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RESEARCH TRENDS IN ENVIRONMENTAL SCIENCE VOLUME I

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PREFACE

As the world faces an ever-increasing array of environmental issues, ranging from climate change and habitat destruction to pollution and resource depletion, the urgency to find sustainable solutions has never been greater. Environmental science, as a discipline, has emerged as a beacon of hope, combining various scientific fields to gain a deeper understanding of our environment and the ways in which human activities impact it.

This book aims to provide readers with a comprehensive overview of the latest research trends and breakthroughs in environmental science. Our intention is not only to present the current state of knowledge but also to foster a spirit of curiosity and collaboration among researchers, policymakers, and concerned citizens. By disseminating cutting-edge research, we hope to inspire collective action and transformative change towards a healthier and more resilient planet.

Within these pages, readers will encounter a diverse array of topics that cover the breadth and depth of environmental science. From studies on biodiversity conservation and ecosystem dynamics to advancements in renewable energy, sustainable agriculture, and waste management, each chapter offers a glimpse into the dynamic landscape of environmental research.

We are indebted to the dedicated researchers, scientists, and scholars who have contributed their expertise and passion to this compilation. Their commitment to advancing environmental knowledge has been instrumental in shaping this publication, and we extend our deepest gratitude to each one of them.

In conclusion, "Research Trends in Environmental Science" seeks to serve as both a resource and a catalyst for positive change. As we navigate the complexities of environmental challenges, we must remember that we are all interconnected with the natural world, and it is our shared responsibility to protect and nurture it for current and future generations.

We hope that the insights and knowledge presented here will spark meaningful discussions, inspire new ideas, and lead to collaborative efforts that pave the way towards a sustainable and thriving planet. Together, let us embark on this voyage of discovery, driven by a common vision for a harmonious coexistence with nature.

Editors

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TOWARDS SUSTAINABLE WASTE MANAGEMENT: CHALLENGES, STRATEGIES, IMPACTS

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Abstract:

Effective waste management is crucial for addressing the global waste crisis and achieving sustainable development. This chapter explores the challenges faced in waste management and presents strategies to overcome these challenges. It discusses the impacts of sustainable waste management on the environment, economy, and society. The chapter emphasizes the urgent need for adopting sustainable approaches to mitigate environmental pollution, conserve resources, and promote a circular economy. The challenges, including rapid urbanization, inadequate infrastructure, inefficient waste sorting, and hazardous waste management, are examined. Strategies such as waste reduction, recycling, composting, and waste-to-energy technologies are highlighted. The positive impacts of sustainable waste management on environmental preservation, economic growth, and social well-being are discussed. By implementing sustainable waste management practices, we can move towards a cleaner, greener, and more sustainable future. The study concludes with key recommendations for policymakers and stakeholders to achieve sustainable waste management practices.

Keywords: Waste management, sustainability, challenges, strategies, impacts, rapid urbanization, infrastructure, waste sorting, hazardous waste, waste reduction, recycling, composting, waste-to-energy, environmental preservation, economic growth, social well-being, circular economy.

Introduction:

The increasing volume of waste has become a global concern, driven by population growth, urbanization, and changing consumption patterns. Improper waste disposal practices, inadequate infrastructure, and limited public awareness have led to significant environmental degradation, health risks, and resource depletion. Sustainable waste management is an increasingly critical issue in our modern world, as the volume of waste generated continues to rise, and its negative impacts on the environment, economy, and society become more evident. Effective waste management is crucial not only for maintaining a clean and healthy environment but also for conserving resources, reducing pollution, and promoting social well-being. The importance of sustainable waste management extends beyond environmental considerations. It also has significant economic and social implications. By implementing effective waste management practices, economies can benefit from reduced costs associated with waste disposal, resource conservation, and the creation of new jobs in waste management industries.

Background on the increasing volume of waste and its negative impacts:

The increasing volume of waste has become a significant global challenge, with profound negative impacts on the environment, human health, and sustainable development. Over the past few decades, the world has witnessed a dramatic rise in waste generation, driven by population growth, urbanization, and unsustainable consumption patterns.

Another key factor in the rising waste volume is changing consumption patterns. The modern consumerist culture, characterized by the "throwaway" mentality, promotes the excessive use of disposable products, single-use packaging, and short product lifespans. This linear economy approach, where resources are extracted, manufactured into products, and ultimately discarded as waste, contributes to the depletion of natural resources and the accumulation of waste.

Importance of sustainable waste management:

Environmental protection: Sustainable waste management practices help protect the environment by minimizing the negative impacts of waste on ecosystems, air quality, and water sources.

Conservation of natural resources: Effective waste management involves resource recovery through recycling and reuse.

Climate change mitigation: Sustainable waste management plays a crucial role in mitigating climate change

Public health and safety: Proper waste management practices protect public health and safety.

Social responsibility: Sustainable waste management is an expression of social responsibility.

Sustainable development: Sustainable waste management aligns with the principles of sustainable development, which seek to meet the needs of the present generation without compromising the ability of future generations to meet their own

Challenges in waste management:

1. Inadequate infrastructure for waste collection and disposal:

Inadequate infrastructure often leads to limited or irregular waste collection services, especially in rural areas or rapidly growing urban areas. In areas with inadequate infrastructure, there may be a lack of waste collection containers, bins, or vehicles.

2. Improper waste disposal practices and illegal dumping:

Improper waste disposal practices and illegal dumping are significant challenges that contribute to environmental pollution, public health risks, and the degradation of ecosystems. These practices involve the disposal of waste in unauthorized locations or through methods that do not comply with proper waste management regulations.

3. Limited public awareness and participation:

Limited public awareness and participation is a significant challenge in achieving sustainable waste management. It refers to a lack of understanding and involvement among the general public in proper waste management practices and initiatives. Many people are unaware of the environmental and health impacts of improper waste management practices.

4. Lack of effective policies and regulations:

The lack of effective policies and regulations is a significant challenge in achieving sustainable waste management. Strong and well-implemented policies and regulations are essential for providing a framework that guides waste management practices, encourages proper waste disposal, promotes recycling, and discourages harmful practices. The absence of inadequacy of such policies and regulations can hinder progress in waste management efforts.

Strategies for sustainable waste management:

1. Waste reduction and prevention measures:

Waste reduction and prevention measures play a crucial role in achieving sustainable waste management goals. These measures aim to minimize the generation of waste at its source, reduce the overall amount of waste produced, and promote sustainable consumption and production practices. By focusing on waste reduction and prevention, communities can minimize the environmental impacts associated with waste generation and disposal.

2. Recycling and reuse of materials:

Recycling and reuse of materials are integral components of sustainable waste management strategies. These practices contribute to resource conservation, energy savings, and the reduction of waste sent to landfills. By recycling and reusing materials, communities can minimize the environmental impacts associated with extraction, production, and disposal.

3. Composting of organic waste:

Composting of organic waste is a sustainable waste management practice that involves the decomposition of organic materials into nutrient-rich compost. It is an environmentally friendly alternative to disposing of organic waste in landfills, as it reduces waste volumes, minimizes greenhouse gas emissions, and produces a valuable soil amendment.

4. Energy recovery from waste:

Energy recovery from waste, also known as waste-to-energy (WtE), is a process that involves the conversion of non-recyclable waste materials into usable energy forms. Waste decomposition in landfills produces methane, a potent greenhouse gas.

Impacts of sustainable waste management:

1. Environmental impacts reduced greenhouse gas emissions, conservation of resources, prevention of pollution:

Energy recovery from waste has several positive environmental impacts, including reduced greenhouse gas emissions, conservation of resources, and prevention of pollution. Here are further details on these impacts:

- Reduced Greenhouse Gas Emissions: Energy recovery from waste helps reduce greenhouse gas emissions, particularly methane. Methane is a potent greenhouse gas with a significantly higher global warming potential than carbon dioxide.
- Conservation of Resources: Energy recovery from waste promotes the conservation of natural resources. By using waste as a fuel source, the demand for fossil fuels is reduced.
- Prevention of Pollution: Waste-to-energy facilities incorporate strict environmental controls and regulations to minimize air and water pollution. Advanced emission control

technologies, such as scrubbers and filters, are used to capture and treat pollutants released during the combustion process.

2. Economic impacts: job creation, cost savings through recycling and energy recovery:

- Job Creation: Waste-to-energy facilities and associated industries contribute to job creation at various stages of the process. Waste-to-energy plants require skilled workers to operate and maintain the facility, including engineers, technicians, operators, and administrative staff. Efficient waste collection and sorting systems are necessary to ensure a steady supply of waste for energy recovery.
- Cost Savings through Recycling: Energy recovery from waste can result in cost savings through recycling. By diverting non-recyclable waste from landfills and recovering energy from it, the volume of waste requiring landfill disposal is reduced.
- Cost Savings through Energy Recovery: Waste-to-energy facilities generate electricity, heat, or biofuels from waste materials, which can offset the need for energy from traditional sources.

3. Social impacts: improved public health, community engagement, awareness raising:

Energy recovery from waste has significant social impacts, including improved public health, community engagement, and awareness raising. Here are further details on these social impacts:

- Improved Public Health: Energy recovery from waste can contribute to improved public health by reducing the environmental and health risks associated with traditional waste disposal methods, such as open dumping or poorly managed landfills.
- Community Engagement: Waste-to-energy projects often involve community engagement and participation, fostering a sense of ownership and responsibility among local residents.
- Awareness Raising and Environmental Education: Waste-to-energy projects provide opportunities for raising awareness and educating the public about waste management practices, resource conservation, and the importance of sustainable development.

Methodology:

Certainly! Here are some important methods commonly used in the study of sustainable waste management:

1. Life Cycle Assessment (LCA):

- LCA is a method used to assess the environmental impact of waste management practices throughout its entire life cycle, from resource extraction to final disposal.
- It quantifies and evaluates factors such as energy consumption, greenhouse gas emissions, air and water pollution, and resource depletion associated with different waste management options.

2. Waste characterization and composition analysis:

- This method involves sorting and analyzing waste samples to determine the composition and characteristics of the waste stream.
- It provides valuable data on the types and quantities of waste generated, facilitating the development of targeted waste management strategies.

3. Waste generation and diversion analysis:

- Analyzing waste generation rates and patterns helps understand the factors influencing waste generation and identify opportunities for waste reduction.
- Waste diversion analysis assesses the effectiveness of recycling, composting, and other diversion methods in diverting waste from landfill disposal.

4. Cost-benefit analysis:

- Cost-benefit analysis evaluates the economic feasibility and financial implications of different waste management strategies.
- It compares the costs of implementing and operating waste management systems with the potential benefits, such as cost savings from recycling and revenue generation from waste-to-energy projects.

5. Social impact assessment:

- Social impact assessment examines the social aspects and implications of waste management practices on local communities and stakeholders.
- It assesses factors like public health, community engagement, social acceptance, equity, and job creation associated with waste management initiatives.

6. Technological assessment:

- Technological assessment involves evaluating the effectiveness and efficiency of different waste management technologies, such as recycling processes, composting systems, and waste-to-energy facilities.
- It considers factors like technological maturity, environmental performance, energy consumption, and scalability.

7. Policy and regulatory analysis:

- This method involves analyzing waste management policies, regulations, and incentives at local, regional, and national levels.
- It assesses the impact of policy frameworks on waste management practices, identifies gaps or barriers, and proposes policy recommendations for sustainable waste management.

8. Stakeholder engagement and participatory approaches:

- Engaging stakeholders, including waste management professionals, policymakers, community members, and NGOs, through interviews, surveys, workshops, or focus groups, helps understand diverse perspectives and involve key stakeholders in decision-making processes.

