microorganisms, that inhabit in polluted environments, are armed with resistance by catabolic processes to remove the toxic compounds. Biological degradation by organisms (fungi, bacteria, viruses, protozoa) can efficiently remove pesticides from the environment, especially organochlorines, organophosphates and carbamates used in agriculture. The enzymatic degradation of synthetic pesticides with microorganisms represents the most important strategy for the pollutant removal, in comparison with non-enzymatic processes. Regarding the use of biopesticides, their main advantage is their environmental–friendly nature when compared to chemicals.

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PLANT MICROBIAL FUEL CELL: A WAY TOWARDS SUSTAINABLE AND PERENNIAL POWER PRODUCTION FROM PLANTS

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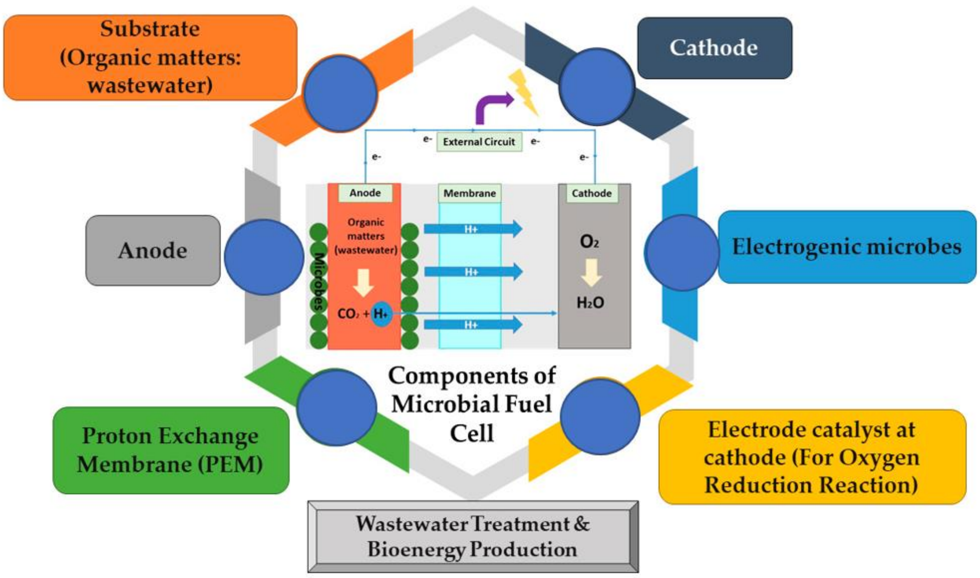
Introduction:

Our world is confronted with an energy crisis on a global scale. Our traditional energy sources like coal, gas and oil are polluting our planet by the release of carbon dioxide and other waste and also these energy sources will perish in a very few decades, that's why demand for new source of energy raises. Energy that is sustainable and renewable and most importantly energy which is available to everyone because all over the world there are 1.2 billion people don't have electricity. Without electricity, they have no light to read, no phone to communicate and no computer to participate in the world. They will lack in their social and economic development. After the raise of solar energy, wind energy, hydro-energy and biomass energy, one more energy source is entered to the group of renewable sources of energy, which is nothing but Plant microbial fuel cell.

Microbial fuel cell

A microbial fuel cell is like a biobattery-a device that utilizes electrochemically active bacteria to catalyze the release of electrons from the degradation of organic matter to generate electricity under anaerobic conditions. In other words, MFC converts chemical energy to electrical energy through the catalytic reaction of bacteria (Allen & Bennetto, 1993).



Components

A simple electrical configuration of an MFC consists of an anode, a cathode and proton exchange membrane (PEM), substrate, electrogenic microbes and electrode catalyst at cathode.

A. Anodic chamber

- **Anode**: A negative or reducing electrode that releases electron to the external circuit and oxidizes during and electrochemical reaction.
- **Substrate:** A range of organic substrates can be used for anaerobic digestion by microbes in bioelectricity production.
- **Electrogenic microbes:** Degrade the organic substrate and releases electron which can be utilized for electricity generation.

B. Cathodic chamber

- **Cathode**: The positive or oxidizing electrode that acquires electron from the external circuit and is reduced during the electrochemical reaction.
- **Catalyst**

C. Proton exchange membrane: Separates anode and cathode chamber and helps in transport of proton from anode to cathode chamber.

How microbial fuel cell works?

Microbial fuel cell works on the principle of redox reaction. The electrogenic micro-organism which is present in the anodic chamber of microbial fuel cell breakdown the organic matter into electron, proton and carbon dioxide in an anaerobic condition. The released electron in this reaction captured by the anode, then it is transported to cathode electrode because of the electro motive force. Proton transferred to the cathode chamber through proton exchange membrane. In cathodic chamber electron, proton and oxygen combines to form water as final product of this electrochemical reaction. Oxygen acts as final electron acceptor which is usually used as catalyst in cathode chamber of microbial fuel cell.

The movement of the electron from anode to cathode generates electricity in the microbial fuel cell. This electricity can be harvested by placing external load in the circuit but this microbial fuel cell couldn’t able to produce electricity continuously because it depends upon the external source of organic substrate.

To make this technology efficient, plant is introduced into the anodic chamber of microbial fuel cell to provide organic matter continuously by the photosynthesis process. This new derived technology is called as plant microbial fuel cell.

History

- In 1911, M. C. Potter, a professor of Botany at the University of Durham, USA, discovered electricity production from the decomposition of organic compounds. It was the first time that microorganisms were found to produce energy from organic matter oxidation.

- In 1931, Barnett Cohen created microbial half fuel cells that, when connected in series, were capable of producing over 35 volts with only a current of 2 milliamps.
- In 1976 Suzuki *et al.*, produced a successful Microbial fuel cell design.
- In 2008, Strike *et al.*, created a plant microbial fuel cell.

Plant Microbial Fuel Cell (PMFC)

Plant microbial fuel cell (PMFC) is a photosynthesis-based technology for harvesting bioelectricity from living plants. It is the derived technology of microbial fuel cell.

Benefits of introduction of plant in MFC

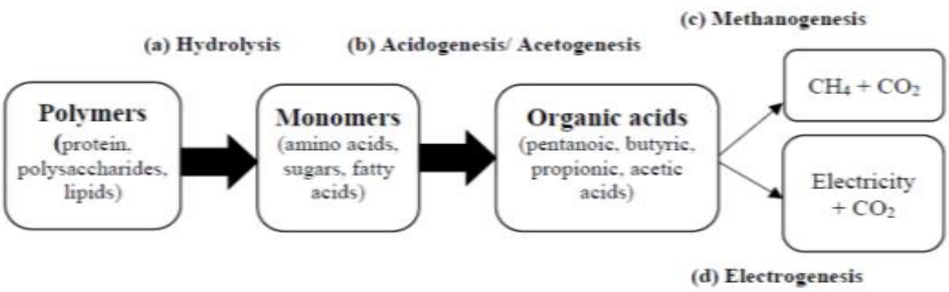
Plants are primary producers that carry out photosynthesis using chlorophyll, and harvest light energy to fix the atmospheric CO_2 to carbohydrates. Annually, 67.5 billion tons of carbon is fixed between land and atmosphere globally out of total fixed carbon (450 billion tons) by terrestrial plants during photosynthesis. Nearly 47.25 billion tons of fixed carbon are translocated to the roots and finally released into the rhizosphere by the process of rhizodeposition.

Rhizodeposition refers to the release of organic compounds by living plant roots into the soil These organic compounds are called rhizodeposits, and they include root exudates, secretion, lysates, and gases. The amount of rhizodeposits can be up to 40% of the plant's photosynthetic productivity and can differ markedly depending on the plant's species, its maturity and its environmental conditions.

Apart from the carbon source, root exudates also stimulate chemotaxis to promote soil microbes to the rhizosphere. Chemoattractant such as aromatic acids, dicarboxylic acids, flavonoids, and amino acids are synthesized to attract rhizobia to root hairs in the rhizosphere. Some of these root exudates and microbial metabolites such as formic acid, succinic acid, and biotin act as mediators for interelectron transfer.

Therefore, the plant rhizosphere facilitates a favourable microenvironment for bacterial metabolism (utilizing plant rhizodeposits) and mediates its reducing equivalents for harnessing bioelectricity through a microbial electrochemical system.

The process of anaerobic digestion of organic matter and electrogenesis



The breakdown of organic matter under anaerobic conditions includes four different stages of digestion: (a) hydrolysis, (b) acidogenesis and/or acetogenesis, (c) methanogenesis; and the process of electricity production in MFC through (d) electrogenesis.

During the first step (i.e., hydrolysis), extracellular enzymes from the microbes react with polymers (a long chain of molecules) and break them down into monomers (simple molecules). Next, in the second stage (i.e., acidogenesis), the monomers-the soluble organic matter-will be transformed into organic acids by acidogenic or acetogenic bacteria. Furthermore, methanogenesis might co-exist with electrogenesis processes. If methanogenesis is taking place, two major gases will be produced: methane and carbon dioxide. If electrogenesis takes place, electricity and carbon dioxide will be produced.

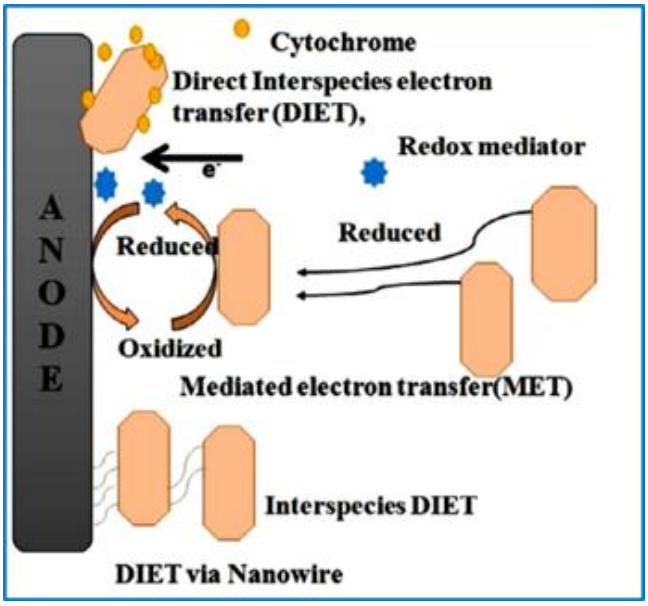
Electrogenic microorganisms:

In plant microbial fuel cell, electrogenesis takes place only in the presence of electrogenic micro-organism. The electrogenic microbes are the microorganisms that serve as the main biocatalysts by transferring the electron produced from the metabolism of organic compounds to the electrode through a series of chemical reactions. These electrogenic micro-organism have the capacity to form the colonies on the surface of the electrode, hence helps in electron transfer from organic matter to anode electrode.

The examples of electrogenic microbes are, *Shewanella putrefaciens*, *Clostridium butyricum Desulfuromonas acetoxidans*, *Geobacter metallireducens*, *Geobacter sulfurreducens Rhodoferax ferrireducens*, *Aeromonas hydrophila*, *Pseudomonas aeruginosa*, *Desulfobulbus propionicus etc.*

Electron transfer mechanisms

There are three different mechanisms involved in the extracellular transfer of electrons to the anode.



Direct electron transfer: Biofilm-forming bacteria have the capacity to transfer electron directly from organic matter to anode electrode.

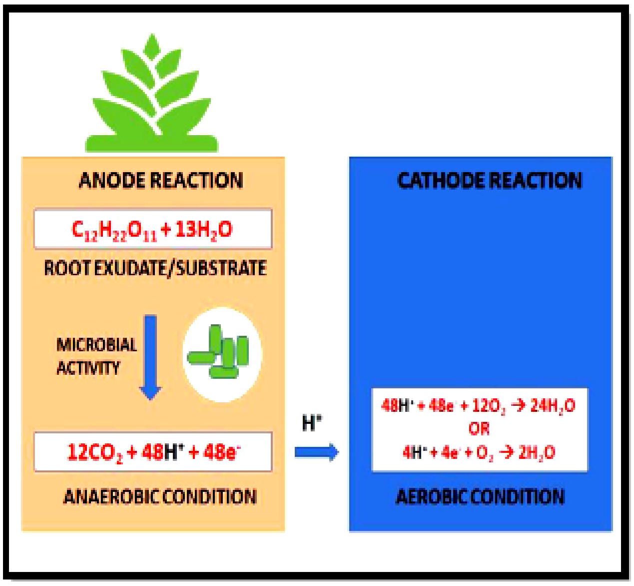
e.g., Geobacter species

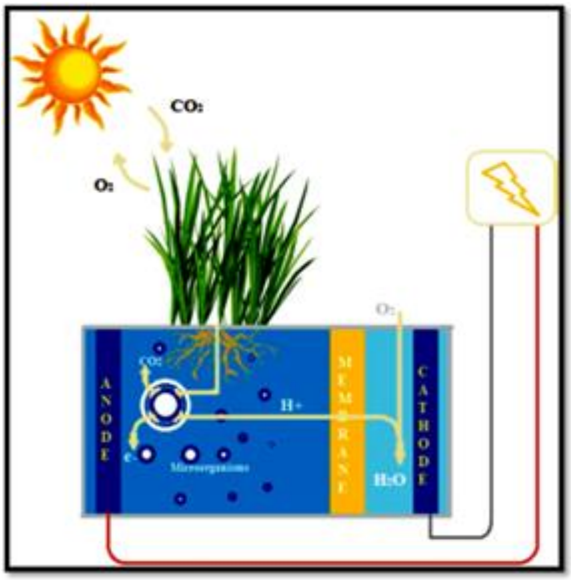
Mediated electron transfer: Fermentative microbes in the rhizosphere such as Pseudomonas, Shewanella, Lactobacillus, and Enterococcus are unable to transfer electrons directly to the anode. Hence these microbes require an external mediator (natural: flavins and cyanins; artificial: thionine, benzylviologen) to facilitate the electron transfer.

Electron transfer through nanowires: Conductive nanowires present in metal-reducing bacteria have been suggested for electron transfer to anode. The electrons get transported through the nanowires and reach the anode.

e.g., *Shewanella oneidensis*

Process of electricity production in PMFC:



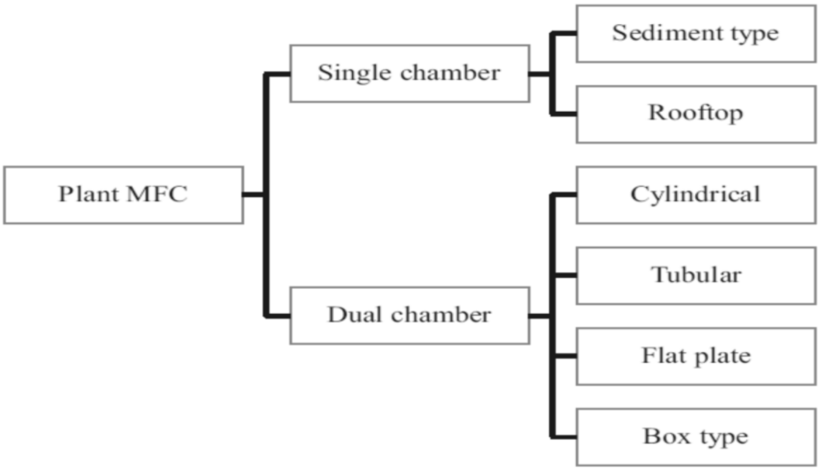


After plant get well acclimatised in the anodic chamber, it starts to release rhizodeposition which is responsible for the power production in the plant microbial fuel cell. This released rhizodeposits get decomposed by the electrogenic micro-organisms in the anodic chamber in an anaerobic condition and produces, proton, electron and carbon dioxide as the end product of decomposition. This released electron don't have any role in the plant metabolism, so we can harvest this electron for electricity generation in plant microbial fuel cell.

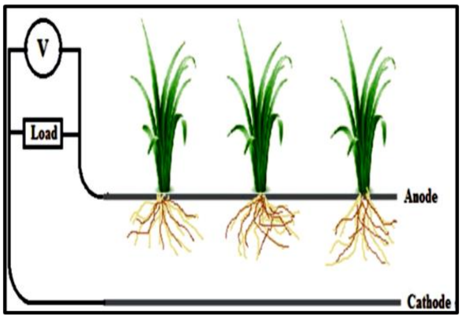
The released electron transferred from source to the electrode by the help of electrogenic micro-organism which act as biocatalyst. Then, electrons are transferred to the cathode through an external circuit because of the electromotive force. Proton transferred from anode chamber to cathode chamber through proton exchange membrane. In cathodic chamber, proton, electron and oxygen combines to form water as final product of this electrochemical reaction. Because of the movement of electron from anode to the cathode, electricity generated in the plant microbial fuel cell, which can be harvested by placing external load in the circuit.

This process continues throughout lifespan of the plant, so this plant microbial fuel cell is one of the green, clean and sustainable sources of energy because it has the capacity to directly transfer the organic matter into the electricity.

Types of plant microbial fuel cell:

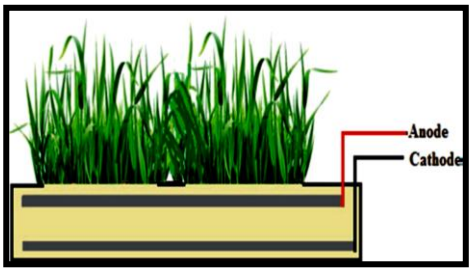


A. Sediment PMFC:



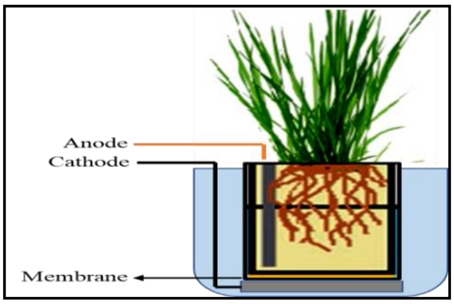
A sediment PMFC consists only of one chamber that maintains both the anode and the cathode. The cathode is however exposed to the atmosphere near the top soil. The absence of the proton exchange membrane makes the system very cost effective. But the rate of current generation is very low due to high diffusion rates of the electrons and proton.

B. Rooftop PMFC:



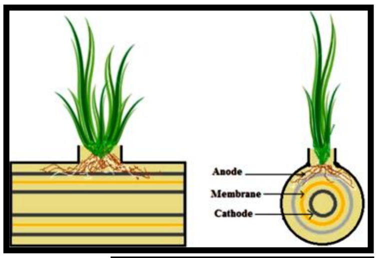
An advanced form of a PMFC is a rooftop system, which combines the advantages of green roofs with that of electricity generation. Rooftop PMFCs are a type of single chamber PMFCs wherein they incorporate the electrode-plant assembly onto the household roofs.

C. Cylindrical PMFC:



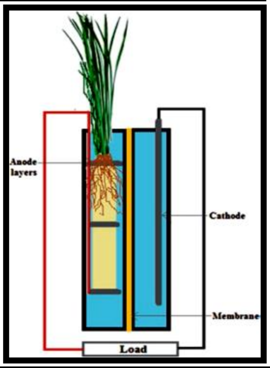
A cylindrical PMFC consists of two concentric cylinders wherein the anode chamber is held in the cathode chamber. The two chambers are separated with a proton exchange membrane.

D. Tubular PMFC:



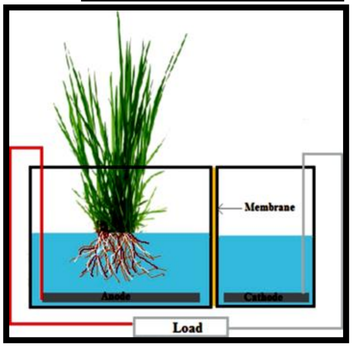
In this design anode, cathode and proton exchange membrane are in tubular shape. A tubular membrane is held through the centre of both discs. Anode is placed outside the membrane in the tube while the cathode is placed inside the membrane.

E. Flat plate PMFC:



A flat porous plate PMFC can be constructed using acrylic sheets. Anode and cathode are separated by proton exchange membrane. Width of this design is less as compared to its length.

F. Box type PMFC:



In a box type dual chambered PMFC, the anode and cathode chambers are separated with a membrane. Both the anode and cathode chambers are of box shape having equal dimensions.

Factors affecting Plant microbial fuel cell:

1. Selection of the Plants
2. Selection of electrode materials
3. Internal resistance
4. pH
5. Population of microorganism

Selection of the Plants:

A. **Photosynthetic pathways and plant rhizodeposition:** Based on their photosynthetic pathways, plants are classified into three categories: C3, C4, and CAM (crassulacean acid metabolism).

- ✓ CAM plants usually not utilized in PMFC because of its slow growth and less biomass production.
- ✓ Between C4 and C3 plants, C4 plants often utilized in PMFC because of the following advantages.
- ➢ C4 plants exhibit the theoretical maximum limit photosynthetic efficiency (Pe), 6.0% against C3 plants of 4.6%.
- ➢ Rhizodeposition is directly proportional to photosynthates formed (Rp) and availability of rhizodeposition to microbes (Ra) and fuel production (Er) which is 30% and 9% respectively.
- ➢ C4 plants thrive well in hot and dry conditions.

Example of some of the C3 plants utilized in PMFC are,


Oryza sativa


Eichhornia crassipes


Lolium perenne


Typha latifolia


Ipomoea aquatic


Glyceria maxima.

Example of some of the C4 plants utilized in PMFC are,


Pennisteum setaceum


Arundinella anomala


Spartina anglica


Canna indica

B. Aquatic, semi-aquatic or one that can tolerate standing water and flooded areas: Not all plants are suitable candidates for PMFC studies. This is because,

- ✓ The plant rhizosphere has to be in an aqueous/electrolyte medium to allow for electrons mobility.
- ✓ Aqueous condition helps to create anaerobic condition in anodic chamber which is necessary for power production in PMFC.

Lack of irrigation has been shown to cause a significant drop in power performance (Chiranjeevi *et al.*, 2012)

C. Non-food crops: With the aim of producing sustainable and clean energy from living plants without issues such as competition with crop plants, the use of non-food crop plants is emphasized in PMFC studies.

- Non-food crop plants are usually chosen based on several characteristics, such as being species of least concern (like non-threatened grasses), highly tolerant (to temperature, drought, salinity, toxicity), ornamental and easy-growing plants.

- Including ornamental plants in PMFC combines the advantage of both aesthetic value and electricity generation. Example for ornamental plants which is used in PMFC are,

Canna indica

Chasmanthe floribunda

Chlorophytum comosum

Sedum spp.

- *Sedum reflexum*
- *Sedum rupestre*
- *Sedum sexangulare*
- *Sedum spurium*

Azri *et al.* (2018) studied the ability of *Chlorophytum comosum, Chasmanthe floribunda* and *Papyrus diffusus* plants to generate electricity in a direct photosynthetic plant fuel cell (DPPFC) under natural sunlight without addition of any nutrients.

Figures 1 a, b, c shows the evolution of the maximum OCV produced by the different plants. The curves are divided into three areas. In the first 10 days, very low activity was observed owing to the time required for the formation of the electroactive biofilm on the anode surfaces. After 10 days, the biofilm was formed and a remarkable increase in voltage (OCV) was observed; *Chasmanthe*, *Chlorophytum* and *Papyrus* generated 390, 780 and 650 mV, respectively, indicating high activity of the bacterial film to generate the load.

The voltage intensity dropped suddenly after approximately 30, 40 and 20 days for *Chasmanthe*, *Chlorophytum* and *Papyrus*, respectively, because of electrode fouling which prevents the electron transfer between the electrode and the biofilm. After the electrodes were cleaned by hand polishing, the voltage increased again and became stable.

Figure 1d shows the current production in the absence of plant. A small potential difference between the anode and cathode was observed in the 10 first days, probably due to organic matter decomposition in the soil. After that, the soil bacteria broke down due to lack of organic materials, preventing electron transport in the circuit and generating a negative voltage.

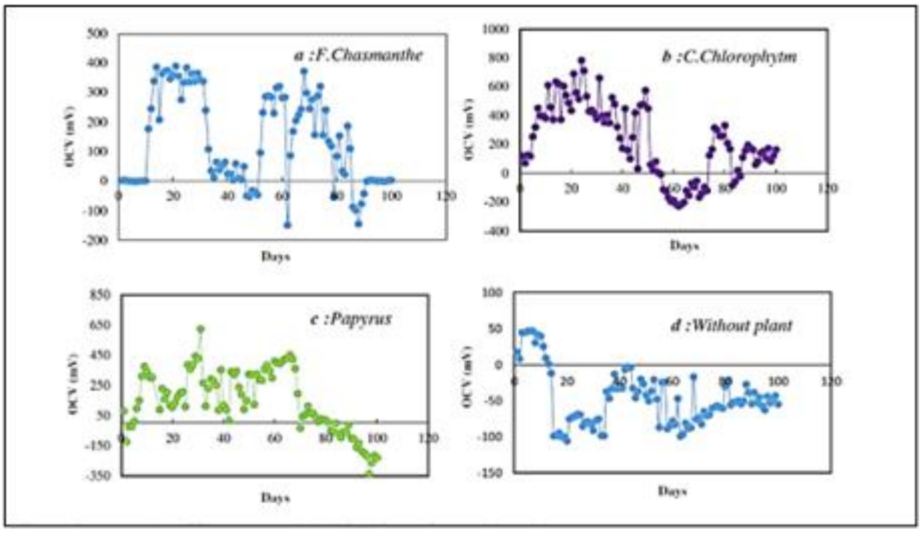


Figure 1: Open-circuit voltage (OCV) variation recorded with fuel cell setup's function during 100 days

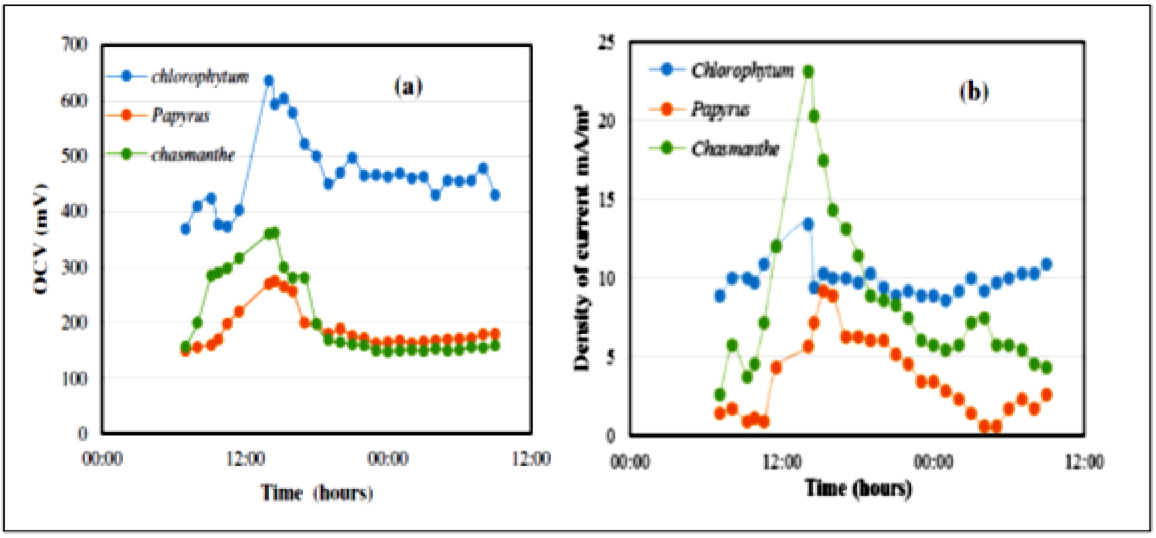


Figure 2: Photosynthesis influence on power output and its dependence on day/night: (a): OCV (mV); (b): Current density (mA/m^2 of anode surface) at 100 Ω.

Fig.2 shows that, for all the plants, the current density increased and reached the maxima at noon when the light intensity was also maximal. Indeed, during illumination beginning at daytime (after sunrise), a marked increase in electrogenic activity was observed because of the photosynthetic process and it increased until light was available.

During the afternoon, the current and OCV decreased gradually owing to the absence of light and this drop continued until morning. Maximum OCV and current density were observed at daytime, 14 h: *Chlorophytum* (636 mV–13.42 mA/m2), *Papyrus* (362 mV– 9.14 mA/m2) and *Chasmanthe* (360 mV - 23.14 mA/m2). This time might be attributed to the relatively higher temperature and light intensity proportional to the exudate release which increased the microbiological activity in soil. During afternoon, at 18 h approximately, the current and OCV decreased because of the weak exudate generation at lower temperatures.

As seen in Figures 2a, b, the plants continued to produce electricity even during night-time, which was attributed to the light-independent processes due to exudates released by photosynthesis, which also means that the PMFC has a battery equivalent built into its system (bio-battery).

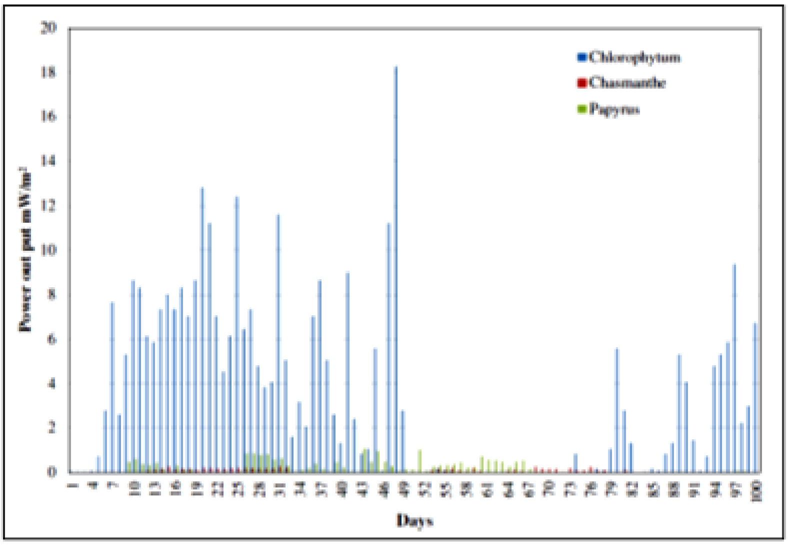


Figure 3: Power density (mW/m^2) of *Chasmanthe*, *Chlorophytum* and *Papyrus* during 100 days of experiment

Fig.3 shows, power density obtained in three different plants. In the three PMFCs, bioelectricity was produced. The highest power densities obtained by the PMFCs with *Chasmanthe*, *Chlorophytum* and *Papyrus* were 0.21 mW/m^2, 18 mW/m^2 and 1.083 mW/m^2, respectively. Thus, the PMFC with *Chlorophytum* showed the highest power density.