These methods can provide valuable insights into the challenges, strategies, and impacts of sustainable waste management. Researchers often combine multiple methods to gain a comprehensive understanding of the subject matter and generate actionable recommendations for sustainable waste management practices.

Result and Discussion:

The study revealed several challenges in achieving sustainable waste management, including rapid urbanization, inadequate infrastructure, inefficient waste sorting, and hazardous waste management. These challenges have significant implications for environmental pollution, resource depletion, public health, and social well-being. However, through the implementation of various strategies, such as waste reduction initiatives, recycling programs, composting projects, and waste-to-energy technologies, positive impacts have been observed. These strategies have demonstrated successful waste diversion, reduction in greenhouse gas emissions, resource conservation, and economic benefits. Moreover, sustainable waste management practices have contributed to the prevention of soil and water contamination. The study also highlighted the economic advantages of cost savings, job creation, and revenue generation. Socially, proper waste disposal and engagement of communities have led to improved public health, empowerment, and social cohesion. Comparative analysis between different regions or countries highlighted variations in waste management approaches and emphasized the importance of supportive policies, collaboration, and investment in infrastructure to achieve sustainable waste management goals. Overall, the study underscores the significance of addressing the challenges through effective strategies and policies to realize the positive impacts of sustainable waste management on the environment, economy, and society.

Conclusion:

Sustainable waste management is a critical component of achieving environmental sustainability and promoting a circular economy. This chapter has explored the challenges, strategies, and impacts of sustainable waste management. The findings highlight the pressing challenges faced in waste management, including rapid urbanization, inadequate infrastructure, inefficient waste sorting, and hazardous waste management. However, through the implementation of various strategies, such as waste reduction initiatives, recycling programs, composting projects, and waste-to-energy technologies, positive impacts have been observed. These strategies have led to waste diversion, reduction in greenhouse gas emissions, resource conservation, and economic benefits. Moreover, sustainable waste management practices have contributed to the prevention of soil and water contamination, resulting in improved environmental preservation. Socially, proper waste disposal, community engagement, and awareness programs have enhanced public health and social well-being. Comparative analysis between different regions or countries has highlighted variations in waste management approaches, emphasizing the importance of supportive policies, collaboration, and investment in infrastructure. It is clear that sustainable waste management is a multifaceted and complex endeavor that requires the involvement of various stakeholders, effective policies, and technological advancements. By embracing sustainable waste management practices, we can create a cleaner, greener, and more sustainable future for generations to come.

Aknowledgement:

Authors would like to express our sincere gratitude to all the researchers, authors, and organizations whose studies and reports have contributed to this literature review on sustainable waste management. Their valuable insights and findings have provided the foundation for our evaluation of waste management strategies based on their environmental, economic, and social impacts. We would also like to thank the academic institutions and libraries for providing access to relevant resources and databases that facilitated our research. Lastly, we extend our appreciation to our colleagues and mentors for their guidance and support throughout the completion of this chapter.

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VALORIZATION OF AGRICULTURAL WASTE

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The term "waste valorization" refers to any industrial processing activities aimed at reusing, recycling, or composting from wastes, useful products, or sources of energy. In the United States, the terms beneficial reuse, reuse, and waste reclamation often are used for waste valorization.

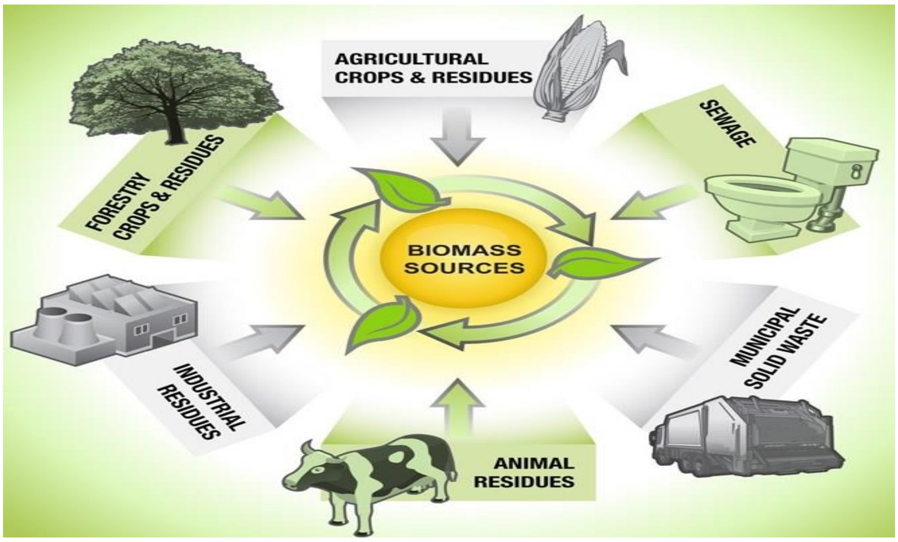
Globally, energy crisis and proper waste disposal are among the major challenges facing most nations. Improper disposal and management of waste lead to enormous environmental hazards. So to overcome these issues, valorization is required to come in the picture.

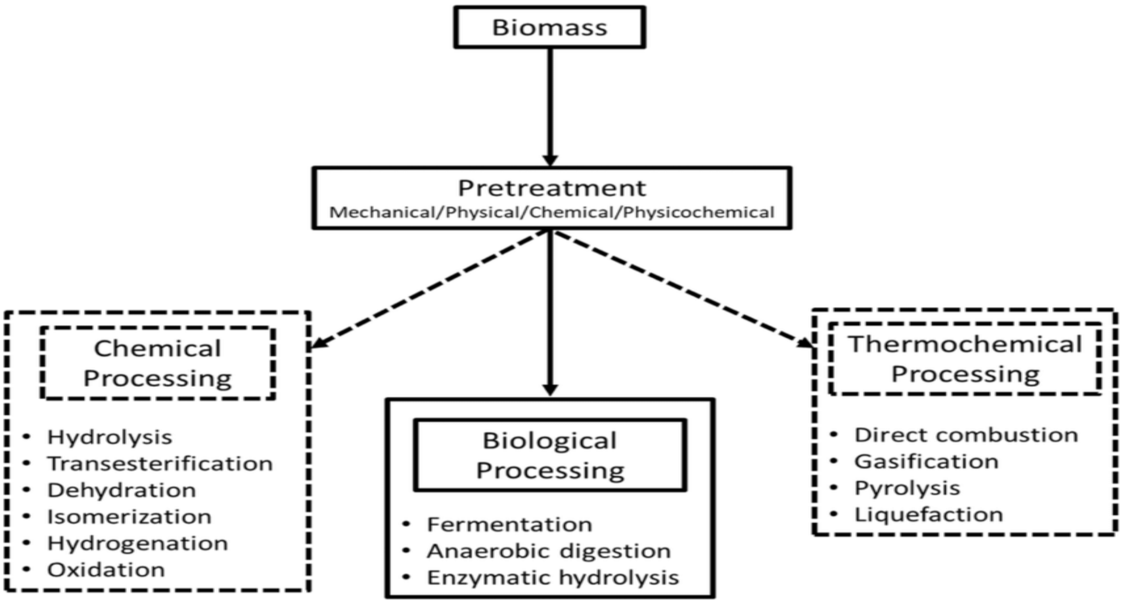
Biomass: Biomass is plant or animal material used for energy production or in various industrial processes as raw material for a range of products. It can be purposely grown energy crops, wood or forest residues, waste from food crops, horticulture, food processing, animal farming, or human waste from sewage plants.

Advantages of exploring biomass for valorization

- ✓ Biomass is always and widely available as a renewable source of energy.
- ✓ It is carbon neutral.
- ✓ It reduces the overreliance of fossil fuels.
- ✓ Is less expensive than fossil fuels. ...
- ✓ Biomass production adds a revenue source for manufacturers.

Sources of biomass





Agriculture

Agriculture is the largest contributor of any resource sector, to the economy. Agricultural wastes mainly comprise of cellulosic fibers possessing high fixed carbon content and multifunctional groups. Agricultural waste shows considerable applicability due to its high strength, environmentally benign nature, low cost, and ease of availability and reusability. India is the world's second largest producer of the agricultural products such as wheat, rice, sugarcane, several dry fruits and largest producer of many fresh fruits like papaya, banana, mango, guava and vegetables. It is also a large generator of waste materials. Agriculture is also called as farming which is the cultivation of animals, plants, fungi, and other life forms for food, fiber, biofuel, drugs and other products used to sustain and enhance human life.

Recently, agricultural waste management and its processing, for the benefit of the world has become an interesting point for researchers.

Usually, in common practice, agricultural waste is discharged to the environment without treatment or is burnt off, thus leading to landfills and environmental load. Hence, these wastes need to be considered as potential raw materials rather than just disposing them, to avoid contamination and transmission of hazardous materials to the environment. This will require better use of technology, incentives, and approaches to agricultural waste management.

Agriculture waste

Agricultural waste is composed of organic wastes (animal excreta in the form of slurries and farmyard manures, spent mushroom compost, soiled water and silage effluent) includes Natural waste, animal waste, plant waste.

Waste management

If wastes are not properly handled they can pollute surface and groundwater and contribute to air pollution. The proper management of waste from agricultural operations can contribute in a significant way to farm operations. Waste management helps to maintain a healthy environment for farm animals and can reduce the need for commercial fertilizers while providing other nutrients needed for crop production. The waste which is reduce, recycle and make it usable for different purpose is a waste management.

Management processes

- ✓ Source
- ✓ Generation
- ✓ Collection
- ✓ Transportation
- ✓ Treatment processes
- ✓ Disposal

Generation

India is one of the richest countries in agricultural resources. Presently in India, annually 350 MT are organic wastes from agricultural sources. The major quantity of solid waste generated from agricultural sources are sugarcane baggage, paddy and wheat straw and husk, waste of vegetables', food products, tea, oil production, jute fibers, groundnut shell, wooden mill waste, coconut husk, cotton stalk, etc.

Collection

Waste like fruit and vegetable waste are collected form houses called domestic waste, waste like dry refuse and green waste, animal dung from agricultural field.

Transportation process

Waste collected from the side of roads, agricultural field all are transported to decomposed site and for further treatment by trucks, trailers, carts. Different types of waste are collected and then transported for further treatment and the waste which is not used is directly disposal to the sanitary land. Wastes are not burn in open air so it is then transported to incineration.

Treatment process

- ✓ Composting
- ✓ Land filling
- ✓ Recycling
- ✓ Incineration

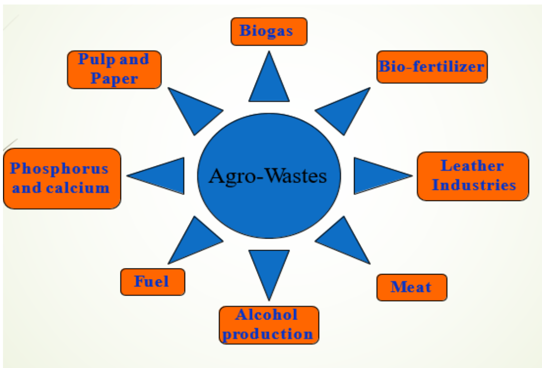
Composting is a method in which organic matter present in agricultural waste is decomposed by aerobically/anaerobically through a biochemical process and converted into humus.

Landfill site (rubbish dump or dumping ground) is a site for the disposal of waste materials by burial. Some landfills are also used for waste management purposes, such as sorting, treatment, or recycling.

Incineration is a modern and most hygienic method of disposal of dry refuse. The method consists of burning the dry refuse in incinerator.