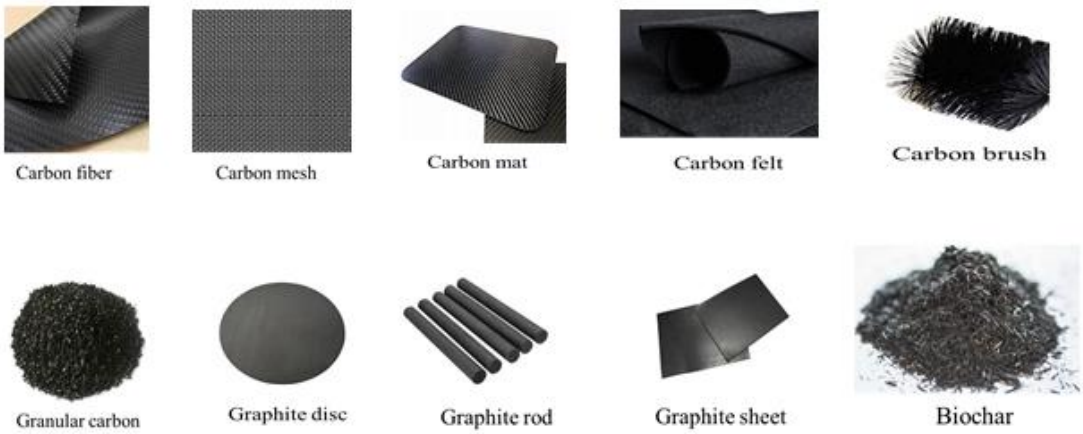
Hence, the three ornamental plants *Chlorophytum comosum*, *Chasmanthe floribunda* and *Papyrus diffuses* were found to be capable of producing electricity without use of any nutrients and membrane. Among 3 plants *Chlorophytum comosum* can be utilized as an effective plant for electricity generation. Photosynthetic activity directly influences the green electricity generation.

2. Selection of electrode Materials: While selecting electrode materials for PMFC, it should have following characters

- Good electrical conductivity
- Good thermal stability
- Low resistance
- Good biocompatibility with the system
- Strong stability and anti-corrosion
- Large surface area
- Good mechanical strength
- Low cost

Usually, carbon and graphite-based electrode materials used in PMFC because of its good electrical conductivity, low resistance and low cost.

Example of Carbon and graphite materials used in PMFC are,



- In a single-chamber MFC where the cathode is exposed to air, researchers have discovered, the use of some electro-catalytic metals integrated with carbon as the electrode material has improved cathode-oxygen contact (Pham *et al.*, 2006).
- The cathode surface area is always important for increasing power. Doubling the anode size increases power by 12%, but doubling the cathode size can increase power by 62% (Cheng & Logan, 2011).
- Regarding anode and cathode spacing, keeping distance to a minimum to reduce the ohmic resistance, which increases the power output. The effect of electrode spacing has been studied by Venkata Mohan and Chandrasekhar (2011), who found that an MFC with anode placed 5 cm away from the cathode–proton exchange membrane demonstrated higher power output (463 mV; 170.81 mW/m^2) than an MFC with a proton exchange membrane sandwiched between electrodes (258 mV; 41.8 mW/m^2).

Sarma and Mohanty (2018) studied the effect on bioelectricity generation of two different indoor plants, *Epipremnum aureum* and *Dracaena braunii* with or without modified anode.

A **B**

Figure 4: (A) Experimental setup of PMFC. (B) Schematic representation of plan and cross section of the experimental setup

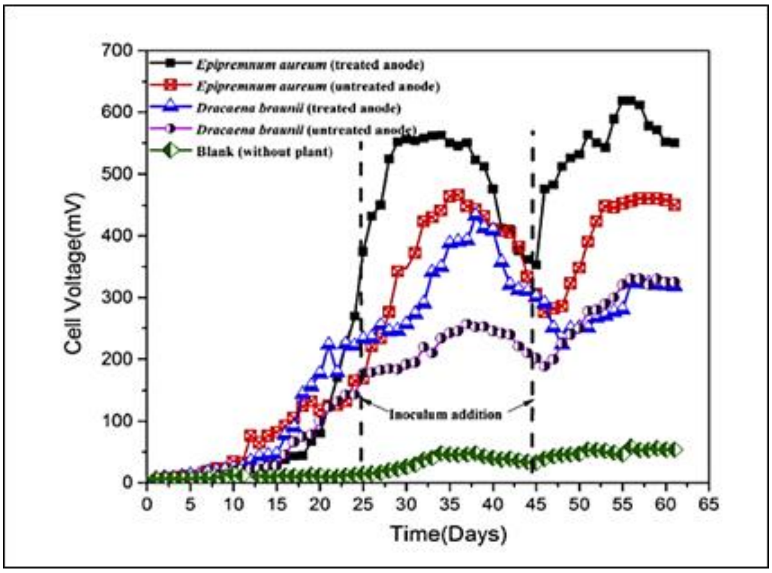


Figure 5: Variation of voltage generation with time

Fig. 5 shows variation of voltage with time in four different microbial fuel cell setups. A comparative analysis among all the four setups in this study showed that *E. aureum* with a modified anode (acid treated) generated higher potential as compared to others with a maximum voltage of 620 mV. The plants in the PMFC took around 15 days to acclimatize to the new soil and environment condition and power production started from 15^{th} day onwards and increased with input of microbial inoculum on the 20^{th} day and gradually started to decrease from 40th day onwards until second inoculum was fed on the 45^{th} day.

The voltage generation then increased again and remains almost constant until the end of the experiments on 60^{th} day, which indicates that, maintaining the optimum population of micro-organism is necessary for getting higher electricity output.

Table 1: Comparison of voltage, power and current generation in different MFCs

MFCs	**Peak voltage (mV)**	**Maximum power density (mW/m^2)**	**Maximum current density (mA/m^2)**	**Internal resistance (Ω)**
***Epipremnum aureum* (acid treated)**	620	15.38	38.46	200
***Epipremnum aureum* (Untreated)**	466	14.05	20.76	260
***Dracaena braunii* (acid treated)**	432	12.42	16.23	287
***Dracaena braunii* (untreated)**	276	12.78	7.54	376
Control (without plants)	58	0.046	0.76	-

A maximum power density of 15.38 mW/m^2 was achieved at a significantly lower internal resistance of 200 Ω by *E. aureum* with surface modified anode as compared to *E. aureum* with unmodified electrode and also similar trend was observed in acid treated *Dracaena braunii and* unmodified *Dracaena braunii* plant. This higher bioelectricity production can be attributed to the favourable bacterial attachment to the electrode. Therefore, the electrochemically active bacteria that colonized on the anode surface appeared to facilitate the electron transfer from bacteria to anode.

A higher power density, current density and voltage was achieved by *E. aureum* with surface modified anode as compared to *Dracaena braunii* plant with surface modified anode because, it was seen that *E. aureum* (money plant) started to increase in length from second week and grows at a faster rate, however, growth of *D. braunii* (bamboo plant) was much slower and its length is almost constant throughout the experiment. Number of leaves increased with the increased in branch length for *E. aureum*, however, the same is not significant in case of *D. braunii*. Similarly, roots development was also seen after the end of the experiment as branching in the roots increased in both the plants as compared to the starting of the experiment. Thus, the higher growth rate of *E. aureum* may have a direct effect on higher bioelectricity generation capacity as compared to *D. braunii.*

- Biomass and bio-electricity can be produced concurrently in PMFCs with *Epipremnum aureum* and *Dracaena braunii*
- The power density and current density increased significantly when carbon fiber was modified by acid treatment.
- Maintaining the optimum population of electrochemical active microorganism necessary to increases voltage and electricity generation.

Khudzaria *et al.* (2018) investigated the potential benefits of using biochar granules as an alternative to the standard carbon felt anode in microbial fuel cells (MFC) and found that biochar as anode give less power output as compared to the carbon felt anode in plant microbial fuel cell and has the higher potential to reduce the methane compared to carbon felt anode.

3. Internal resistance:

Increase in internal resistance decreases power output in PMFC.

- Two ways to decrease internal resistance are either to increase solution conductivity or to decrease electrode spacing (Liu *et al.,* 2005).
- High salinity content forms an ionic state in MFC, resulting in low resistance i.e., high ionic conductivity, which facilitates proton transfer and, hence, is beneficial to power production (Lefebvre *et al.,* 2012).
- Electricigens such as *Geobacter spp.* have demonstrated tolerances up to 10 g/L NaCl (Nevin *et al.,* 2005).

Khudzaria *et al.* (2017) analyzed the electricity production from alkali grass in saline and non-saline conditions in growing media with different organic matter content and found that MFCs produced best power density at the salinity level of 6 kg m^{-3}.

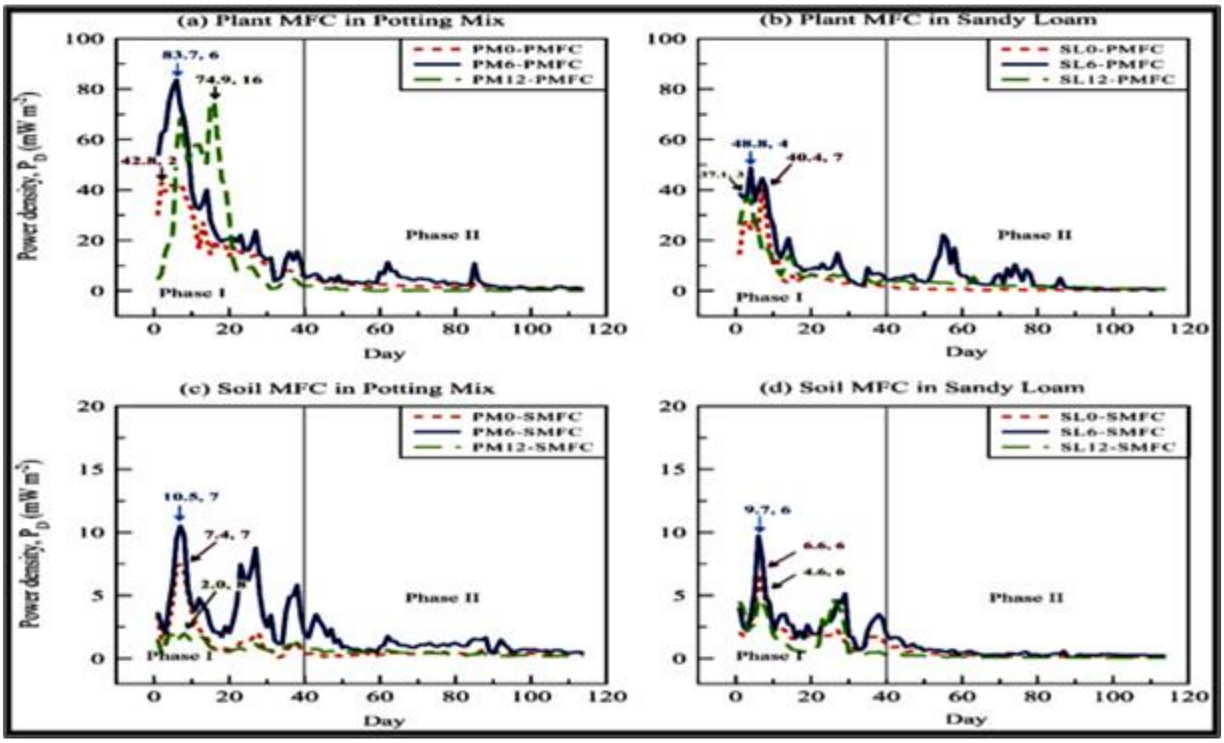


Figure 6: Electricity production in plant MFCs (a, b), and soil MFCs (c, d) for 114 days

It was found that the effect of salinity and growing media on power production was more pronounced in PMFCs than in the SMFCs. In general, the power production of the MFCs increased with the increasing salinity level. However, we also found that increasing the salinity from 6 to 12 kgm^{-3} did not necessarily increase the power production. In PMFC, the power production from saline conditions was greater in comparison to the non-saline condition. The decrease in power density with the increase in NaCl concentration was attributed to the increase in osmotic potential of the growing medium. Many microorganisms are inhibited or killed through plasmolysis when exposed to high osmotic pressure deficit resulting from high NaCl concentration (hypertonic medium).

4. pH value:

Maintaining electrode conditions at near-neutral pH values is essential.

- Maintaining the pH of MFCs in the range of 6–8 is crucial to promoting the growth of electrochemically active bacteria and enhancing the degradation of organic matter (Wang *et al.*, 2015).
- A decline in voltage output due to decreasing pH at the anode was observed in previous research (Rozendal *et al.*, 2006).

5. Population of microorganism:

- Among microbial communities, electrochemically active bacteria are responsible for generating electricity in the MFCs.
- One straightforward approach to enhancing electricity production in an MFC is to increase the population of electricigens at the anode.
- The superior characteristics of electricigens for electricity production is proven by its Coulombic efficiency, which is up to 90% higher than fermentative microorganisms (Lovley & Nevin, 2008).
- Coulombic efficiency is defined as the fraction (or percent) of electrons recovered as current versus that in the starting organic matter.
- From the perspective of energy recovery, a high Coulombic efficiency is desirable.

Kumar evaluated the performance of horizontal (type- I) and vertical (type-II) designs of terracotta-based ceramic-PMFCs (C-PMFC) with internal cathode installed in a paddy field.