Recycling is the Process to change waste into new products. It Prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage. Reduce air pollution from incineration and water pollution from land filling. Key component of modern waste reduction and is the third component of the "Reduce, Reuse, Recycle"

Management of recycling agro-wastes:



Utilization of agro-waste to produce value-added compounds

Value addition: The concept of "waste valorization", or adding value to the waste stream, refers a process of increasing the economic value and consumer appeal of an agricultural commodity. Adding value to products can be accomplished in a number of different ways, but generally falls into two main types:

1. Creating Value (Innovation, Industrial Innovation) and

2. Capturing Value (Coordination).

Creating value occurs with actual or perceived value to a customer for a superior product or service, innovative new products, enhance a product's characteristics.

Capturing value happens by changing the distribution of value in the food/fibre production chain. It is meant to 'capture' more of the consumer dollar through: direct marketing, vertical integration, producer alliances, and cooperative efforts.

Agricultural waste can be converted into different forms which are beneficial to reduce pollution and to provide wealth.

Convert agricultural waste to animal feed:

Most of the agricultural waste have monetary importance for the farmers. Waste generated from post-harvest operations viz. threshing, de-husking and the milling process can be used directly on the farm for the feeding of various animals and for the development of various value-added products. Rice and wheat bran can be served directly to some animals such as goat, cattle, even pigs.

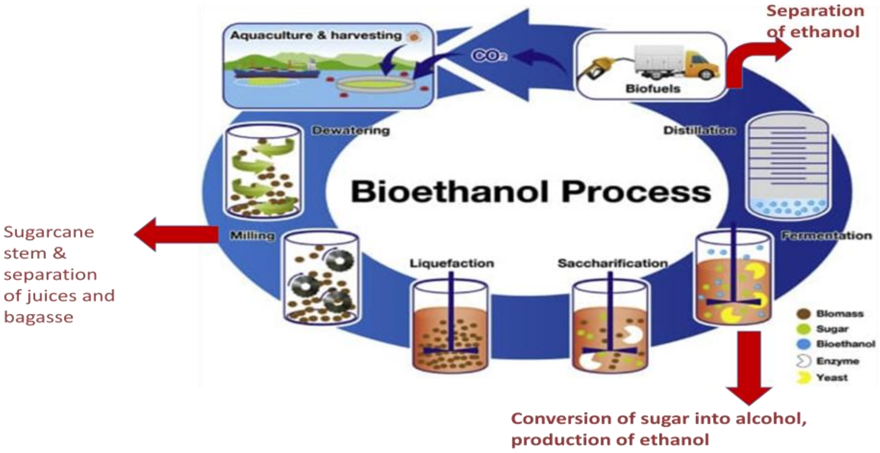
Convert agricultural waste to fuel:

Biomass, major by-product produced from agricultural offers the discovery of bio-fuel and biogas. Globally, 140 billion MT of biomass is generated every year from agriculture. The generation of biogas from food and animal waste helps to reduce or cut down the cost of acquiring cooking gas. Biogas is also used as fuel for power plants. Interesting thing about this technology is that is economical and bio-friendly.

Production

It includes mainly:

1. Milling,	2. Liquefaction	3. Saccharification
4. Fermentation	5. Distillation	6. Dehydration

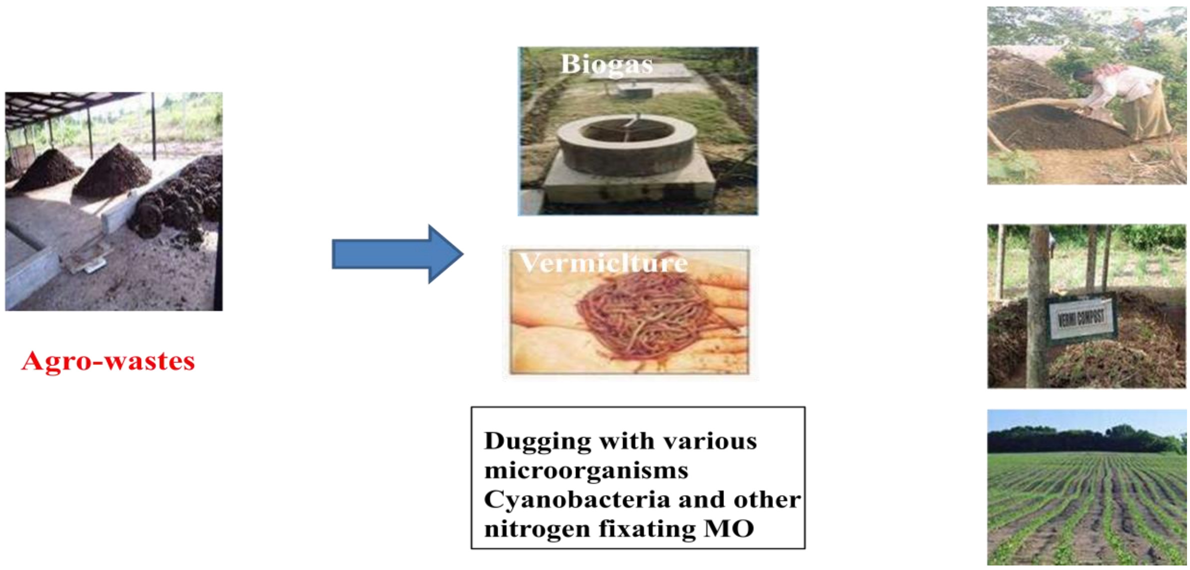


Convert agricultural waste to organic manure

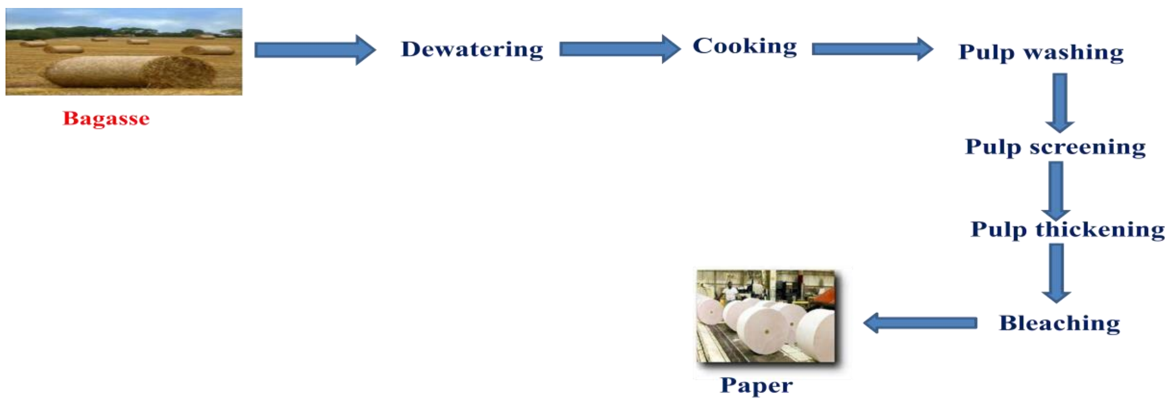
It can be converted into organic manure, which is a better option than the inorganic manure for optimum crop production. Organic manure boosts the crop production and as well as lower the cost involvement

The use of organic manure is good but the application of raw animal waste on farm land could lead land pollution. So the best advice is to let waste decompose first. Decomposition helps to breakdown the acidic content of the waste and makes it less harmful to the soil and the plants which it is meant to nourish.

Bio-fertilizers production



Sugarcane bagasse used for paper production



Government initiatives for promoting agricultural waste to wealth

Government is promoting various schemes/ campaigns to reduce the waste generation and to convert it into wealth. Ministry of Drinking Water & Sanitation has launched Gobar-Dhan (galvanizing organic bio agro resources) aims to positively impact village cleanliness and generate wealth and energy from cattle and organic waste and to create new jobs linked to waste collection, transportation, biogas sales, etc.

Himachal Pradesh Government launched a Zero Budget Natural Farming (ZBNF) project to promote organic farming. Farmers use earthworms, cow dung, urine, plants, human excreta and such biological fertilizers for crop protection by eliminating chemical fertilizers and pesticides.

Preventive measures for reduction of agricultural waste

- **Segregation of waste:** It is necessary to understand the science and art of waste management and product development. It will trace the life cycle of various forms of waste, starting from its generation to diverse forms of disposal; classification as biodegradable or non-bio-degradable and hazardous or non-hazardous. Segregation is the pivot for recycling and for realizing *"Waste to Wealth"*.
- **Adoption of 5 R principle:**

- **Development of small scale industries:** This step will reduce the production of waste and reduce pollution, transportation cost while transporting from field to cities. It can be harnessed by developing and promoting enterprises at or near farms, which are based on the output from agriculture and manage the post-harvest on-farm value addition as goods or market linking services.
- **Development of protocols for waste management:** Development of protocols related to collection, storage, treatment, transfer and utilization of agro-waste is necessary. Proper waste utilization will assist in developing our agricultural sector and provide viable wealth resource for many

Concerns about agricultural waste management

- ✓ If not managed properly, agricultural waste can pollute the environment.
- ✓ The degradation of water quality can impact adjacent waterways and groundwater both onsite and offsite.
- ✓ This degradation reduces the ability of these resources to support aquatic life and water for human and animal consumption.
- ✓ Nitrates can found in fertilizers and agricultural waste runoff, can seep into groundwater.
- ✓ Well water contaminated with nitrates is hazardous to humans, as it results in oxygen depletion in the blood

Conclusion:

Proper management of waste from agriculture operations can contribute a lot in reducing the environmental pollution. Also, this can be a good approach to generate value added products for industrial purposes at minimal cost. With the escalating quantities of agricultural and food wastes, there is a need to utilize and develop these materials by processing them for their positive application. This personal account summarizes the valorization potential and state-of the- art technologies of food and agro-waste products. Therefore, a good amount of research and experiments are required to optimize the studies on valorization technologies and there must be a focus on large scale waste management technology rather than laboratory scale, so that their relevance for industrial application can be realized.

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OVERVIEW ON RECENT DEVELOPMENTS IN PHYSICAL, CHEMICAL AND BIOLOGICAL WASTE WATER TREATMENT TECHNOLOGIES

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Abstract:

Water is the most important factor for life on the earth. Due to various reasons including natural and artificial the water has been polluted day by day. At this time pollution level has been increased. It is impossible to prevent the water resources from the pollution. Reuse of water after treatment is the only path to save the environment/earth. This chapter mainly focuses on thevarious types of waste water treatment methods and their steps.

Keywords: waste water, treatment, pollution, purification, technology.

Introduction:

Process of removing contaminants from wastewater is known as waste water treatment. The main aim of wastewater treatment is to reduce the pollution from water and also make an effluent that can be safely returned to the environment, either for reuse or to prevent pollution (Crini & Lichtfouse, 2019). Wastewater treatment can be done using physical, chemical, and biological processesthat remove contaminants such as organic and inorganic materials, bacteria, viruses, and other harmful substances (Sonune & Ghate, 2004). The treatment process can vary depending on the type and source of the wastewater. There are several recent strategies that have been developed to improve wastewater treatment efficiency and reduce environmental impacts. The first step is usually screening or grit removal to remove large objects and debris. Then, the wastewater undergoes a primary treatment process that involves settling and removal of solids. Secondary treatment involves biological treatment where microorganisms break down organic matter in the wastewater and disinfected to remove harmful pathogens and bacteria, typically using chlorine or UV light. Finally, the treated wastewater is released into a receiving body of water or reused for various purposes.It is a critical process for protecting public health and the environment, and it plays a vital role in ensuring a sustainable water supply for future generations (Muga & Mihelcic, 2008). In the chapter, some of the recent advancement in the strategies for wastewater treatment has been discussed.

Physical wastewater treatment

Physical treatment is the first stage of the wastewater treatment process, where the wastewater undergoes a series of physical processes to remove solid materials, oils, and grease from the water. Physical treatment is also known as primary treatment and is typically the first step in wastewater treatment before it undergoes further treatment processes.Physical wastewater treatmentusuallyinvolves the removal of suspended solids, organic matter, and other pollutants using physical processes such as screening, grit removal, sedimentation,filtration, and flotation.The primary goal of physical treatment is to remove large solids and materials that can cause blockages or damage to downstream equipment (Noor *et al.* 2023).

Screening: Screening is a physical wastewater treatment process that involves the removal of large debris and objects from the wastewatersuch as plastic bags, rags, rocks, and other materialsbefore it undergoes further treatment. The purpose of screening is to provide suitable environment/condition for the. Also prevent the equipment from damage and blockage. Screening process may be enhancing the effectiveness of the process. It also helps to improve the efficiency and effectiveness of subsequent treatment processes by removing large solids that can interfere with biological and chemical treatment processes.Screening can be done using various types of screensor grates, such as coarse screens, fine screens, and microscreens. Coarse screens typically have larger openings and tree branches, plastic bags, and bottles. Fine screens have smaller openings and can remove smaller debris, such as leaves, twigs, and food waste. Microscreens have even smaller openings and can remove very small particles and solids, such as hair and fibres. The removed materials are typically collected and transported to a landfill or incineration facility for disposal. This process prevents these objects from clogging downstream processes and damaging equipment (Bahuguna *et al.,* 2021).

Sedimentation: Sedimentation is a physical wastewater treatment process that involves the settling of solid materials that have a higher specific gravity than water, such as sand and other inorganic materials. The process is used to remove suspended solids and heavy particles from the wastewater, making it easier to treat in subsequent treatment processes. Sedimentation is typically used in the primary treatment stage of physical wastewater treatment and is often combined with other physical processes such as screening and grit removal. The wastewater is first screened to remove large debris and then sent to sedimentation tanks, where it is allowed to settle. In the sedimentation tanks, the wastewater is held for 5-6 hours, to settle down heavier materialsin the bottom of the tank. The settled materials form sludge that is removed from the bottom of the tanks using specialized equipment, such as sludge pumps or scrapers. The clarified water at the top of the tanks is then sent for further treatment, such as biological treatment, to remove dissolved organic materials and nutrients. The sludge removed from the sedimentation tanks can be treated further, such as with anaerobic digestion or dewatering, before being disposed of or reused. Sedimentation is a critical process in physical wastewater treatment, as it removes heavy solids that can interfere with subsequent treatment processes, such as biological treatment. It also reduces the organic load of the wastewater, making it easier to treat in downstream processes (Musa & Idrus, 2021).

Filtration:

Filtration is a physical wastewater treatment process that involves the removal of suspended solids and other impurities from the wastewater using filters such as sand filters, activated carbon filters, or membrane filters and a porous medium used such as sand, gravel, or cloth. Filtration is typically used as a secondary treatment process in physical wastewater treatment, following sedimentation or other primary treatment processes. Filtration can be accomplished through various methodsincluding rapid sand filtration, slow sand filtration, and multimedia filtration. In rapid sand filtration, the wastewater is passed through a layer of sand, where suspended solids are trapped and removed from the water. In slow sand filtration, the water is passed through a thick layer of sand at a slower rate, allowing for greater removal of impurities. Multimedia filtration involves the use of multiple layers of different filter media, such as sand, gravel, and anthracite, to achieve greater removal of impurities. The filter media are arranged in layers with the coarsest media at the top and the finest at the bottom. The filtered water is typically sent for further treatment, such as disinfection, before being discharged into the environment or reused. The solids and other impurities that are removed from the wastewater during filtration are collected and disposed of or reused, depending on the level of treatment and the local regulations. Filtration is an important process in physical wastewater treatment, as it removes impurities and solids that can cause harm to the environment and public health. It also helps to improve the quality and safety of the treated water, making it suitable for reuse in various applications (George *et al.,* 2015).

Overall, physical wastewater treatment is an important first step in the treatment process, as it removes large solids and materials that can cause problems downstream, such as blockages and damage to equipment. By removing these materials, physical treatment helps to ensure the efficiency and effectiveness of subsequent treatment processes.

Chemical wastewater treatment

Chemical wastewater treatment involves the use of chemicals such as coagulants, flocculants, and disinfectants to remove pollutants from wastewater.

Coagulation and flocculation: Coagulation and flocculation involve the addition of chemicals such as alum, ferric chloride, or polyaluminum chloride to wastewater to destabilize suspended solids and organic matter. This process allows the solids to clump together and settle more easily during sedimentation (Gupta *et al.,* 2012).

Disinfection: Harmful microorganisms present in the water can be kill using chlorine, ozone, or ultraviolet radiation is known as disinfection process.

Biological wastewater treatment

Biological wastewater treatment involves the use of microorganisms such as bacteria, fungi, and algae to remove pollutants from wastewater.

Activated sludge process: The activated sludge process involves the aeration of wastewater in the presence of microorganisms to break down organic matter and other pollutants. The resulting sludge is settled and removed, and the treated effluent is discharged into the environment.

Anaerobic digestion: Organic matter break down using microorganisms without oxygen is known as anaerobic digestion. In this process biogas has been produced (Donkadokula *et al.,* 2020).

Membrane Bioreactors (MBRs):

In this process combination of biological treatment with membrane filtration have been used for wastewater treatment. The treated water is then passed through a membrane that filters out any remaining impurities, including bacteria and viruses. MBRs have several advantages over conventional wastewater treatment systems, including higher treatment efficiency, smaller footprint, and reduced sludge production. MBRs have been used for the treatment of various waste water samples (Al-Asheh *et al.,* 2021).

Anaerobic Membrane Bioreactors (AnMBRs):

In this process combination of anaerobic digestion with membrane filtration have been used for wastewater treatment. The treated water is then passed through a membrane that filters out any remaining impurities. AnMBRs have several advantages over conventional anaerobic digestion systems, including higher treatment efficiency, reduced sludge production, and the ability to treat high-strength wastewater. AnMBRshave been used for the treatment of various waste water samples (Al-Asheh *et al.,* 2021).

Advanced Oxidation Processes (AOPs):

AOPs mainly produce the hydroxyl radical in the system for the treatment of pollutant. AOPs can be used to treat all types of wastewater. AOPs have several advantages over conventional treatment methods, including high removal efficiency, the ability to treat a wide range of pollutants, and the production of clean effluent. However, AOPs can be costly and require a high level of expertise to operate (Pare *et al.,* 2012, 2017).

Constructed Wetlands (CWs):

CWs are engineered systems that use natural processes to treat wastewater. The process involves the use of wetland vegetation and soil to remove contaminants from the wastewater. The vegetation provides a habitat for microorganisms that break down organic matter in the wastewater, while the soil acts as a filter to remove pollutants. CWs have several advantages over conventional treatment methods, including low energy consumption, low maintenance requirements, and the ability to provide habitat for wildlife. CWs have been used to treat various types of wastewater (García-Ávila *et al.,* 2023).

Electrochemical technologies:

Electrochemical technologies are a group of treatment processes that use electric currents to treat wastewater. The process involves the use of electrodes that generate an electric field in the wastewater, which can oxidize and degrade pollutants. Electrochemical technologies can be used to treat various types of wastewater, including industrial effluents, municipal wastewater, and landfill leachate. The process has several advantages over conventional treatment methods, including high removal efficiency, the ability to treat a wide range of pollutants, and the production of clean effluent. However, the process can be costly and requires a high level of expertise to operate (Martínez-Huitle *et al.,* 2023).

Solar-powered aeration systems

Aeration is an important process in wastewater treatment that helps to break down organic matter and provide oxygen to the microorganisms that treat the wastewater. Solar-powered aeration systems use solar panels to power the aeration equipment, reducing energy costs and carbon emissions (Kumar & Prajapati 2023).

Anaerobic digestion

Organic matter breaks down using microorganisms in presence of oxygen is known as anaerobic digestion. In this process biogas has been produced. Anaerobic digestion can be combined with other treatment processes such as MBRs or constructed wetlands to further treat the wastewater and produce renewable energy (Mendoza-Tinoco *et al.,* 2023).

Advantages:

- Relatively simple and cost-effective compared to other treatment strategies.
- Can be used to disinfect wastewater to prevent the spread of waterborne diseases.
- Can produce renewable energy in the form of biogas.
- Sustainable technologies can reduce energy consumption, water usage, and carbon emissions.
- Combining different technologies can improve the efficiency and effectiveness of wastewater treatment.
- Limited applicability to high-strength and complex wastewater streams (Rao *et al.,* 2019).
- Effective removal of a wide range of pollutants, including persistent organic pollutants, endocrine-disrupting compounds, and pharmaceuticals (Zhang *et al.,* 2020).

Disadvantages:

- Requires frequent maintenance to prevent clogging of equipment and filters.
- Limited applicability to low-strength wastewater streams (Bae *et al.,* 2020).
- Limited scalability for large-scale wastewater treatment (Vymazal, 2018).
- Requires a higher level of technical expertise compared to physical or chemical treatment strategies.
- Can be sensitive to variations in influent characteristics such as pH, temperature, and organic loading.
- Limited scalability for large-scale wastewater treatment (Dong *et al.,* 2021).
- The initial capital costs of sustainable technologies can be higher than traditional wastewater treatment technologies.
- Limited scalability for large-scale wastewater treatment (Zhang *et al.,* 2020).
- Limited applicability to cold and arid climates (Vymazal, 2018).
- Limited applicability to wastewater streams with low conductivity.

Conclusion:

Reuse of water after treatment is the only path to save the environment/earth. Wastewater treatment can be done using physical, chemical, and biological processes. This chapter mainly focuses on the types of waste water treatment methods and their steps.

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NEXT GENERATION OIL DRILLING FLUIDS

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The chemistry of drilling fluid additives

Drilling fluid constitutes of additives such as clay, minerals, natural/synthetic polymers and surfactants etc. Chemical interaction of the additives involves formation of colloidal suspension, intercalation, flocculation, deflocculation, aggregation of polymer and surface-active agents etc.

Clay chemistry

Hydratable clays such as montmorillonite and attapulgite are preferred as a viscosifier for drilling fluids preparation. Clays stays upon dispersion in water, absorbs the water molecules into the flat and large planar surface of clay sheets. As of this which result, the distance between the two clay layers increases and results in the colloidal suspension or gel. The water absorption tendency of the clay depends on the cation present in the clay.