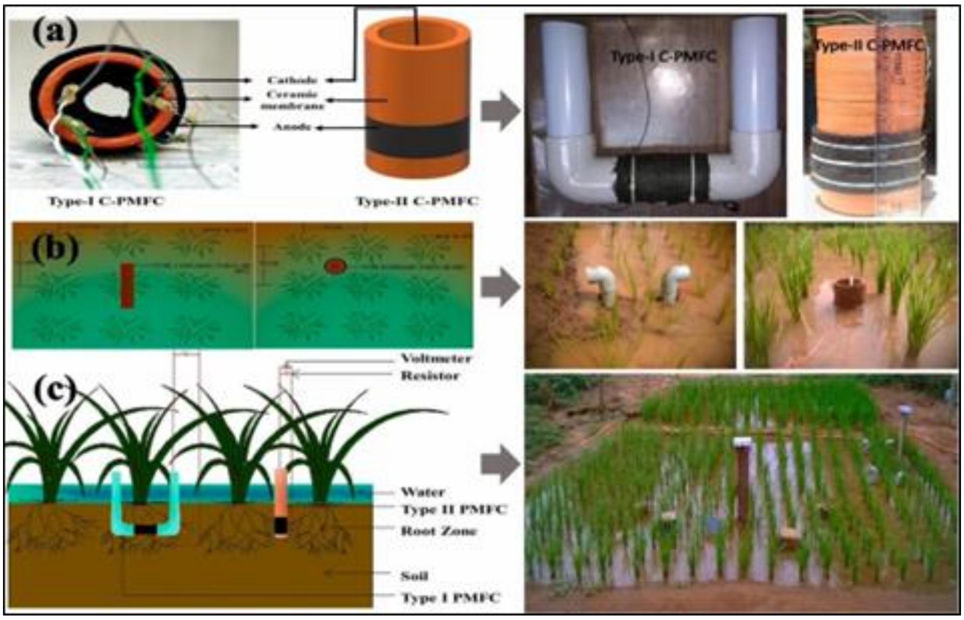


Figure 7: Paddy based C-PMFCs; (a), (b) and (c) showing the schematic illustration and real image of construction and installation of type-I and type-II C-PMFCs

In both types of C-PMFCs, higher energy was harvested in the active tillering phase and the lowest energy was harvested in the early ripening phase. The highest average power density of 26.37 mW/m^2 (type 1) and 24.04 mW/m^2 (type 2) was achieved at active tillering phase and lowest power density of 0.91 mW/m^2 (type 1) and 1.42 mW/m^2 (type 2) achieved in early ripening period. The varied amount of root exudates discharged by the rice plant at different growth stages influence the power output from paddy based PMFC at different growth phase of the plant. Also concluded that, different plant growth phases influence the power output in a rice based PMFC and higher power density observed in type II PMFC (Vertical type)

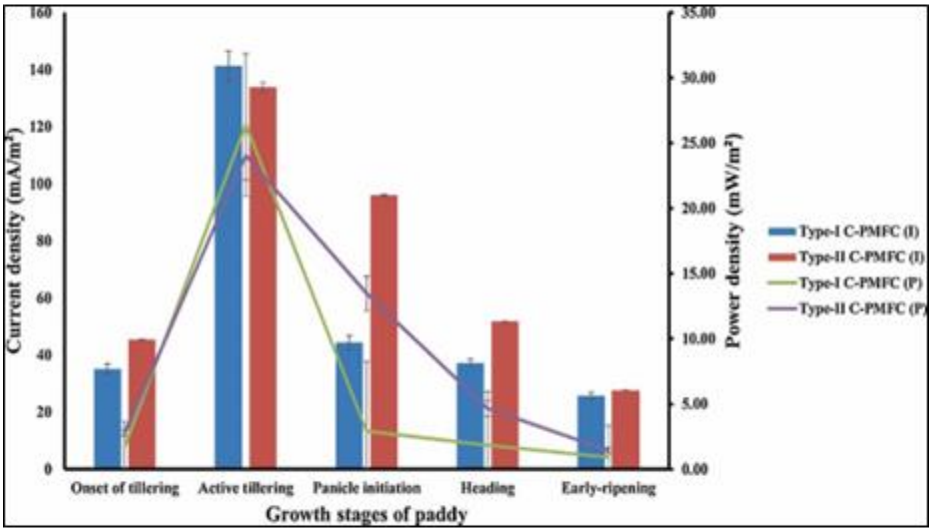


Figure 8: Current density (mA/m^2) and power density (mW/m^2) at different growth phases of the paddy in the two types of C-PMFC (Ceramic plant microbial fuel cell)

Table 2: List of major plant species incorporated with MFCs based on research articles published between 2008 and March 2018, retrieved from Scopus database

Plant species	Common name
Oryza sativa	Rice paddy
Phragmites australis	European common reed
Spartina anglica	Cordgrass
Canna indica	Indian shot
Glyceria maxima	Reed mannagrass
Ipomoea aquatica	Water spinach
Graminacae/Poaceae	Grasses family
Marsilea quadrifoli	Water clover
Sedum hybridum	Siberian stonecrop
Typha latifolia	Cattail
Acorus calamus	Sweet flag
Artemisia fukudo	-
Arundinella anomala	-
Arundo donax	Giant cane
Brassica juncea	Chinese mustard
Carex	Sedges
Chasmanthe floribunda	African flag
Chlororophytum comosum	Spider plant
Cynodon dactylon	Bermuda grass
Ejichhornia crassipes	Common water hyacinth

Epilobium parviflorum	Hoary willowherb
Hydrocotyle verticillata	Whorled pennywort
Juncus effuses	Common rush
Lolium perenne	English Ryegrass
Lycopius europeanus	Gypsywort

In the decade between 2008 and 2018, the PMFCs of 47 plant species were studied according to our literature search in Scopus as of March 22, 2018. The most popular plant species in PMFC studies is *Oryza sativa* (13 publications), followed by *Phragmites australis* (10 publications), *Spartina anglica* (8 publications), *Canna indica*, *Glyceria maxima* (6 publications) and so on.

PMFC applications, advantages and challenges:

Application:

1. PMFCs are capable of continuous bioelectricity generation without harvesting the plant, therefore, they can produce stable power all year round for biosensing, monitoring of ecological and water quality in remote areas while remediating the ecosystem.
2. PMFCs can be applied in locations unsuitable for food production such as green roofs and wetlands to restrain the rate of rainwater flow, parks and gardens to add aesthetic value, and indoors to reduce GHG emissions and to keep temperature stable.
3. PMFCs can be integrated into agricultural lands without competition with food production (rice paddy field) for arable lands to harvest bioelectricity.

Advantages:

- **Clean:** No combustion gasses.

Reduces methane emission.

- ***In-situ* bioenergy:** Electricity without harvesting plant
- **Sustainable:** Nutrient preservation

Combined food production

Plant stays alive

Self-sustaining

- **Efficient:** Lower molecular weight carries direct electricity

  Low-cost material

- **Renewable:** Dependent on solar energy

Challenges:

The major challenge of PMFCs is their low bioelectricity generation, therefore, further researches are necessary for,

1. Improvement in reactor design, configuration and electrode modification to optimize the operational conditions for commercial application.
2. Identification and selection of plant species with unique growth habits and characteristics to excrete different organic substrate for the root dwelling EABs to produce electrons for bioelectricity generation.
3. Genetic isolation and engineering of EABs strains that can efficiently disintegrate different substrates for sustainable bioelectricity generation.

Plant-e company

"Plant-e," a spin-off company started in 2013 at the subdepartment Environmental Technology at Wageningen University (CEO Marjolein Helder and David Strik, scientific researcher), started developing new tubular designs for applying P-MFCs in wetland systems, marshes, river deltas, and floodplains for power generation enabling multifunctional land use.

Figure 9: (a) A tubular PMFC system for demonstration purposes at the Wageningen campus. (b) Visitors can press the button to turn on the LED light powered by the PMFC system (Plant-e, 2016).

Figure 9 shows, one application of wetland PMFCs. A tubular system was installed at the boggy part of the grassland. The electricity produced by the PMFC was used to illuminate the information display panel at the site. This invention belongs to Plant-e (http://www.plant-e.com), a young Dutch spin-off company of Wageningen University & Research, The Netherlands.

Figure 10 shows one of the latest innovations in PMFC. Implementing this idea was made possible through collaboration between two Dutch companies, Living Plant (https://livinglight.info/) and Plant-e. The lamp is built to be an entirely self-sufficient closed loop power source that does not need electric sockets. The amount of energy produced depends on the well-being of the plant.

Figure 10: The ordinary plant is transformed into a living lamp. The light is activated by softly touching the leaves (Living-Light, 2018).

Conclusion:

Concurrent bioelectricity and biomass production make this technology an appealing choice for future green energy. Use of resistant and vigorous plants with higher rhizodeposition and efficient engineering for a higher rate of electron transfer would ultimately lead towards the practical application of this system. For this, multidisciplinary boosting and declining factors for the system performances need to be intensely researched.

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DECOLORIZATION OF TEXTILE HUES- A GREENER PALETTE TOWARDS SUSTAINABLE ECOSYSTEM

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Abstract:

Textile industry is widely recognized as a significant source of pollution for groundwater and surface water reservoirs, impacting human health and the environment. The decolourization and degradation of these dyes are a complex process involving various biological and physicochemical methods. The current literature on decolorizing and degrading textile dyes from wastewater significantly emphasizes utilizing biological methods to address this environmental challenge. The impact of textile dyes on the ecosystem is also discussed, highlighting the need for effective and eco-friendly strategies for their removal. As one of the largest consumers of chemicals, energy, and water, the textile industry releases a significant amount of untreated effluent into water bodies, accounting for 80% of the total industry emissions. Bioremediation is an eco-friendly and cost-effective method for treating textile dyes, employing biological materials to degrade, remove, modify the chemical structure and immobilize or detoxify various environmental pollutants. Several factors, including the dye properties, treatment methods, and various environmental conditions influence the efficiency of dye wastewater treatment.

Keywords: Textile Dyes, Physicochemical and Biological Treatment Of Dyes.

Introduction:

Water is the most valuable resource on the planet and is essential for all living creatures in its purest form because it comprises the majority of living tissues. The concept of life is impossible without water and indispensable in the global economy (Yadav *et al.*, 2014). The environment has been severely polluted over the last few decades as a result of a large number of inorganic and organic contaminants released due to anthropogenic activities such as rapid industrialization, urbanization, inadequate sewage treatment, chemical wastes, petroleum refining wastes, mining, electroplating, radioactive waste materials, and modern agricultural practices such as pesticides and fertilizers, as well as natural sources, have degraded the quality of the environment (Goodman *et al.*, 2018). Water pollution is a severe problem worldwide, threatening human health and the environment. Even though water covers 70% of the planet, water contamination has become a pressing global issue, with many regions lacking access to safe drinking water (Tan *et al.,* 2000). Controlling water pollution is the primary concern of modern civilization, and dye pollution is one of the significant environmental issues. Dyes are water-soluble synthetic colouring compounds with an annual production of about 7105 tonns commonly used in industries such as papers, plastics, food processing, cosmetics, textiles, pharmaceuticals, etc. (Yang *et al.,* 2020).

Generally, dyes comprise chromophoric, auochromic, and conjugated aromatic structures. Dyes are classified based on their origin, chromophores nature, chemical structure, method of application, and water solubility. They are classified into acid, basic, Vat, direct, disperse, azo, anthraquinone, indigoid, phthalocyanines, Di- and tri-aryl carbonium, Triarylmethane, nitro, mordant, reactive, solvent, and sulfur dyes. The wastewater released from textile industries consists of organic dyes, phosphates, nitrates, heavy metals, micronutrients, and harmful microorganisms (Yeap *et al.,* 2014). Therefore, the presence of textile dyes in water, even in low concentrations of industrial effluents, reduces light transmission, resulting in an increase in biochemical oxygen demand and impairing the photosynthetic activities of aquatic flora; as a consequence, the food source of aquatic organisms severely harmed. To avoid the negative impacts of dyes in wastewater, it is necessary to create low-cost, easy, effective, and ecologically friendly strategies for their removal. As a result, extensive research has been conducted into novel, practical methods for the remediation of dye-containing wastewater (Ihsanullah *et al.,* 2020).

Bioremediation concerns the biological restoration and rehabilitation of polluted sites as it offers many advantages over conventional treatment techniques (Yusuf *et al.,* 2017). Bioremediation of textile dyes is a fascinating approach to treating textile effluents using bacteria, algae, seaweed, plants, and fungi to degrade, remove, modify the chemical structure, immobilize, or detoxify various environmental pollutants witnessed tremendous research progress in developing biological systems for the efficient and economical removal of dyes from wastewater (Robinson *et al.,* 2001).

Adopting the most effective technique fulfills the purification objective when water treatment is a concern. The conventional methods for addressing the purification process use different physicochemical treatments such as flocculation, precipitation, ion exchange, filtration, coagulation, electro-coagulation, ozonation, adsorption, irradiation, and membrane separation (Shi *et al.,* 2007). Even though physicochemical techniques are effective, there are disadvantages, such as low efficiency, high cost, a complicated process, production of large amounts of sludge, and less feasibility on a commercial scale (Goudjil *et al.,* 2021).

In pursuing enhanced treatment options for textile wastewater, researchers actively explore innovative approaches, including integrating hybrid technology. These methods blend physical or chemical processes with biological mechanisms for more efficient treatment. This review endeavours to comprehensively survey the current literature problem about decolourising and degrading textile dyes in wastewater effluents. Notably, this review significantly emphasises using seaweed within biological methods to address this environmental challenge (Khader *et al.*, 2023).

Textile dyes- An overview

Dyes impart colour to the fabric because chromophoric groups in their structure and the solubility of dyes in water also differentiate them. Dyes are predominantly classified based on their physical and chemical nature of dyes (Ghaedi *et al.*, 2015). Chromophores are the key components responsible for giving dyes their distinct colours, while auxochromes enhance these colours by electron substitution, either by donating or removing electrons (Ahmed *et al.*, 2016). Chromophores typically contain functional groups like –N═N–, –C═O, O═ (C_6H_4) ═O, and $–NO_2$, whereas auxochromes contain groups such as $–SO_3H$, –OH, –COOH, and $–NH_3$ (Zhou *et al.*, 2019). Sulfonate groups in auxochromes are especially known for their high solubilizing ability. Auxochromes can be further classified into various types based on their reactivity: acid, base, vat, pigmented, disperse, astringic, anionic, or cationic. They can exist in dissolved or undissolved forms. Additionally, dyes are categorized according to the reactive groups they form covalent bonds with, such as -SH and -OH groups, based on the type of fibre they are used for, including cotton, wool, silk, and nylon (Saratale *et al.*, 2011).

In the textile industry, dyes are diverse and classified based on their origin, chemical compounds, and industrial applications (Regti *et al.*, 2017). There are two types of dyes, namely, natural and synthetic. Natural textile dyes are derived from plants, insects, and minerals, while synthetic dyes are produced from organic and inorganic compounds, often derived from petroleum by-products or various earth minerals (Elsahida *et al.*, 2019). Natural dyes, while facing challenges like low fixation, poor colour fastness, and limited colour range (Saravanan *et al.*, 2021), still find a use for their beneficial functional properties in textiles, such as antimicrobial, anti-insect, anti-inflammatory, UV protection, and deodorising qualities (Lee *et al.*, 2006). Synthetic dyes are favoured in the textile industry due to their water solubility, ease of absorption and rapid colouration compared to natural dyes (Jamee *et al.*, 2019). The classification of dyes based on their chemical structure focuses on the specific chromophore groups they contain. These classes include azo, xanthene, indigo, nitro, nitrosated, nitrated, anthraquinone, azine, phthalocyanine, oxazine, diphenylmethane, triphenylmethane, and polymethic dyes. Among these, azo, anthraquinone, and triphenylmethane dyes are the most widely employed. However, their aromatic nature presents a challenge in terms of stability, making them resistant to degradation (Vazquez *et al.*, 2020).