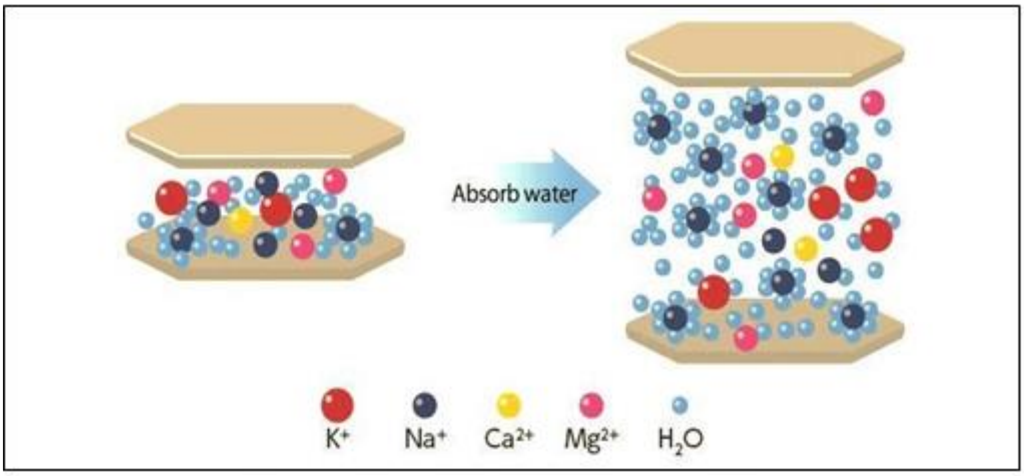

Figure 1: Mechanism of Clay Swelling

Montmorillonite belongs to smectite (is the name used for a group of phyllosilicate mineral species) clay category having 2:1 mineralogy where one octahedral layer is sandwiched between the two tetrahedral layers. Smectite clays have very high-water absorption tendency due to presence of high cation exchange capacity. This results in more water molecules getting absorbed on the clay platelets forming stable suspension and usually possess high water retention capacity (Charles, 1973; Velde, 1992; Lagaly and Ziesmer, 2003).

Monovalent sodium ion (Na^+) has less force of attraction between the clay layers if we compare to divalent cation magnesium ion (Mg^{2+}), calcium ion (Ca^{2+}). Divalent cation has a strong force of attraction which decreases the water absorption between the clay sheets. From this we can confirm that sodium montmorillonite has high gelation tendency comparing to calcium montmorillonite. Montmorillonite acts both as viscosifier and fluid loss controller in drilling fluid.

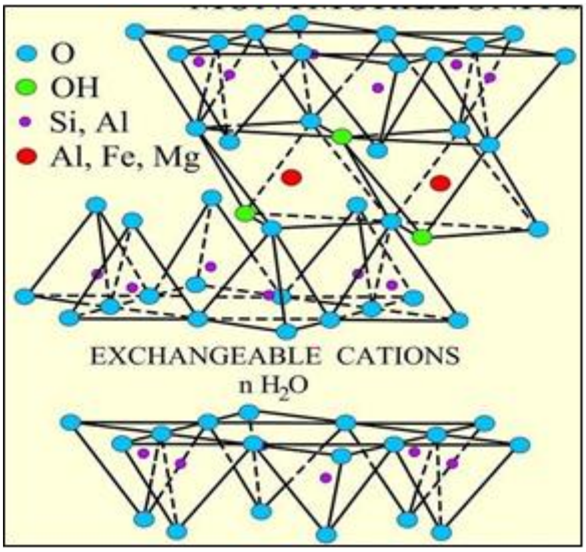

Figure 2: Diagrammatic representation of Structure of Montmorillonite (Grim, 1962)

Attapulgite having formula $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4(H_2O)$ is a magnesium aluminium phyllosilicate. Attapulgite possesses needle like crystalline structure as shown in figure 3.

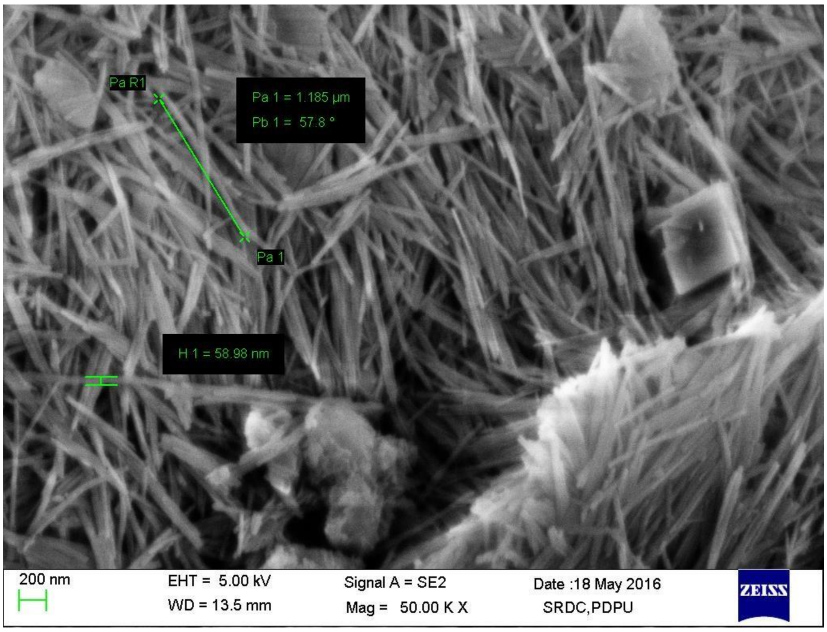

Figure 3: Copyright from (M-I, 1998; KMC, 2016) Structure of Attapulgite (SEM Image)

Unlike montmorillonite, the attapulgite stable in salt solution and forms a stable gel in salt solutions. Formation of gel is due to the rupture of needle shape crystal upon applying the parallel upward force which is also called shearing force on the particle. High shearing force leads to more stable gel suspension (Charles, 1973; Velde, 1992; Lagaly and Ziesmer, 2003). Attapulgite does not have good water retention capacity, hence it is generally used as viscosifier for salt/ sea water-based drilling fluid (M-I, 1998; KMC, 2006).

Clay particles upon addition with aqueous medium tend to associate in one or more in combination of the following stages; i) aggregation, ii) dispersion, iii) flocculation and iv) deflocculation (Charles, 1973).

Aggregation

The interaction of the clay platelets via face-to-face forms thicker platelets which leads to thick gel formation with low plastic viscosity. High cation exchange capacity of clay leads to aggregation or addition of divalent cation forms the aggregation. Drilling contaminants such as gypsum or lime having divalent calcium ion causes the aggregation. Aggregation breaks with temperature and leads to dramatic changes in the viscosity (Goldeberg *et al.*, 1988; M-I, 1998).

Dispersion

Generally clay particles aggregate at the beginning and upon shear or time they disperse with hydration in the medium. Dispersion of clay particles in aqueous medium leads to high plastic viscosity. High dispersion may lead low hydration and low yield point. The cause for dispersion is clay concentration, time, temperature, and presence of electrolyte in aqueous medium etc., (Frenkel *et al.*, 1977; Goldeberg *et al.*, 1988; M-I, 1998).

Flocculation

Clay particles in aqueous medium have tend to form linkage between the two edges of clay platelets or association through edge to face leads to form flocculated structure with high viscosity and high fluid loss (M-I,1998). As the flocculation increases, the thixotropic nature of the fluid decreases. High temperature and drilling contaminants such as divalent cation increase the flocculation (Se and Yulin 2004; Penkavova *et al.*, 2015; Karim *et al.*, 2016).

Deflocculation

Deflocculation is the process of dissociating the flocculated clay particle in the aqueous medium. Additives which dissociate the flocculated particles or neutralize the changes of clay are called deflocculants. The deflocculants reduces the bonding of face to edge and edge to edge between the clay platelets (Se and Yulin 2004; KMC, 2006). Mechanism of flocculation and deflocculation is as shown in figure 2.10. Deflocculation process causes the reduction in viscosity and there by uniformly dispersing the fluid rheology and are referred as fluid thinners. Fluid thinner reduces the fluid loss caused due to the flocculation and aids in formation of uniform fluid cake (M-I, 1998; Penkavova *et al.*, 2015; Karim *et al.*, 2016).

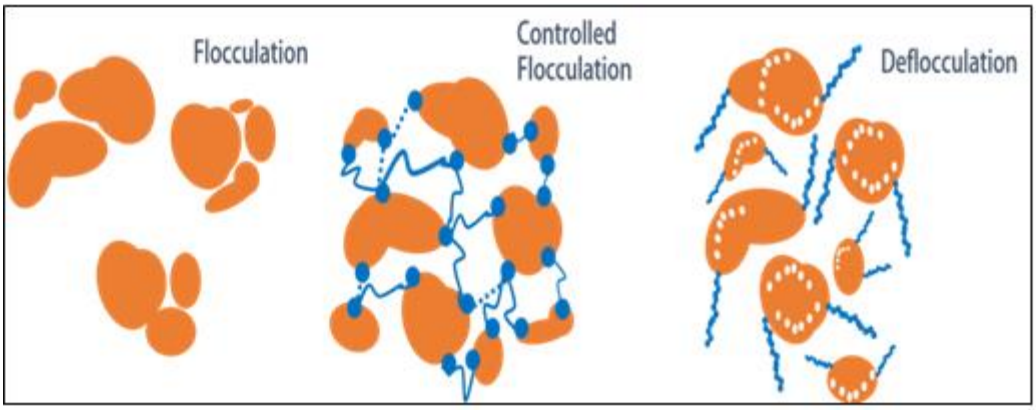

Figure 4: Schematic Diagram of Flocculation and Deflocculation Mechanism (fsw.cc, 2018)

Polymers for drilling fluids

Natural/ synthetic polymers are generally used as fluid loss controlling additive and viscosifier for drilling fluids. Natural polymer constitutes of polymerized glucose units and generally referred as polysaccharides (M-I, 1998). Natural polymers are high molecular weight compounds and have complex structures compare to the synthetic polymers. Low tolerance towards temperature and bacterial degradation were the drawback of natural polymers (Alsbagh *et al.,* 2014; Mansoor *et al.,* 2016; Alireza *et al.,* 2018). Synthetic anionic polymers are widely preferred for drilling fluid formulations. Anionic polymers such as starch derivatives, carboxymethyl cellulose (CMC), xanthan gum (XCP), partially hydrolyzed polyacrylamide (PHPA) etc., are commonly used. These anionic polymers contain a distinguishing carboxyl group which varies the solubility and functions for the polymers. Alkali metal hydroxide used as base for the ionization of carboxyl group through which solubility of the polymer occurs (M-I, 1998; Fan *et al.,* 2016; Hafiz *et al.,* 2018).

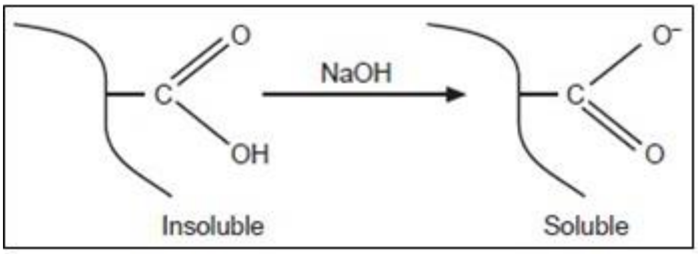

Figure 5: Solubility of Polymer in Alkaline Medium (M-I, 1998)

Water molecules are attracted towards the carboxylate ion and polymer hydration spreads by forming envelope of polymer suspension. Viscosity of the polymer solution increases with increase in size of the polymer. The pH 8.5 to 9.5 found to be the optimum pH, at which the maximum solubility of the polymers occurs. Low pH below 7 decreases the gelation and high pH may cause precipitation or low gelation of the polymers (M-I, 1998; Alsbagh *et al.,* 2014; Mansoor and Ariffin, 2016).

Starch derivatives

Starch is natural polymer obtained from potato, corn etc. Starch constitutes of amylose (backbone) and highly branched amylopectin carbohydrate units. Raw form of starch is not water soluble. Starch is modified by rupturing the protective coating of amylopectin to expose amylose for interaction with water molecules to make water soluble. The process of modification is called as pre-gelatization (Kees *et al.,* 1997; M-I, 1998; Michailova *et al.,* 2001; Kuenchan *et al.,* 2009).

Property of the starch varies with the ratio of the amylose and amylopectin units. Pre-gelatinized form of starch is used as fluid loss controller for water based drilling fluids. Pre gelatinized starch is biodegradable in nature and adequate concentration of biocide is added for the drilling fluid formulation to avoid bacterial degradation (Kees *et al.,* 1997; Michailova *et al.,* 2001; Kuenchan *et al.,* 2009).

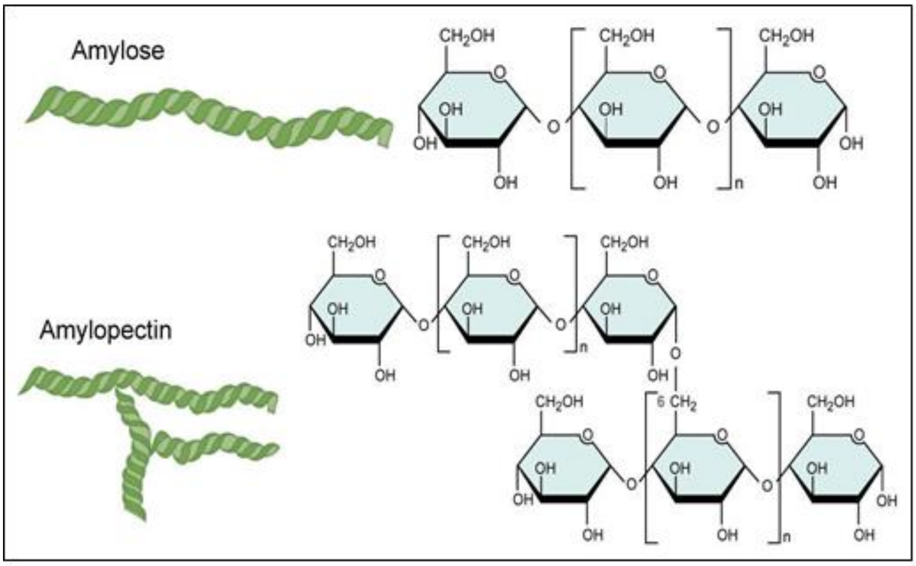

Figure 6: Amylose and Amylopectin (M-I, 1998; pinterest.com, 2018)

Xanthan gum

Xanthan gum or XC polymer is one of the widely used viscosifier for water based mud. It is natural polymer produced from bacterial called Xanthomonas campestris through complex enzymatic process (Rosalam and England, 2006; Montri and Manop, 2006). Xanthan gum is an anionic polymer with highly branched structure and water soluble. Molecular weight of polymer ranges between 2-3 MDa (Barbara, 1998; Gracia *et al.*, 2000; Rosalam and England, 2006; Montri and Manop, 2006). The backbone of xanthan gum consists of glucose residues and side chains include various functional groups such as carboxyl group, hydroxyl group and carbonyl group etc., which are responsible for unique shear thinning and viscosifying nature of xanthan gum. Formation of weak intermolecular hydrogen bonding in absence of shear and breaking of intermolecular hydrogen bonding on application of shear is responsible for shear thinning nature of xanthan gum (Gracia *et al.,* 2000; Rosalam and England, 2006). Structure of xanthan gum is as shown in figure 7.

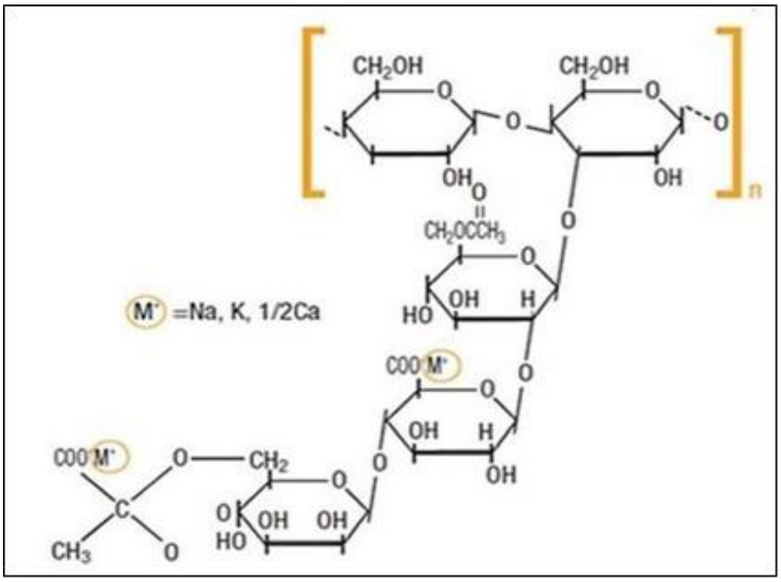

Figure 7: Xanthan Gum (XC Polymer) (KMC, 2006)

Cellulose derivatives

Cellulose is a carbohydrate constituted natural polymer, which is insoluble in water in its raw form.

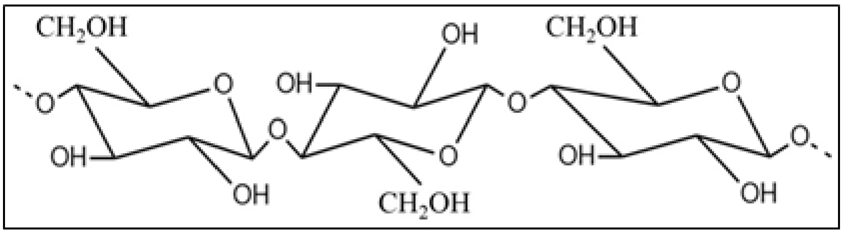

Figure 8: Structure of Cellulose (Kisuk *et al.,* 2017)

Derivatives of cellulose is prepared by modification through attaching anionic carboxymethyl group. The modification increases the affinity of water molecules towards cellulose through anionic carboxymethyl group and makes cellulose derivatives water soluble. Different derivatives of cellulose such as hydroxyethyl cellulose (HEC), carboxymethyl cellulose (CMC) and polyanionic cellulose (PAC) is used as drilling fluid additives for water based mud (May *et al.,* 2017; Collins *et al.,* 2017; Kuri *et al.,* 2017). These derivatives varies with the molecular weight and functional groups. The molecular weight of cellulose derivatives is increased by increasing the degree of polymerisation and high degree of polymerisation increases the viscosifying nature of the derivatives. Depending upon the degree of polymerisation and viscosifying nature CMC derivatives are referred as CMC-low viscous grade (CMC-LVG) and CMC-high viscous grade (CMC-HVG) (M-I, 1998; May *et al.,* 2017). Also the degree of substitution of the function group on cellulose chain increases the solubilty of the cellulose derivative. Additive polyanionic cellulose differs from CMC in terms of degree of substitution. Higher the degree of substitution, solubility will be better. Solubility PAC is higher compare to CMC, as degree of substitution for PAC is high compare to CMC (M-I, 1998; Xue *et al.,* 2017; Heinze *et al.,* 2018).

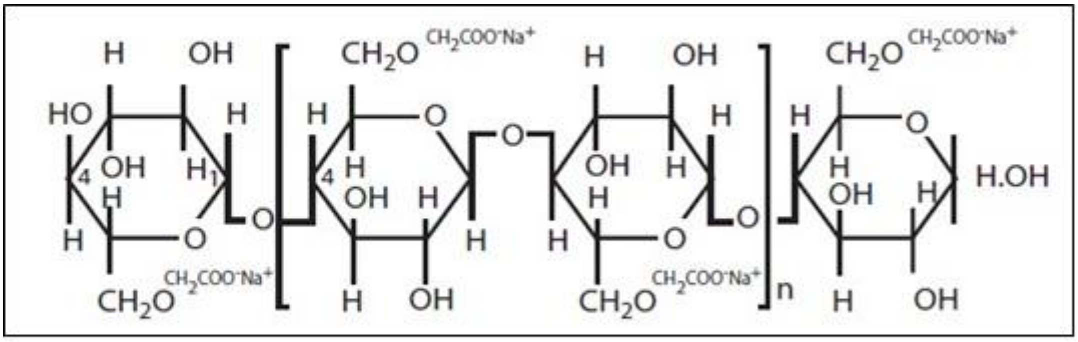

Figure 9: Carboxymethyl Cellulose (KMC, 2006)

Derivatives of polyacrylamide

A polyacrylamide derivative is prepared by sodium acrylate copolymerization. As such polyacrylamide is insoluble in water. The copolymerization of sodium acrylate increases the solubility of polyacrylamide. During copolymerization, amide groups and carboxyl groups are randomly distributed between carbon-carbon backbone. The thermal stability of polyacrylamide derivative is due to the formation of C-C bond (KMC, 2006; Xiaoping *et al.,* 2017).

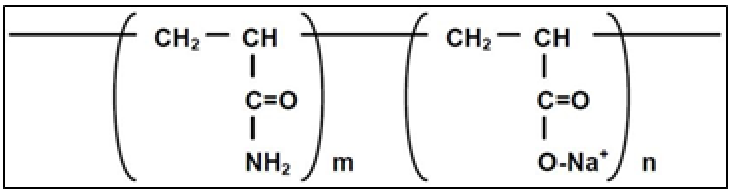

Figure 10: Polyacrylamide Derivative (Pan *et al.*, 2016)

Partially hydrolyzed polyacrylamide (PHPA) is used as a shale inhibitor in water based mud formulation. PHPA provides a unique property of solid encapsulation, which helps in shale inhibition, cutting encapsulation and effective hole cleaning. PHPA is effective in both fresh water and salt water formulations. Literature reveals that PHPA acts as viscosifier and shale inhibitor when prepared in 30:70 ratio of acrylate to acrylamide units (M-I, 1998; KMC, 2006; May, 2016). The structure of PHPA is as shown in figure 11.

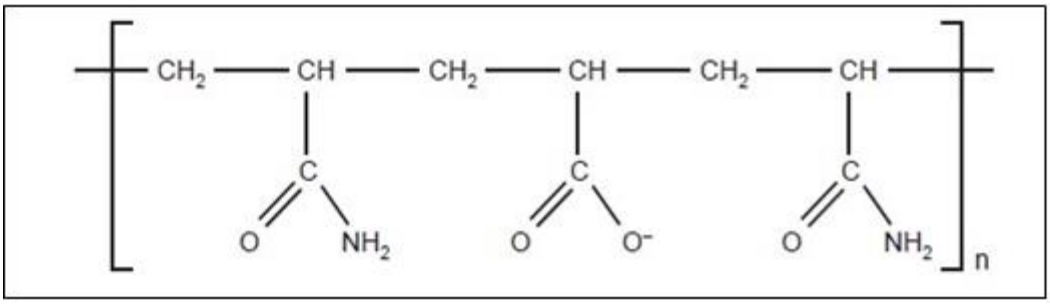

Figure 11: Partially Hydrolyzed Polyacrylamide (PHPA) (M-I, 1998)

The PHPA in both fluid formulations as well as in presence of shale formation attracts the clay particles and disperses the fluid system. Amide group provides the dispersion nature for PHPA, by preventing the interaction of carboxyl group and clay charges (M-I, 1998; Gregor *et al.*, 2015; Xiaoping *et al.*, 2017).