Impact of textile dyes on ecosystem

The textile industry is one of the global economic drivers; however, it is also one of the largest consumers of high amounts of chemicals, energy and water (Chikri *et al.,* 2020). The textile industry uses over 8000 chemicals, most of which are hazardous to the environment and human health. The release of untreated effluent into the water bodies, which accounts for 80% of the total industry emissions, has a negative environmental impact (Zhang *et al.,* 2022). Excess dyestuff is discharged into the environment during the dyeing process, leading to incomplete exhaustion of dyes released into the water bodies (Hagan *et al.,* 2021). Textile wastewater comprises dyes, suspended solids, inorganic salts, other chemicals, and non-biodegradable organic compounds from textile effluent (Gupta *et al.,* 2011). In addition to dyes, wastewater also contains other toxic substances such as sulphur, naphthol, nitrates, acetic acid, soaps, chromium compounds, and heavy metals like copper, nickel, arsenic, lead, cadmium, mercury and cobalt, formaldehyde-based fixing agents and hydro-carbon based softeners. When these pollutants are washed off into water bodies, they are detrimental to the environment, cause deterioration of the ecological balance and are also hazardous to humans (Karcher *et al.,* 2002). Textile dye industries emit toxic gases such as sulfur, nitrogen oxides, particulate matter volatile compounds, formaldehyde and dust, all characterized by unpleasant odour. This air pollution can negatively impact humans, animals, the final product, and the environment (Giovanella *et al.,* 2020).

Textile effluent significantly impacts the environment in multiple ways. The dyes and pigments in the effluent alter water colour and pH, leading to high levels of biological and chemical oxygen demand, an increase in total organic carbon, and elevated suspended solids. These changes disrupt and inhibit ecological processes within aquatic life, affecting water bodies aesthetic quality and transparency. The obstruction of light penetration into deeper water layers reduces photosynthesis, resulting in oxygen depletion and under-oxygenation of stagnant aquatic environments. This, in turn, deteriorates water quality, lowers gas solubility, and can be toxic to aquatic flora and fauna. Other negative impacts include bacterial proliferation and foul odours. Environmental contamination with dyes can bioaccumulate in aquatic organisms, posing a risk to higher species in the food chain, such as humans. The toxic substances in dyeing effluent are resistant to biodegradation, light, temperature changes, detergents, chemicals, soaps, and bleaches, persisting in water bodies. Additionally, the toxicity of dyes in wastewater can alter soil composition by destroying microorganisms, thereby affecting agricultural productivity. Irrigating with textile industry effluent can clog soil pores and harden its texture, preventing root penetration (Aldalbahi *et al.,* 2021).

Textile dyes and pollutants from the textile industry are highly toxic, carcinogenic, and mutagenic, posing significant health risks. Exposure to these dyes and pigments in water can lead to respiratory issues, including itchy and watery eyes, sneezing, and asthma-like symptoms such as coughing and wheezing. In severe cases, exposure may also affect the immune system. Additionally, chemicals present in dyes can cause skin irritation. Various synthetic substances used in the textile industry, such as optical whiteners, soda ash, caustic soda, bleach, formaldehyde-based resins, ammonia, acetic acid, and certain shrink-resistant chemicals, also have adverse health effects. Absorption through the skin may cause allergic reactions, including irritated and blocked noses, sniffling, and sore eyes. Moreover, dye effluents contain trace metals, leading to severe skin irritation, dermatitis, skin ulceration and nausea upon exposure (Moghaddam *et al.,* 2010).

Globally, wastewater regulatory agencies strive to control the discharge of hazardous substances into the environment. The goal of treating wastewater is to minimize the presence of harmful substances such as *Nonylphenol Ethoxylates*, textile dyes, brominated and chlorinated flame retardants, chlorobenzenes, chlorophenols, chlorinated solvents, heavy metals, organotin compounds, perfluorinated chemicals, phthalates, and short-chained paraffins to permissible levels. The documented negative impacts of the textile industry on the environment and human health underscore the need for sustainable dyeing practices. These practices may include optimizing the dyeing process, enhancing wash fastness, and employing innovative, effective, and economical methods for treating textile wastewater before its discharge. Additionally, reducing the process temperature can help conserve energy (Huang *et al.,* 2014).

Factors affecting dye decolourisation

The chemical structure and type of dye greatly influence its decolourization. pH is a critical factor in this process, with the optimal pH varying based on the dye type and treatment method. Some decolourization processes are more efficient in acidic conditions, while others perform better in alkaline environments. Temperature also affects the rate of dye decolourization, generally enhancing reaction kinetics at higher temperatures. However, excessively high temperatures can degrade dyes and form harmful by-products. The dye concentration in wastewater directly impacts the efficiency of decolourization processes, with higher dye concentrations often requiring longer treatment times or larger amounts of treatment agents. Contact time plays a major role in dye removal; the removal efficiency of the dye is increased with an increase in contact time. As the adsorbent dose increases, the dye removal efficiency also increases due to greater adsorption of dyes onto the adsorbent surface. Other pollutants, such as heavy metals, organic matter, or chemicals, can also interfere with the decolourization process. Depending on their nature and concentration, these co-pollutants may inhibit or enhance decolourization (Vikrant *et al.,* 2018).

Approaches for textile dye abatement

Various approaches exist for remediating dyes in textile effluents, including physicochemical and biological methods. Physicochemical methods have limitations such as limited efficiency, high operational costs, significant energy requirements and secondary waste production. In contrast to these traditional methods, bioremediation has emerged as a cost-effective alternative for treating textile wastewater, utilizing biological materials to address dye contamination (Bilal *et al.*, 2022).

Physicochemical methods

Physical methods such as coagulation and flocculation have proven effective for decolorizing wastewater containing dyes. In the coagulation process, ferric chloride and ferrous sulfate are commonly used to capture dyes from textile effluents. Additionally, research has shown successful applications of alternative coagulants, including aluminum chloride, polyaluminum chloride and magnesium chloride, in textile wastewater remediation. However, coagulation has limitations, including relatively low decolourization efficiency, high costs, and the generation of substantial amounts of sludge (Szyguła *et al.*, 2008).

Adsorption is extensively used in water treatment to eliminate diverse pollutants, valued for its simplicity, cost-efficiency, and high efficacy. It has gained prominence for effectively decolorizing various dyes found in textile wastewater (Subramaniam *et al.*, 2019). According to the literature, a range of adsorbents have been investigated for dye remediation from wastewater, such as activated carbon, biochar, wood, fly ash, metal oxides, rice husk, zeolites, metal-organic frameworks, carbon nanotubes, and peat (Singh *et al.*, 2020). Key characteristics of an effective adsorbent for water treatment include a strong affinity for specific dyes, high pollutant uptake capacity, cost-effectiveness, and the ability to be regenerated effectively (Mohammadi *et al.*, 2011).

Membrane filtration techniques have been used to treat textile wastewater, including nanofiltration, reverse osmosis and ultrafiltration. The use of membranes in dye treatment presents several benefits, such as requiring a small physical footprint, minimal maintenance, and easy installation and operation. Advanced membrane technologies described in the literature enable the selective separation of diverse dye molecules. However, membrane-based dye treatment faces challenges in handling large dye volumes, generating concentrated residue, and potential issues with membrane clogging (Liang *et al.*, 2014).

Textile effluents are treated using various conventional methods, including oxidation techniques such as advanced oxidation processes (AOP) and chemical oxidation. During AOP, hydroxyl radicals formed in the process oxidize dye molecules, breaking down their complex structures. Chemical oxidation typically employs oxidizing agents like H_2O_2 and O_3 to mineralize organic pollutants. These agents generate plentiful hydroxyl radicals that degrade dye structures into smaller, non-chromophoric molecules. While chemical oxidation methods are effective for double-bonded dye molecules, they generally exhibit lower degradation rates compared to AOP due to the production of fewer hydroxyl radicals (Arslan *et al.,* 2000).

Ozonation is a common method in water purification that effectively degrades toxic organic pollutants without producing sludge or increasing wastewater volume. However, it has certain drawbacks, including the formation of toxic byproducts, high costs, and issues with ozone stability, which can be affected by factors such as temperature, pH, and salt presence. Ion-exchange resins are also used for textile effluent remediation, but this approach is relatively expensive and less efficient for dye removal. Additionally, physicochemical methods generate a significant amount of sludge in the environment (Zubai *et al.,* 2018).

Biological methods

Biological methods are well-established for treating textile dyes, posing significant benefits such as cost-effectiveness and producing harmless, non-toxic byproducts. However, these methods involve complexities due to the intricate nature of dyes and the challenges posed by using bacteria, fungi, algae, seaweed, chitin, yeast, etc. The subsequent sections explore various bioremediation techniques, which focus on the biological degradation of organic waste into benign compounds or their concentrations to acceptable levels (Tripathi *et al.,* 2023).

Dye decolourisation involves aerobic and anaerobic bacteria metabolising dyes through oxidative and reductive processes. White-rot fungi are particularly effective due to their ligninolytic enzymes, which break down a variety of dyes. Microalgae absorb and metabolize dyes, utilizing biosorption and biodegradation mechanisms (Patel *et al.,* 2021). Seaweed plays a crucial role in dye decolourization, particularly in wastewater treatment and environmental remediation. Dye decolourization involves removing or degrading synthetic dyes from industrial effluents, which is vital for preventing water pollution and protecting aquatic ecosystems. Seaweeds exhibit high biosorption capacity for various pollutants, including synthetic dyes. Their cell surfaces contain functional groups such as carboxyl, amino, and hydroxyl groups, which bind to dye molecules through chemical interactions like ion exchange, hydrogen bonding, and van der waals forces. This biosorption process effectively reduces dye concentrations in wastewater (Kamati *et al.,* 2024).

Enzymatic decolourisation leverages isolated enzymes such as laccases, peroxidases, and azoreductases to catalyze dye breakdown. Laccases oxidize phenolic and non-phenolic substrates, while peroxidases use hydrogen peroxide to oxidize dyes, and azoreductases specifically target azo bonds under anaerobic conditions. Phytoremediation uses plants to extract, degrade, or stabilize dyes. Aquatic plants like water hyacinth and duckweed and terrestrial plants such as sunflowers and Indian mustard, absorb dyes from water and soil, metabolizing or accumulating them in their tissues. These biological methods offer significant advantages, including lower operational costs and reduced environmental impact, but they also present challenges such as efficiency variability, the need for condition optimization, and scale-up difficulties (Telke *et al.,* 2015).

Conclusion:

The textile industry generates effluents containing high levels of toxins with persistent compounds and dyes, harming the environment and human health. Various biomasses, including plants, bacteria, algae, yeast, seaweed, fungi, etc are employed to decolourize, transform or mineralize textile dyes to mitigate or eliminate these harmful products from the environment. While these bioremediation methods yield excellent results, each has its own limitations. However, advancements in molecular biology, genetic engineering, and nanotechnology, alongside rigorous academic and scientific research, can address these limitations by focusing on developing more efficient and stable engineered enzyme-producing organisms, environmental biotechnology emerges as an ethical and effective tool to promote sustainable development in the future.

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RENEWABLE ENERGY APPLICATIONS IN THE AGRICULTURE SECTOR

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Abstract:

Agriculture is the primary sector for the source of various sectors, including food, textile, etc. It is a highly energy-dependent sector. It accounts for the second most significant Greenhouse Gases (GHGs) emission due to fossil-fuel-based farm robots and the burning of agricultural wastes. Application of renewable energies includes solar energy for irrigation, drying products, lighting, functioning farm robots, heating, and cooling; geothermal energy for heating soil, plant production, and drying products; wind energy for heating, cooling, lighting, irrigation and water pumping; hydropower for irrigation and electricity production; biomass energy for electricity production and fertilizer production in agriculture. Applying nanotechnologies to renewable energy technology increases the efficiency of green energy generation, quality, and sustainability efficiency and reduces even the minimal emission of GHGs in biomass energy conversion. The planning for the installation of renewable energy needs to consider the nation's economy, energy requirement, geography, depending on the source, and varying parameters such as wind flow, temperature, climate, etc. Developing biofuel-based tractors and farm motors could enhance the implementation of renewable energy applications in sustainable agriculture.

Keywords: Agriculture Development; Nanotechnology Application; Renewable Energies; Sustainability; Economic Growth

Introduction:

"Agriculture" is one of the ancient businesses that drives human cultural evolution and is the common point of all other businesses (Koondhar *et al.*, 2021). As the primary and vital sector for the source of food, textile, biofuels and other major sectors, the energy consumption for the agricultural sector from direct and indirect use accounts for 18.5% of India's net energy consumption (Vijayakumar *et al.*, 2023). In the European Union, 3.7% (at least 1435 PJ) of the net annual energy consumption is utilized for open-field agriculture, mainly from nonrenewable energy sources. Among 3.7%, indirect sources use 55% of total energy inputs. In detail, seeds, irrigation, pesticides, and storage and drying each report for 5% of total energy inputs. Around

30% of total energy inputs are reported for on-farm diesel used for farm equipment. The significant share is 50% of net energy inputs reported for fertilizer – the most considerable energy-consuming activity in EU open-field agriculture. Fertilizer and pesticide production are indirect sources that happen off-farm (Paris *et al.,* 2022). Agriculture includes energy consumption for irrigation, transportation of produce, fertilizer and pesticide production, processing the products (refrigeration, drying or other processes), and other farm activities such as running machinery for sowing, spraying, fertilizing, weed removal, and harvesting. Energy consumed for activities held in farmland was categorized as direct energy consumption, such as sowing, irrigation, weed removal, fertilization, processing of products, and transportation of produce. On the other hand, energy consumed for the activities held off farmland was categorized as indirect energy consumption, like fertilizer and pesticide production and marketing (Majeed *et al.,* 2023). Below in Figure 1 impact of conventional/non-conventional an energy source on the environment has shown.