Role of surfactants in drilling fluid

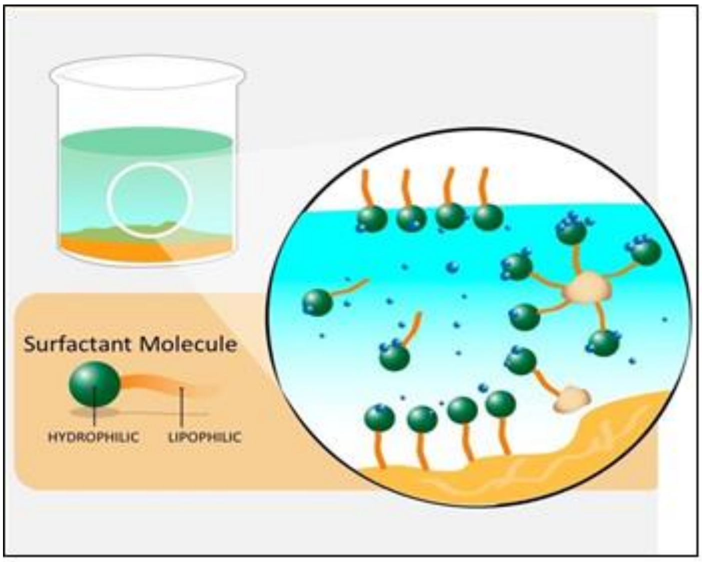

Figure 12: Mechanism of Surfactants (Kemet, 2018; pinterest.com, 2018)

Surfactants or surface active agents plays unique and crucial role in drilling fluid formulations. Generally non aqueous drilling fluids are invert emulsions prepared with surfactants. Surfactants in oil base mud acts as emulsion stabilizers between oil and water phase and wetting agents for viscosifier, fluid loss controller, weighting additives. Surfactant reduces the surface tension between the surfaces and increases the area of contact, contact angle between liquid-liquid, liquid-solid and solid-solid phase (M-I, 1998; Daojin *et al.*, 2016; Guanzheng *et al.*, 2017; Jianhle *et al.*, 2018).

Surfactants have a non-polar tail and a polar head. Depending on the polarity of the molecule hydrophilic attracted towards polar head and lipophilic/organophilic molecule attracted towards non-polar tail. The functionality of a surfactant can be characterized using hydrophilic-lipophilic balance (HLB) range. Figure 13 describes the classification of surfactants based on hydrophilic-lipophilic balance scale (Rui *et al.*, 2017; Naim *et al.*, 2017; Zhou *et al.*, 2018).

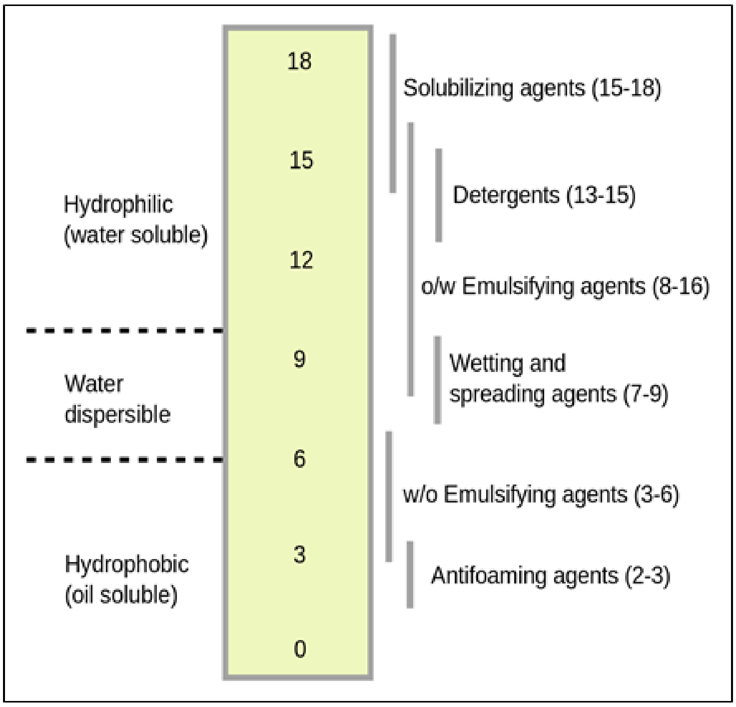

Figure 13: Classification of Surfactants Based on Hydrophilic-Lipophilic Balance Scale (Griffin, William C., 1949. 1954; Davies 1957; Zhou *et al.*, 2018)

Emulsifiers

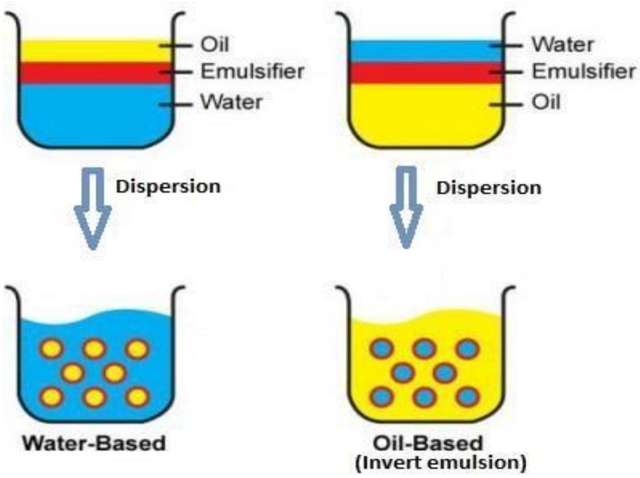

Figure 14: Schematic Representation of Oil in Water Emulsion and Water in Oil-Invert Emulsion (riyan, 2018)

Emulsifiers/ emulsifying agents are surfactants that reduce the surface tension between liquid-liquid phase such as oil and water in non-aqueous fluid formulation. Emulsifiers are partially soluble in hydrophilic and lipophilic phase. They are cationic, non-ionic and anionic molecules having long chains of fatty acids, alcohols etc., (Daojin *et al.,* 2016; Rui *et al.,* 2017; Zhou *et al.,* 2018). Stable emulsion formation between oil and water is as shown in figure 14.

Wetting agents

Interfacial tension between solid-liquid phase can reduced using wetting agents. The wetting agent is a type of surfactant having partial affinity with one end towards a solid as well as the other end towards a liquid surface. Wetting agents reduces the contact angle and interfacial between the solid-liquid phases (M-I, 1998; Daojin *et al.,* 2016). The reduction of interfacial tension with contact angle increases the spread of liquid phase on solid surface. Wetting agents have one end that is soluble in the continuous-phase liquid and the other that has a strong affinity for solid surfaces, as shown in figure 2.21. Wetting agents are added to synthetic oil based fluids for preferential wetting of clays, barite with base oil, also to avoid the aggregation and settling of drill solids (Rui *et al.*, 2017; Naim *et al.*, 2017;
Guanzheng *et al.*, 2017).

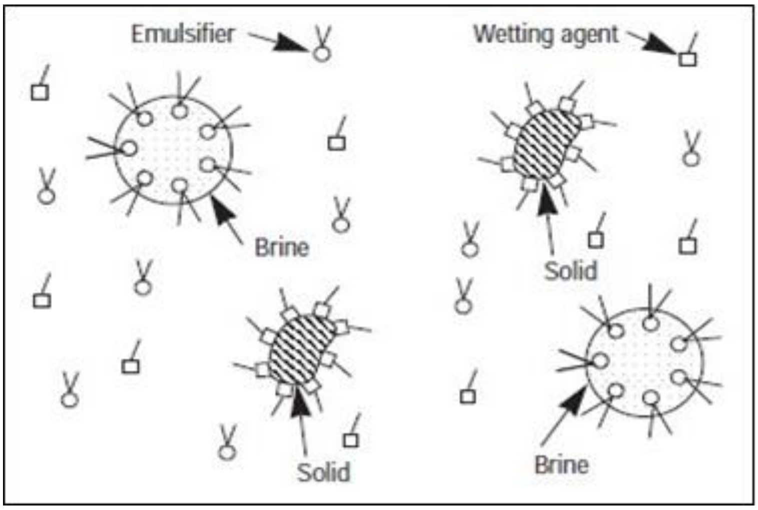

Figure 15: Schematic Representation of Emulsifier and Wetting Agent (M-I, 1998; Naim *et al.*, 2017)

Eco- friendly drilling fluid additives

Non aqueous drilling fluids are not cost effective and possess disposal concern compare to water base drilling fluids. Cost effectiveness and eco-friendly nature of WBM makes it attractive fluid option for majority drilling operations. Major component involved in any mud by volume is base fluid. WBM constitutes of water as base fluid. Water being an universal solvent with superior ability to dissolve a variety of substances, properties like highest surface tension, dielectric constant, heat of fusion, heat of vaporization makes it economically viable fluid. The interaction of base fluid with clay additives, polymers in presence of electrolytes is a key factor for fluid properties. Thin filter cake and lubricous nature of low solid polymer additives and brine based fluids proven to reduce the torque and drag of WBM. For extended reach wells an additional extreme pressure lubricant is required for achieving deeper well targets.

Environmental regulations and cost factors has globally shifted the attention from hydrocarbon based additive to environmentally acceptable alternatives of esters, fatty acids constituted WBM. Quality of the base fluid parameters must be maintained in order to achieve the desired fluid properties. The pH and hardness of base fluid must be maintained prior to addition of other additives. Non-maintenance of the same may impinge the rheology and filtration property of the mud by lowering the efficiency of the additives. Thus requires an additional dosage of the additives leading to increase the fluids cost. Additives of WBM for achieving desired functional properties are pH controller, hardness reducer, fluid loss controller, Viscosifier, clay hydration inhibitor, dispersant, lubricant, biocide and weighting agent.

1. pH controller

Sodium hydroxide (NaOH) or potassium hydroxide (KOH) is added as pH controller for maintaining optimum pH of 8.5-9.5 of the mud. Very high and low pH leads to corrosion in drill strings and reduces the shelf life of drilling equipment's (Jamal and James, 1975). Also fluid additive also tends to reduce their functionality under low or extreme high pH conditions. The causes for low pH under drilling process are presence of acid gases like H_2S, CO_2, anhydrites and water contaminations (Andy, 2012). The decrease of pH during drilling process leads to excess fluid loss and undesired rheological profile of the mud (Ryen, 2011).

Magnesium oxide (MgO) is also used as source for alkalinity control for WBM. MgO is water soluble, compatible with brine polymer fluids and fresh water fluids. The maximum pH can be obtained using MgO is 10.3 (approx.). Buffering tendency of MgO below pH of 10.3, is an advantage over NaOH. Measurement of pH at frequent intervals and maintaining optimum pH is must for the mud.

2. Hardness reducer

Hardness of water is a crucial parameter of base fluid in mud preparation. The higher limit depends on optimum pH 8.5 to 9.5. From literature it is observed that maximum hardness limit for base fluid is 600 mg/L, below which the drilling fluid additives exhibits high performance (KMC, 2006). Sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$) are used for removing hardness constituent calcium from water, mud.

3. Fluid loss controller

Fluid loss controller reduces the fluid loss occur during drilling process. Generally pre-gelatinized starch and poly-anionic cellulose, lignite based materials are used as fluid loss controller for drilling fluids. The additive concentration varies from 1-3 % (w/v) for starch and 0.5 - 1.0 % (w/v) for cellulose, lignite additives depending upon the depth and temperature profiles. Our eco-friendly drilling fluid formulation involves cetyltrimethylammonium bromide (CTAB) and CTAB grafted PAM gel as fluid loss controllers.