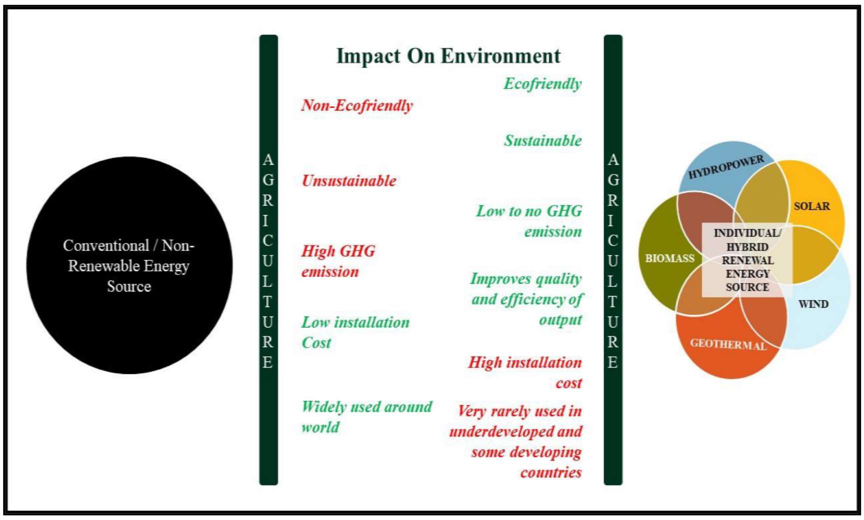

Figure 1: Impact of conventional/non-conventional energy sources on environment

The growing human population is estimated to increase between 9.6 and 12.3 billion by 2100 (Kant Bhatia *et al.,* 2021), which shows a requirement for a significant increase in agricultural production, which means the energy demand in agriculture will increase by several folds in the upcoming days. So, applying renewable energies in agriculture is insisted to lead a sustainable agricultural practice. Renewable energies are sustainable and do not harm the environment and ecosystem, but the installation cost is high (Elahi *et al.,* 2022). Solar energy, wind energy, hydropower energy, biomass energy, geothermal energy, and ocean energy are the renewable energies discovered yet (Ahmadi *et al.,* 2019; Hatamkhani and Moridi, 2019; Jena and Saryam, 2023; Majeed *et al.,* 2023). Renewable Energy (RE) installation and application are geographically dependent and can only be installed in some places (Majeed *et al.,* 2023). This chapter emphasizes the potential proper establishment of RE plants for agriculture. Agriculture sector industrialization only helps implement sustainable practices and energy management through renewable sources. It is hard to implement a RE source for every small farmland, but not the same case for the collective of small farmlands. The solutions are all there, but the cooperation from the public is not supportive, and execution plans from the governments of the developing countries are ineffective.

Agriculture energy requirements and management

Depending on the level of development, agricultural practices, and geographical location, the challenges in energy for agriculture vary. With increased population growth, urbanization and climate changes, and economic and technological development, energy demand is rapidly increasing and is predicted to increase by 50% globally by 2030 (Majeed *et al.* 2023). Economic structure, urbanization, and GDP per capita negatively influence agricultural energy efficiency. Energy mix and pesticide use significantly drive energy efficiency, and the ratio of agricultural land has varied influences on different quantiles. The modernization of the agricultural sector improved the quantity and quality of production. However, modernization increases agricultural commercial energy use (Liu *et al.* 2021). Adapting RE and energy management practices will reduce the high input cost of energy usage in agriculture (Majeed *et al.*, 2023).

Energy use in Agriculture includes human, animal, mechanical, coal, fertilizer, seed, petroleum products, and agrochemicals (Jena and Saryam, 2023). For mechanized activities on the farm, electricity is used to pump water for irrigation, run motors and sprayers, and light the farm. Fossil fuel is used in the power grid for tractors, transportation, and electricity generation. Electricity for farm activities is mainly from the power grid. Hence, increased mechanized activity for more production increases fossil fuel usage (Majeed *et al.*, 2023). More consumption of fossil fuels causes an increase in carbon dioxide intensity in the atmosphere. The agricultural sector contributes about 14% of global GHG emissions and approximately 20% of CO_2 emissions (Liu *et al.*, 2021; Pata, 2021). Significant CO_2 emissions are observed in agriculture from these three components – transport, chemical fertilizer, and agricultural waste burning. While transporting agricultural inputs and farm products, using petroleum products results in CO_2 emission. In the case of fertilizer, the CO_2 emission is from production and over-application. In production, the heavy consumption of energy and the release of smoke (carbon emissions) into the atmosphere. Due to the over-application of chemical fertilizers, the excess fertilizer reacts with water, resulting in carbon emission and diminishing soil fertility, ultimately leading to increased demand for fertilizer use in the long run. Burning of agricultural wastes also results in Carbon emission and diminishing soil fertility. These practices ultimately result in global problems, climate change and global warming (Jena and Saryam, 2023; Koondhar *et al.*, 2021).

As discussed earlier, energy use in agriculture is categorized into direct and indirect use. The direct use includes activities from the farm to marketing the final product, whereas the indirect use includes fertilizer and pesticide production and agricultural input import. About

1.2% of the world's energy is utilized for fertilizer production. Most of this is consumed to produce ammonia (Majeed *et al.,* 2023). Diesel fuels, electricity, and fertilizer account for 75% of farm energy use (Jena and Saryam, 2023). All these sources are directly or indirectly a source of fossil fuel. The increase in the cost of fossil fuels and energy negatively affects agriculture, which in turn causes reduced earnings for the farmers and agriculture will be only for energy-intensive consumers (Boltianska *et al.,* 2021; Jena and Saryam, 2023). Issues with fossil fuels could be resolved by replacement with RE, as they are not dependent on foreign fuels. They are sustainable and emit little to no pollutants (Jena and Saryam, 2023). Implementation of RE will be achieved by following the under mentioned four strategies in order:

- Analyzing the geographical features of a region or a country and compiling a cartographic atlas of renewable sources.
- Adopting a law on RE and development and implementation of new technologies and techniques by industrial means.
- Demonstrating the broad application of developed technologies in sustainable agriculture and other day-to-day activities.
- Replacing traditional energy sources with renewable sources as much as possible (Boltianska *et al.,* 2021).

The renewable energies are solar energy, wind energy, hydropower energy, biomass energy, geothermal energy, and ocean energy (Ahmadi *et al.,* 2019; Hatamkhani and Moridi 2019; Jena and Saryam 2023; Majeed *et al.,* 2023). Apart from RE application integrated farming technology, stricter environmental standards in agro-environmental policies and industrial agglomeration will increase energy efficiency in agriculture (Liu *et al.,* 2021).

Application of the renewable energy

Even though 75% of global electrical energy is obtained from fossil fuel sources, also termed Conventional Energy Sources (CES), the global attention is towards clean and sustainable energy systems (Elkadeem *et al.,* 2019) mainly due to their sustainability and causes nearly no damage to the environment. CES are the primary reason for the increasing GHG emissions. The heavy decrease in natural fossil fuel reservoirs will raise the price of fossil fuels in upcoming years, which would be the major drawback of CES. So, the International Renewable Energy Agency (IREA) has planned to increase the Renewable Energy Sources (RES) in global energy generation to 85% by 2050 from 25% in 2017 by expanding the cost effective share of renewable (Elkadeem *et al.,* 2019). The increased consumption of RES will achieve the balance between a nation's economy and environmental development (Qiao *et al.,* 2019). The drawbacks of RES when individually consumed for load demand are unreliable and low security due to the intermittent, dynamic, and unpredictable nature of the RE resources. The RES only depend on the varying climatic conditions for their respective sources and need to be steadier, and unceasing. The combination of two or more RES, termed Hybrid Renewable Energy Systems (HRESs), was developed to meet the load demand connected with the grid or off-grid for electricity generation to tackle the financial, technical, and environmental problems. Energy Storage Systems (ESSs) could be employed for load levelling and constant power supply with drawbacks such as contribution to energy loss and higher installation cost, which leads to overall system cost and reduced energy conservation efficiency (Elkadeem *et al.,* 2019).

Application of RE in agriculture leads to more independence and high profit in the long run. It also helps in the energy security of agriculture. Current agricultural practices cause GHG emissions, which will be hindered by using the RES. In agriculture, RE can be consumed for irrigation, ventilation, heating, drying, greenhouse, refrigeration and many more (Majeed *et al.,* 2023). Different materials employed in RE made them cost-effective and more efficient. Solar PV water-pumping systems for pumping water from various distances to irrigate crops in remote areas of developing countries will be the best choice. Instead of fossil-fuel-based power systems, the HRESs made of wind and solar power can be employed for freshwater production in the greenhouse. In greenhouses, the HRESs made of solar, PV, and wind energies can be employed to humidify and dehumidify the greenhouse to maintain a suitable climate for crop production and to produce freshwater from seawater (Acosta-Silva *et al.,* 2019). These are some detailed examples of the application of RES in agriculture in the application of solar, wind, hydro, ocean, geothermal, and biomass are discussed in the upcoming sections.

Solar energy

On average, 1366 W of solar energy is received per square meter of Earth's surface, depending on latitude. Around 4,000,000 t of solar fuel is transformed into solar energy every second on the Sun's surface. The stellar environment absorbs Most of this, and very little energy reaches Earth as radiation (Majeed *et al.*, 2023). Active solar systems convert solar energy into the most applicable form of energy. This system is of the following types: solar collector, photo catalysis, solar Photo-Voltaic (PV), and Dye-Sensitized Solar Cell (DSSC). The solar collector is a system that absorbs solar heat and transfers it to working fluids in the system. Photocatalysis uses solar energy to oxidize or reduce materials to produce fuel components such as hydrogen (Chemical energy). It has a high capacity for energy saving. TiO2 has several applications in industries, from water and air purification to cancer treatment in the medical sector. PV converts solar energy into electricity and heat. The PV cells' temperature increased due to radiation absorption, and the reverse saturation current started growing and reduced the open voltage and energy gap. Recent studies focus on cooling PV modules to recover heat and increase electricity generation. DSSCs directly convert solar energy into electricity. Its conventional efficiency depends on sensitizing wide bandgap semiconductors, photoelectrode specification, and electrode characteristics (Ahmadi *et al.*, 2019).

In agriculture, solar energy is employed for irrigation, sowing, spraying, refrigeration, cold storage, drying, greenhouse heating, functioning farm equipment, and fertilizer production. In developing countries like India, crop irrigation with solar-powered pumping systems will transform the lives of farmers as they are energy-sufficient and cost-effective. PV-based pumping system helps lift water from rivers, canals and ponds. It distributes it into lands for irrigation purposes—a compact model of PV-based sprayers designed with rechargeable batteries for small land-holding farmers to spray pesticides. The spraying activities are primarily performed during the daytime, so the sprayers are directly charged by sunlight. If not, the rechargeable batteries help to charge wherever required. Solar-based machines with radiofrequency (Bluetooth controlling) help farmers sow or spread seeds at a particular depth and distance apart. These technologies are more effective in efficiency, green energy, and easy access than conventional heavy machines that work with diesel or electricity from the grid. Solar dryers are available in various forms and sizes. There are two types: active and passive dryers. Active dryers use external energies, such as fans, pumps, etc., to transfer heat from solar energy. Passive dryers employ naturally occurring forces like wind pressure, buoyancy force, or transfer solar energy. These technologies reduce processing time, working area, and fossil fuel consumption with proper maintenance of the quality of drying products. There is a decrease in drying time by 40% and the collector efficiency by 23.5-36% in the hot climatic regions using solar tunnel dryers. The conventional cold storage system demands more energy to refrigerate the produce or commodities. The solar-based refrigeration system (refrigerator or air conditioner) increases energy saving by 40-50%. Solar-based systems are available for heating and lighting the greenhouse instead of conventional gas- and oil-based ones. The solar-based tractors started evolving nowadays with PV modules and batteries.

People are working to brighten agriculture with green energy. According to study conducted in the year 2018, 250 pet joules of energy per year was saved by reducing the 10% usage of urea or ammonia-based fertilizer (Majeed *et al.,* 2023). Nevertheless, what could be the source of nitrogen fertilizer? Solar-based fertilizer, or biofertilizer, at standard temperature and pressure, symbiotic nitrogen fixation involves solar energy to reduce inert nitrogen gas into ammonia. The microorganism satisfies all the nitrogen requirements by the plant (Lindström and Mousavi 2020), but in some cases, the requirement is not met due to unfavourable conditions. Using chemical fertilizer at low and required amounts is advisable only during unfavourable conditions. There needs to be data required for climate change and nitrogen fixation efficiency. However, the overuse of chemical fertilizers also leads to climate change. Sowing, weeding, spraying, ploughing, and harvesting robots are available with rechargeable batteries and electric motors. Applying a PV module will be a trivial solution towards green energy (Majeed *et al.*, 2023).

Solar energy falls at a rate of 120 petawatts on the Earth's surface, which indicates that the energy received from the Sun in one day could satisfy the world's energy demand for 20 years (Acosta-Silva *et al.*, 2019). However, due to extensive land requirements, most energy is non-consumable. However, the Agro-Photo-Voltaic (APV) technology was proposed by Goetzberger and Zastrow (1982) for the synergistic combination of green energy and agriculture. In agriculture farms, they set the solar collector 2 m above the ground and increase the spacing between them to reduce the shading of crops. Applying this technique increases the farms' yield by 30% if suitable crops are planted to reduce the yield loss due to the shading effect (Weselek *et al.,* 2019). The Application of APV is illustrated in Figure 2. The application of nanotechnology in RE is one of the hot topics of current research to increase the efficiency of RES. In PV, the modification of interaction between material and lights helps in the semiconductor process with low cost in photovoltaics. Improves the efficiency of photocatalysts to convert solar energy into chemical energy (producible fuels). Nanotechnology helps produce compact batteries with high power capacity achieved by increasing the efficiency of bidirectional conversion of chemical energy into electric energy (Ahmadi *et al.*, 2019).

Figure 2: Illustration of the application of Agro-Photo-Voltaic (APV) in agricultural farm (Source: Weselek *et al.*, 2019)

Wind energy

Wind energy is available 24 hours daily (Majeed *et al.*, 2023). It is the movement of air masses in the velocity proportional to the pressure gradient between the high atmospheric area and adjacent low atmospheric pressure area. The direction of the wind is from the high atmospheric pressure area to the lower atmospheric pressure, (Acosta-Silva *et al.* 2019) which is illustrated in Figure 3. Wind turbines convert wind energy into electrical energy, windmills convert wind energy into mechanical energy, and wind pumps pump water or drainage using wind energy (Ahmadi *et al.*, 2019). For the economic, environmental, and social aspects before the installation, the wind potential of an area must be evaluated. Farms integrated with wind power can reduce operational and maintenance costs and the amount of imported fuel to run the farm. Depending on the size of the farm, its energy requirement varies from 400 W to 40 kW. Small wind turbines can achieve this small demand (Majeed *et al.*, 2023).

In most of the world, wind energy is economically insignificant. However, the Netherlands widely applies wind energy (Acosta-Silva *et al.*, 2019). Some agriculture applications include direct water pumping and electricity generation to operate farm equipment. In direct water pumping, the kinetic energy of wind is transformed into mechanical energy to hydraulic energy for water pumping. Depending on the weather, the giant wind turbines affect the crop positively and negatively by causing changes in carbon dioxide, moisture, and heat fluctuation. Some studies reveal that climate change is due to wind turbines. It also affects pathways for tractors, bird flight path impedance, noise pollution, soil erosion, visual pollution, and microclimate. The modern method implements low-speed and high-speed turbines for low noise. Depending on the underneath crop plantation, the energy generated from will turbines fluctuated, which is proven in a study conducted in 2016, where 14% of enhancement in output energy is shown when the underneath crop is changed from corn to soybeans (Majeed *et al.*, 2023).

Nanotechnology helps wind energy conversion by providing developed coating, lubrication, lightweight with high durability materials, and sensing material to detect and monitor possible damages and stability of the windmills and wind turbines (Ahmadi *et al.*, 2019).

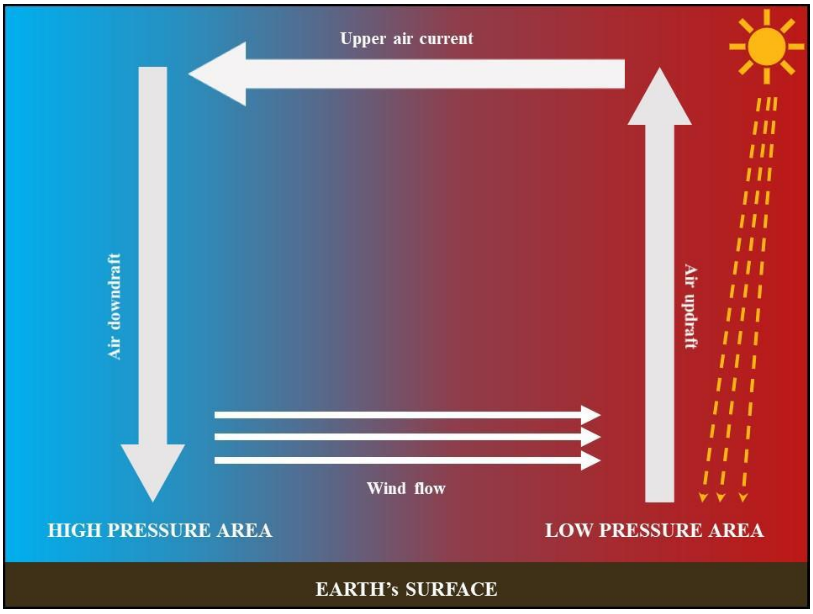

Figure 3: Illustration of wind flow and it's direction (Source: Majeed *et al.*, 2023)

Biomass energy

Biomass is an important and versatile RES of all time worldwide, usually the output of agriculture, especially the non-human consumable organic matter and some animal sources (fats and manure). The biomass-derived energy includes biogas, bioethanol, biodiesel, and biofuels. Modern worlds rely on biomass-derived energy for various needs. For the sustainable exploitation of biomass energy, its production and use must regulate. Without the regulation, it induces unwarranted land use change, like stimulating land conversion into less suitable for agriculture and forestry. It also affects the global carbon and nitrogen cycle and water availability and quality (Thrän *et al.,* 2020). However, biomass-derived energies have a high potential to impact environmental damage and rural development (Samadi *et al.,* 2020). It is produced from various organic biodegradable organic materials, including municipal organic solid waste, energy crops, livestock manure, and agricultural wastes. Denmark utilizes livestock manure along with energy crops for biogas production. In 2018, Danish produced 13.4 PJ of biogas, which is expected to increase between 23 and 107 PJ (Korberg *et al.,* 2020). In Asia, rice is the most stable food crop. Its straw is not used for consumption. It is burned chiefly directly in the farmlands via a closed combustion method, often leading to excess emission of short-lived pollutants, GHGs, and other pollutants (Cuong *et al.,* 2021). Instead of burning, which also affects soil fertility, these wastes can produce biofuels.

By origin, biomass inputs are the output of solar energy; by producers, the solar energy is trapped and utilized to fix carbon for their various metabolic activities via photosynthesis. The agricultural residues are used for energy production in biomass energy conversion. Bioenergy shares 9.5% of net primary energy and 70% of net RE usage (Majeed *et al.,* 2023). The environment has various advantages in utilizing plant-derived alcohols for combustion (Ahmadi *et al.,* 2019). Bioethanol can be mixed with gasoline for internal combustion engines in a small proposition as it has a higher-octane number (Majeed *et al.,* 2023). Land accessibility and crop selection are considered for biomass fuel utilization. Non-food feedstock will contribute majorly to sustainable bioenergy generation. Eco-friendly production of biofuels is achieved by combining nano-catalysts with biomass. The conventional biofuel production methods augmented to emit GHGs to some extent, which can be overcome by applying nano-catalysts with algae for biofuel production. Nanocatalysts can break down methane into hydrogen and carbon in anaerobic electricity production from biogas-fuelled electricity. Nano-catalyst is sustainable and reusable. They can be recovered, recycled and reused, which cannot be done in conventional methods. Nanocatalysts improve bioenergy generation and the quality of biofuel and provide appropriate working conditions. Ni3Cu(SiO2)6 is a nanoalloy catalyst used in biomass gasification for biomass synthesis (Ahmadi *et al.,* 2019).

Geothermal energy

Earth's heat energy, or geothermal energy, is non-carbon native, environmentally friendly RE (Majeed *et al.,* 2023). It is trapped in hot rocks or hot water springs and can be directly used or converted into electricity in a Geothermal Power Plant (GPP). The working fluid absorbs water from the hot rock lying under the ground and while passing it through the steam turbine the thermal energy is converted into electrical energy. The water again cooled and passed to the hot rock for the next cycle. The heated water is directly used in industries and agriculture (Ahmadi *et al.,* 2019). In agriculture, it is directly used for soil heating, greenhouse heating to extend production duration for out-ot-season vegetables and flowers, and irrigation where water is not readily available. It needs to be closely monitored for its chemical composition to avoid a negative impact on plant growth during the direct application of geothermal water (Majeed *et al.*, 2023).

Geothermal energy is produced by volcanic and tectonic activities on Earth's surface. Brine solution (mineral-laden hot water) and steam are the two working fluids that transfer heat from reservoirs to the surface via the drilled well. Depending on the characteristics of the reservoir, the free-flow method or pumping method is employed. It accounts for 28% of the world's energy generation capacity. It is sustainable, non-fluctuating and available throughout the year due to its independence on season, climate, and geographical conditions (Majeed *et al.*, 2023). The application of nanotechnology for nano-coating reduces heat corrosion and introduces nanofluids to enhance the fluids' thermal properties. For example, nanoscale montmorillonite-based nanoscale coating increased the melting point from 40°C to 290°C (Ahmadi *et al.* 2019).

Hydropower energy

Climate change affecting Southeast Asian countries, temperature rise in atmospheric air of Southeast Asia recorded increasing by 0.1°C – 0.3°C every decade between 1951-2000, rainfall trending downwards, rise in heavy precipitation is recorded between 1900 and 2005, and the increase in number of cyclones from 1990 to 2003. Climate change has magnified the water shortage and created significant challenges in finding sufficient water supply sources (Sahukhal and Bajracharya, 2019). However, hydropower contributes 16% of electricity generation worldwide and 85% of global renewable electricity. Upstream water consumption and irrigation water requirement directly influence hydropower production by determining the surface water required. However, energy production and agricultural development are contradictory. Both require large land for more production. An increase in agricultural cultivation area has decreased energy production in the river basins (Hatamkhani and Moridi, 2019). More studies need to be carried out to optimize hydropower and agricultural productivity. The hydropower generated near the river basin can be distributed to the nearest farmland and domestic uses to reduce transportation loss. Moreover, the studies need to integrate hydropower in the agricultural land for sustainable power RE generation and agriculture.

Conclusion:

Agriculture is the second largest GHG emitter due to fossil-fuel-based farm equipment and biomass burning. GHG emission is the primary cause of global warming. According to the United Nations Food and Agricultural Organization (FAO), 21% of net GHG emissions are from the agricultural sector. The Group of Twenty (G20) countries, considered the world's leading economies, emit about 74.9% of global carbon dioxide emissions, and they hold about 77.1% of the global economy. Carbon dioxide accounts for 72% of net GHGs. To avoid these hazardous activities against the environment, applying renewable energy in various sectors is required, especially in agriculture. Further investigations are required to find the link between carbon dioxide emission, agricultural development, economic growth and RE production (Qiao *et al.* 2019). As discussed above, solar energy can be used to irrigate, dry products, lighting, functioning farm robots, heating, and cooling; geothermal energy for heating soil, plant production, and drying products; wind energy for heating, cooling, lighting, irrigation and water pumping; hydropower for irrigation and electricity production; biomass energy for electricity production and fertilizer production in agriculture (Ahmadi *et al.,* 2019; Qiao *et al.,* 2019; Majeed *et al.* 2023). For sustainable agriculture with balancing productive and economic stability by limiting natural resource exploitation and environmental damage, RES must be suggested to the farmers. They have more potential to uplift the agricultural sector (Acosta-Silva *et al.,* 2019).

Developing biofuel/biodiesel-based tractors and water pump motors could be a great alternative to implementing the RE-based technology because these agriculturally commercial vehicles and motors can be replaced more effectively than the other commercial vehicles. The agricultural areas are enriched in agricultural wastes and livestock manures. Installing a biodiesel plant in the outer village and distributing biodiesel to the nearby bunks will be sufficient for agricultural vehicles and motors. As there is easy access to raw materials to produce biodiesel and the tractors are not used for long-distance transportation, there will be no challenges in finding biofuels (if a biofuel plant is installed in that respective village). Hence, it will be the initial step to solve the major issues. However, the land requirement for building the biofuel plant will take much work. According to the geographical location, biofuel plants must be designed depending on the village's energy requirement.

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ETHNOMEDICINAL STUDY OF SELECTED PLANTS USED BY THE NATIVE OF BARPALI N.A.C., BARGARH DISTRICT, ODISHA

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Abstract:

Present study concentrated on the ethnomedicinal study on essential plants of Barpali N.A.C. of Bargarh district of western Odisha, India. The study site was frequently visited and close interactions were made with the local practitioners involved in herbal medicines. During field surveys, interviews were conducted with the practitioners and their recommendation towards plant parts, mode of administration, and used for the diseases were noted. A total of 40 different plant species from 37 genera belonging to 28 different families were documented. Out of 40 plant species, there were 13 (32.5%) species of herbs, five (12.5%) species of shrubs, 20 (50%) species of trees and only two (5%) species of climbers were recorded.

Keywords: Ethnobotany, Ethnomedicinal Use, Medicinal Plants, Barpali NAC, Bargarh District

Introduction:

Since ancient times, plants have been used as a potential source of medicine by the tribal people of India to cure different diseases and disorders (Sahu *et al.*, 2010). According to WHO report, more than 80% of the world population depend on traditional medicine for their primary health care purposes (Sahu *et al.*, 2013). Till yet, study of traditional medicine became scientifically significant and economically important task of ethnobotanists. In the previous few decades more numbers of work in identification, documentation and detection of traditional medicine have been made in India. Ethnobotanical studies are often important in revealing nearby significant plant species particularly for the discovery of crude drugs (Sahu and Sahu, 2017). Although the demand of modern medicine is increasing now-a- days, but due to its side effects many peoples depend on traditional medicines. Further, these modern medicines do show effectiveness against the specific disease and increase the power of our immune system, they also tend to have high chances of reaction such as allergic reaction, uncomfortableness. Also, intake of high doses of medicine is harmful for our health.

On the other hand, plant parts and traditional extract from medicinal plants show great effectiveness when properly used, and that too without much reaction. That is why plant-based medicines are extremely used by tribal people and village people. Thus, the aim of this research was to document the ethnomedicinal use of selected plants found in the locality of Barpali N.A.C., Bargarh district in Western Odisha, India.

Materials and Methods:

Study site

Barpali is one of the three N.A.C.s in Bargarh district in the Western Odisha. The area is located in the 21.1922º N latitude and 83.5879º E longitude. Barpali N.A.C. consist of 11 words and its area is 31.7793 square kilometers. The population was 20841 as per 2011 census.

The plants and data were collected by frequent exploration throughout the area, but before that, a survey was done by taking observations and direct personal interviews of the locals and experts about the use of medicinal plants found in their locality. The information about the ethnomedicinal uses for selected plants were documented and photographs were taken. The scientific names and family names were further checked by using local flora books (Saxena and Brahman, 1994-1996; Haines, 2008). Further the local names were cross checked by using different studies carried out by various authors in Odisha (Sahu *et al.*, 2010; Sahu *et al.*, 2013; Sahu *et al.*, 2016; Sahu *et al.*, 2020; Sahu and Ekka 2021; Sahu and Sahu, 2017, 2019; Sahu and Raal, 2024).

Result and Discussion:

During research and exploration, we documented information of 40 medicinal plant species from 37 Genera belonging to 28 families, that were collected from various localities of Barpali NAC. The documented data includes the scientific names, family names, local names, used parts, habit and purposes. Out of 40 plant species, there were 13 (32.5%) species of herbs, five (12.5%) species of shrubs, 20 (50%) species of trees and only two (5%) species of climbers (Figure 2). In Table-1, all the species are documented in alphabetical order along with their local name, family name, parts used and purpose of use. The histogram for the number of species vs families and the pie chart for the habits of the plant species are shown in figure-1 and 2, respectively.

From the documented data, it is shown that the family Fabaceae dominated the category with a total of five species [*Butea monosperma* (Lam.) Taub., *Clitoria ternatea* L.**,** *Dalbergia sissoo* DC., *Pterocarpus marsupium* Roxb. and *Tamarindus indica* L]**,** followed by family Malvaceae with three species (*Abelmoschus crinitus* Wall., *Hibiscus rosa-sinensis* L., *Sida acuta* Burm. f.)**,** while six families such as Rutaceae [*Aegle marmelos* (L.) Correa, and *Citrus limon (L.*) Burm. f.], Euphorbiaceae (*Euphorbia hirta* L., *Ricinus communis* L.), Moraceae (*Ficus glomerata* Roxb., *Ficus religiosa* L.), Phyllanthaceae (*Phyllanthus emblica* L., *Phyllanthus fraternus* G.L.Webster.), Solanaceae (*Capsicum frutescens* L.**,** *Datura stramonium* L.), and Asteraceae [*Eclipta prostrata* (L.) L., *Tridax procumbens* L] contributed two species each. Rest, 18 families (Amaranthaceae, Acanthaceae, Nyctaginaceae, Asclepidaceae, Amarylliadaceae, Convolvulaceae, Lytheraceae, Sapotaceae, Oleacea, Myrtaceae, Zingiberaceae, Lauraceae, Oxalidaceae, Meliaceae, Liliaceae, Magnoliaceae, Laminaceae, Puniaceae) contribute one species each (Table 1, Figure 1).

Various authors from various parts of Odisha also reported the ethnomedicinal uses of plants, which are described as follows. Sahu *et al.* (2010) reported the ethnomedicinal uses of 209 plant species by the native of Bargarh district, Odisha, India. Sahu *et al.* (2013) reported a total of 117 medicinal plants by the native of Sohela block of Bargarh district, Odisha, India. Sahu and Sahu (2017) reported the use of 57 plants used for the treatment of dental and oral healthcare by the peoples of Bargarh district. Sahu *et al.* (2020) reported the use of 49 species of plants belonging to 42 genus and 29 families for oral care (tooth ache, tooth decay, pyorrhea, foul smell and as tooth brush). by the tribal people in Kalahandi district of Odisha. Sahu *et al.* (2020) reported a total of 22 medicinal plants species belonging to 20 genera from the family Fabaceae were used by the natives for the treatment of different diseases like jaundice, malaria, tooth diseases, eye infection, headache, leprosy, diabetes, etc. Among these 22 plants; 12 species were tree, five herbs, four climbers and one shrub. Rana *et al.* (2020) documented a total of 20 species from 19 genera of plants belonging to 17 families that were used by the Gond tribal community of the Amlipali Village, Padampur NAC, Bargarh district. Sahu *et al.* (2020) explored and identified 108 species of medicinal plants which were belonging to 99 genus and 54 families in the campus of Saraswati +3 Science College, Bhawanipatna and it's adjacent areas, Kalahandi District, Odisha. Behera *et al.* (2021) documented a total of 39 plant species belonging to 34 genera and 25 families from Chandli Reserve Forest, Balangir District, Odisha, India and plants were categorised based on their ethno-botanical significance. Sahu *et al.* (2021) focused a total of 28 species belonging to 27 genera and 17 families were to have ethnobotanical significance towards urogenital ailments by the Binjhal tribes of Bargarh district of western Odisha, India. Sahu *et al.* (2021) documented a total of 52 plant species belonging to 45 genera and 32 families based on their ethno-botanical significance by Sahara tribal groups of Kangaon village of Bargarh District, in western Odisha, India. Mishra *et al.* (2022) had reported a total of 39 medicinal plants representing 29 families for their therapeutic use against skin disorders by the native of Bargarh district, Western Odisha. The family Fabaceae is predominant family *i.e.* contributes five species. In this present paper authors had described most preferred species for the treatment of skin disorders are *Achyranthes aspera* L., *Aegle marmelos* (L.) Corr., *Annona squamosa* L., *Bombax ceiba* L., *Carica papaya* L., *Cynodon dactylon* L. and *Ocimum sanctum* L. Sahu and Mishra (2022) reported a total of 31 medicinal plants from 30 Genera, belonging to 22 different families used by the native of Bargarh district for gynecological disorders. Behera and Sahu (2023) reported a total of 15 medicinal plant species belonging to 14 genera from the

Fabaceae Family were used by the natives Lathor village, H.S. Road, Balangir district for the treatment of different diseases. Rout and Sahu (2023) reported the ethnomedicinal use of 30 different plants belonging to 30 different genera and 24 different families by the native of Kalahandi District, Odisha. Sahu and Sahu (2023) recorded data on 29 plant species having a place with 25 genera and 20 families utilized by Gond tribes of the Nabarangpur region of Odisha for the treatment of Asthma. Among them, the family Apocynaceae is addressed by the greatest number of plants (five species) trailed by Solanaceae (tree species) and Lamiaceae, Moraceae, and Piperaceae (two species each) while the rest 15 families contribute one species each. Sahu *et al.* (2024) reported distribution, morphological description, phytochemical screening, biological activity, and therapeutic capability of *Hibiscus rosa-sinensis*. Sahu *et al.* (2024) reported 16 different important spices plant species belonging to nine families are being commonly used as ethnomedicine by the native of Bargarh municipality in the state of Odisha, India. In this paper authors had reported Maximum numbers of five species from family Apiaceae followed by three species by members of Zingiberaceae, two species from the family Lauraceae and one species each from the other six families. Nayak *et al.* (2024) described about the screening of phytochemicals like alkaloids, tannins, terpenoids and flavonoids; activity of the aqueous extract of *Tridax procumbence* against isolated microbes like Gram-positive bacteria, like Staphylococcus aureus, Gram-negative bacteria, like Escherichia coli and Pseudomonas, and pathogenic fungi like *A. niger, A. flavous,* and *Fusarium* and anticoagulant activity. Further, The MIC (minimum inhibitory concentration) and MFC (minimum fungicidal concentration) values indicated the concentration of the extract required to completely inhibit microbial growth and induce fungal death, respectively. Moreover, the extract highly inhibited the growth of *Pseudomonas* and *A. flavous*. These findings highlight the promising antimicrobial potential of *T. procumbens* extract, supporting its traditional use as a medicinal plant in managing infectious diseases caused by bacteria and fungi.

Table 1: List of medicinal plants found in the locality of Barpali NAC, Bargarh District, Western Odisha

Scientific name	Family name	Local name	Habit	Parts used	Purpose of use
Abelmoschus crinitus Wall.	Malvaceae	Bonbhendi	Herb	Leaf, Root	Cramps, Cuts, Joint pain
Achyranthes aspera L.	Amaranthaceae	Apamarga	Herb	Leaf, Root, stem	Typhoid, Toothbrush, Tongue cleaner
Aegle marmelos (L.) Correa	Rutaceae	Bel	Tree	Leaf, Stem	Acidity, Gastric, Toothbrush, Nausea, Dysentery, Dyspepsia
Aloe vera (L.) Burm.f.	Liliaceae	Gheekuanri	Shrub	Leaf	Wound, Jaundice, Leprosy
Andrographis paniculata (Burm. fil.) Nees	Acanthaceae	Bhueinlim	Shrub	Leaf, stem	Headache, dysentery, diarrhea, intestinal worm infection, toothbrush
Averrhoa carambola L.	Oxalidaceae	Karamanga	Tree	Leaf, Fruit	Edible, cure psoriasis, scabies
Azadirachta indica A. Juss.	Meliaceae	Lim	Tree	Leaf, twig	Leaf extract used to cure worm
Boerhavia diffusa L.	Nyctaginaceae	Gadha purni	Herb	Root	Cough
Butea monosperma (Lam.) Taub.	Fabaceae	Palas	Tree	Gum, young twigs	Diarrhea, toothbrush, and tongue cleaner
Calotropis gigantea (L.) W. T. Aiton.	Asclepiadaceae	Arakh	Tree	Flower, Latex	Asthma, pain reliever
Capsicum frutescens L.	Solanaceae	Mircha	Herb	Leaf, Fruit	Tonsils, Toothache, Gonorrhea, Helminthiasis
Cinnamomum tamala (Buch.-Ham.) Th. G. G. Nees	Lauraceae	Tejpatar	Tree	Leaf	Indigestion, Headache, Cure dry whooping
Citrus limon (L.) Burm. f.	Rutaceae	Lembu	Tree	Fruit juice, fruit peel	Acidity, Cold, Cough, Headache, Abdominal pain, Rheumatism

Clitoria ternatea L.	Fabaceae	Aparajita	Climber	Leaf, Root, Seed	Brain tonic, Sore throat
Curculigo orchioides Gaertn.	Amaryllidaceae	Talmulee	Herb	Rhizome	Piles
Cuscuta reflexa Roxb.	Convolvulaceae	Nirmuli	Climber	Stem	Epilepsy, Flu
Dalbergia sissoo DC.	Fabaceae	Sissoo	Tree	Seed oil	Applied on burned skin to cure itching
Datura stramonium L.	Solanaceae	Dudura	Herb	Leaf, Seed, Fruit	Ear pus, Dandruff, pimples, Skin diseases
Eclipta prostrata (L.) L.	Asteraceae	Bhringraj	Herb	Leaf	Leaf juice is used to cure fever, headache
Euphorbia hirta L.	Euphorbiaceae	Chitakuti	Herb	Root	Common cold and fever
Ficus glomerata Roxb.	Moraceae	Dumer	Tree	Fruit, Bark	Diabetes, Dyspepsia, Asthma, Increase in milk secretion
Ficus religiosa L.	Moraceae	Pipal	Tree	Bark	Skin diseases, Boils, Blisters, Carbuncles
Hibiscus rosa-sinensis L.	Malvaceae	Mandar	Shrub	Stem, Bark, Flower bud	Abortion, Contraceptive, Hair growth
Lawsonia inermis L.	Lythraceae	Benjati	Shrub	Root	Anemia, jaundice
Madhuca indica J.F. Gmel.	Sapotaceae	Mahul	Tree	Bark, young twigs	Dysentery, hair oil, mature fruit is edible
Michelia champaca L.	Magnoliaceae	Champa	Tree	All parts	Brain disorder, Gonorrhea, Helminthiasis
Nyctanthes arbor-tristis L.	Oleaceae	Ganga siuli	Tree	Leaf	Malaria
Ocimum sanctum L.	Laminaceae	Tulsi	Shrub	Leaf	Common cold, Bronchitis, Tuberculosis
Phyllanthus emblica L.	Phyllanthaceae	Amla	Tree	Fruit, Seed oil	Digestion, hair oil, Mature fruit is edible
Phyllanthus fraternus G.L.Webster.	Phyllanthaceae	Bhuein amla	Herb	Root	Dysentery, Diarrhea
Pterocarpus marsupium Roxb.	Fabaceae	Bija	Tree	Bark, Gum	Stomach pain, Cracks-cream

Punica granatum L.	Puniaceae	Dalim	Tree	All parts	Malaria, Kidney stone, Leukoderma
Ricinus communis L.	Euphorbiaceae	Jada	Herb	Seed	Inflammation Treatment, Liver disease
Sida acuta Burm. f.	Malvaceae	Bajramuli	Shrub	Leaf, Root, Stem	Root extract to cure white vaginal discharge, eye pain
Syzygium cumini (L.) Skeels.	Myrtaceae	Jam	Tree	Seed	Diabetes
Tamarindus indica L	Fabaceae	Tamarind	Tree	Fruit	Inflammation treatment, Stomach pain, Throat pain, Rheumatism
Terminalia arjuna (Roxb.) Wight & Arn.	Combrataceae	Kau	Tree	Bark	Cure leukoderma
Terminalia chebula (Gaertn.) Retz.	Combrataceae	Harda	Tree	Fruit	To remove cough, Stomach problems
Tridax procumbens L	Asteraceae	Bisalyakarani	Herb	Leaf	Ringworm, stop bleeding, Disinfect wound
Zingiber officinale Roscoe.	Zingiberaceae	Ada	Herb	Rhizome	Cold, Cough, Toothache, Asthma, Rheumatism, Stomache

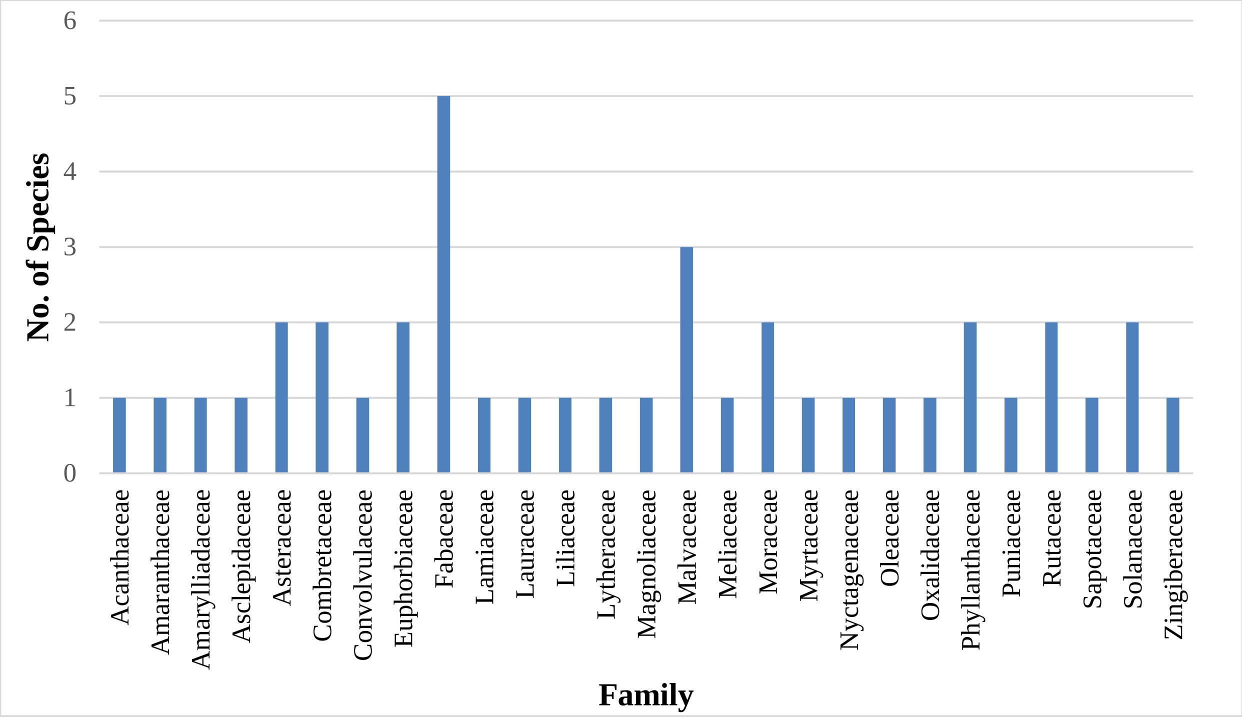

Figure 1: Number of species per families.

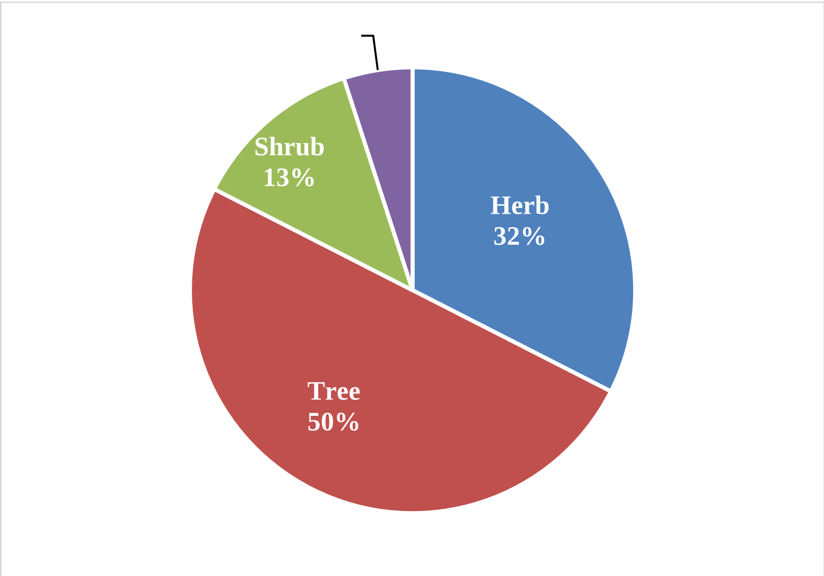

Figure 2: Habit of plant species

Conclusion:

These medicinal plants play an important role in rural areas as well as tribal areas. The native people there frequently use the parts and extract of these medicinal plants for medical purposes, for curing diseases and wounds, for maintaining a good health. People for urban areas should be aware of ethnomedicinal properties of such plants and use them in their daily life purposes. But gradually the people even from rural areas are leaning more towards the modern technology and lifestyle and abandon such traditional practices. This is causing the traditional and direct effective use of medicinal plants is being forgotten. Thus, the documentation of such information is going to help and aware the future generations about the day-to-day use of medicinal plants found in the locality in their normal lifestyle and stay healthy organically.

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