4. Viscosifier

Viscosifier provides rheology for the drilling fluids. Better rheology of fluid enhances the cutting lifting and hole cleaning property of the fluid under different well conditions. Depending on the formation depth and temperature profile viscosifier are added. For top hole sections generally clay based viscosifier such as montmorillonite ($Al_2O_34SiO_2H_2O$) are preferred. As montmorillonite provides good rheological profile at a concentration 7 - 10 % (w/v), fluid loss controlling property makes it economic additive (KMC, 2006). The filter cake formed from montmorillonite is impervious and also stabilizes the seepage into permeable formation. Montmorillonite is generally preferred for fresh water as it does not hydrate in salt water. Formations having presence of contaminants such as magnesium sulfate, salt and calcium sulfate prevents the montmorillonite swelling and results in low yield (Darley, 1988). Such formations requires salt tolerant viscosifier such as attapulgite having formula $(Mg,Al)_2Si_4O_{10}(OH)\cdot4(H_2O)$ or $Mg(Al_{0.5-1}\ Fe_{(0-0.5)}Si_4O_{10}(OH).4H_2O$ (Harben, 2002). Attapulgite show excellent rheological profiles in presence with extended thermal stability. Unlike montmorillonite, the attapulgite does not have fluid loss controlling property and requires an additional fluid loss controller in the formulation (Haden, 1961; Darley, 1988).

Xanthan gum or XC polymer is one of the widely used polymer based viscosifier for WBM. It is produced from the bacterial action of Xanthomonas on carbohydrates. XC polymer shows excellent shear thinning property at very low concentration of 0.4 - 0.6 % (w/v) in salt and fresh water fluids. It is highly recommended in formulating non-damaging drilling fluid for drilling pay zone formations (Beck,
1993; Walker, 1993).

5. Clay hydration inhibitor / suppressant

Potassium chloride (KCl) or sodium chloride (NaCl) is used to prepare brine for formulation of inhibited drilling fluids. Inhibited drilling fluids are generally used for drilling shale or reactive clay formations. During drilling process clay swelling prevention is required to stabilize the well, as well as to maintain the permeability (O'Brien and Chenevert, 1973). KCl as a source of K^+ ion replaces Na^+ ions from reactive clays and inhibits the hydration. K^+ ions are more effective inhibitors compare to Na^+ ions as ion exchange tendency is higher in K^+ with clay. The concentration of KCl in the formulation depends upon the type and age of clay/shale formations. Dosage varies from 3 - 5 % (w/v) for older shale formations and 10 - 15 % (w/v) young hydratable shale/clay formations. K^+ ions sources such as K_2SO_4, K_2CO_3, KNO_3, $K_4P_2O_7$ and $KC_2H_3O_2$ were also used for inhibited mud formulation
(Ichenwo and Okotie, 2015).

6. Dispersant

Chrome free lignosulphate/ lignosulfonate is an environment-friendly mud thinner/ dispersant for WBM. It is effective in low concentrations 0.4 - 0.7 % (w/v) with enhanced deflocculation and rheology stabilization property (Park, 1988). It has wide range of applications in salt water, fresh water and sea water based mud formulations (KMC, 2006).

7. Lubricant

Lubricant reduces the friction during drilling process and helps in increasing the penetration rate, shelf life of drill bit. A thin film of very high film strength formed between the drill string and formation extends the extreme pressure stability to the additive. An extreme pressure lubricant will not affect the rheology of the mud and is suitable for application in freshwater and salt water mud systems (Rosenberg and Tailleur, 1959).Generally lubricating additives constitutes of fatty acid derivatives, poly-propylene glycol based oils, petroleum based oil, seed oil and triglyceride based oils etc., (Ahmet *et al.,* 2013).

Lubricating property varies with the functional moiety present in the additive. Excellent lubricity and film strength observed for the additive having oxygen moieties. The order of the oxygen atom carrying functional moieties: -COOH > CHO > -OH > -$COOCH_3$ > -C=O > -C-O-C (Gerhard *et al.,* 2005). Extreme pressure lubricants are the additives which remain adhered to the moving surfaces under high pressure and torque conditions. It is observed that for extended reach wells liquid lubricants are found to be more suitable than solid lubricants, as solid lubricants possesses threat of pore plugging (Schamp *et al.,* 2006). Extreme pressure lubricant possesses high film strength of 20000 – 25000 psi in fresh water mud and coefficient of friction less than 0.15. For salt water mud lubricity coefficient should be less than 0.2 and film strength above 20000 psi (SIEP, 2003).

8. Biocide

Biocides are added to reduce the bacterial degradation of bio-polymer additives present the mud. Starch derivatives and natural polymers are generally subjected to bacterial degradation. The degradation of polymers can lead to reduction in in functional property of additives there by causing excessive fluid loss and low permeability. Biocide inhibits microorganisms by reducing their metabolic activity (Sunde, 1990; Van 2003; Turkiewicz, 2011). Variety of chemical compounds, both organic substances like formaldehyde, glutaraldehyde and inorganic substances like quaternary ammonium salts are used as biocides (Anna *et al.,* 2013).

9. Densifier / weighting agent

Formation pressure is one of the unpredicted drilling complications. To carry out the successful drilling activity, appropriate mud weight must be maintained. Depending on low-pressure formation or high pressure formation, mud needs to be formulated with slightly higher than the formation pressure. Densifier / weighting agent are added to increase the density of the mud to maintain the hydrostatic pressure of wellbore higher than formation pressure to prevent the blow out (Bongayre and Cheneverl, 1986). Heavy solid such as barium sulfate ($BaSO_4$) specific gravity 4.14.2 is one of the extensively used weighting agents for WBM. Dosage of the additives varies as per the formation pressure. Barite is non-reactive with mud additives and insoluble in water. The inert nature of barite and fine particle size enhances its compatibility for wide range of WBM formulations for a specific gravity up to 2.2 (Walker, 1974; Bongayre and Cheneverl, 1986).

Calcium carbonate ($CaCO_3$) having specific gravity 2.6 - 2.8 and insoluble in water. The particle size of varies from medium, fine to micronized depending on pore size of the formation. It is used as one of the eco-friendly weighting and bridging agent for non-damaging drilling fluids (Mahajan and Barron 1980; Cargnel and Luzardo, 1999). Easy removal of filter cake formed by the mud containing $CaCO_3$ in pay zone formations increases the production of hydrocarbons. As a result in general pay zone formations are drilled WBM containing $CaCO_3$

(Hands *et al.,* 1998; Mohammed *et al.*, 2006). Dosage of $CaCO_3$ varies with formation pressure and has applicability upto a specific gravity of 1.35 (KMC, 2006).

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TOWARDS SUSTAINABLE AGRICULTURE: MITIGATING THE ADVERSE EFFECTS OF STUBBLE BURNING IN INDIA

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Abstract:

Stubble burning, a common agricultural practice in India, has emerged as a significant environmental and health concern in recent years. The practice involves the burning of crop residues, particularly after the harvest of paddy, wheat, and other crops. This article aims to provide a comprehensive analysis of stubble burning, including its causes, consequences, and various management strategies implemented in India. By examining the current state of stubble burning and its impact on air quality, climate change, soil health, and public health, this article will shed light on the urgent need for sustainable and effective management practices. Furthermore, it will explore the policies, technological interventions, and alternative uses of crop residues that can help mitigate the adverse effects of stubble burning and foster a cleaner and healthier environment.

Keyword: Crop residues, environmental concern, management strategies, stubble burning, sustainable agriculture.

Introduction:

Agriculture plays a pivotal role in India's economy, employing a significant portion of the population and contributing to food security. However, the post-harvest practice of stubble burning has become a pressing concern due to its adverse effects on the environment and public health. Stubble burning refers to the deliberate setting of crop residues on fire to clear fields for the next cultivation cycle. This practice has gained attention due to its contribution to air pollution, climate change, and soil degradation. This article aims to provide a detailed analysis of stubble burning and its management in India. It explores the causes and practices of stubble burning, its environmental and health impacts, existing management strategies, alternative uses of crop residues, international best practices, challenges, and recommendations for the future. By delving into these aspects, this article seeks to raise awareness and promote effective solutions to address the stubble burning crisis in India.

Stubble burning: Causes and practices

- **Agricultural practices in India:** India is predominantly an agrarian society, with a significant portion of the population engaged in farming. Traditional agricultural practices, combined with the advent of modern farming techniques, have led to an increase in the cultivation of crops such as paddy and wheat. However, these practices generate a large volume of crop residues, creating a challenge for farmers in their disposal.

- **Reasons for Stubble Burning:** Stubble burning has become a common practice due to several reasons. Firstly, it provides a quick and cost-effective method for farmers to clear fields and prepare them for the next crop cycle. Secondly, the time constraint between the harvesting of one crop and the sowing of the next leaves farmers with limited options for managing crop residues effectively. Lastly, economic considerations, such as the high cost of manual labor and lack of viable alternatives, further contribute to the prevalence of stubble burning.

- **Regional Variances in Stubble Burning:** The incidence of stubble burning varies across different regions of India. The states of Punjab, Haryana, and Uttar Pradesh witness a significant number of stubble burning incidents due to the concentrated cultivation of paddy and wheat. Other states, like Bihar, Madhya Pradesh, and Rajasthan, also engage in stubble burning to a lesser extent. Understanding these regional differences is crucial in formulating targeted management strategies.

Environmental impact of stubble burning

- **Air pollution:** Stubble burning releases a cocktail of harmful pollutants, including particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs). These pollutants have severe implications for air quality and human health, leading to increased respiratory problems, cardiovascular diseases, and reduced visibility.
- **Climate change:** Stubble burning contributes to greenhouse gas emissions, primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases trap heat in the atmosphere, exacerbating global warming and climate change. The emissions from stubble burning also deplete the ozone layer, further amplifying the environmental impact.
- **Soil health:** Stubble burning not only depletes the organic carbon content in the soil but also destroys essential soil microorganisms. This degradation negatively affects soil fertility, water retention capacity, and overall agricultural productivity. The practice also disrupts the natural nutrient cycle, requiring farmers to rely heavily on chemical fertilizers.
- **Biodiversity and ecosystems:** The burning of crop residues destroys habitats and disrupts ecosystems, impacting wildlife, birds, insects, and beneficial organisms. The loss of biodiversity has cascading effects on the environment, affecting pollination, natural pest control, and the overall balance of ecosystems.

Health effects of stubble burning

- **Respiratory issues:** The pollutants released from stubble burning have severe implications for respiratory health. The inhalation of fine particulate matter and toxic gases can cause respiratory distress, aggravate existing conditions such as asthma, and increase the risk of respiratory infections and lung diseases.
- **Eye irritation and allergies:** Burning crop residues release irritant compounds that can cause eye redness, itching, and watering. People exposed to stubble burning smoke may also experience allergies, leading to symptoms like sneezing, coughing, and skin irritation.
- **Long-term health impacts:** Prolonged exposure to stubble burning emissions has been linked to long-term health consequences, including chronic respiratory diseases, cardiovascular problems, and even increased mortality rates. Vulnerable populations, such as children, the elderly, and individuals with pre-existing health conditions, are particularly at risk.
- **Vulnerable populations:** Stubble burning disproportionately affects vulnerable populations residing in rural areas. Farmworkers, who spend a significant amount of time in the fields, are particularly susceptible to the health risks associated with stubble burning. Children, who have developing respiratory systems, and the elderly, who have weakened immune systems, are also more vulnerable to the adverse effects.

Existing management strategies

- **Government initiatives and policies:** The Indian government has implemented various initiatives to tackle stubble burning, including the National Policy for Management of Crop Residues, the Pradhan Mantri Krishi Sinchayee Yojana, and the Sub-Mission on Agricultural Mechanization. These policies emphasize the promotion of sustainable alternatives to stubble burning, financial incentives for farmers, and the adoption of modern machinery.
- **Technological interventions:** Technological interventions, such as the Happy Seeder and Super SMS machines, have gained traction in recent years. These machines allow farmers to sow seeds without prior crop residue removal, reducing the need for stubble burning. Other innovations, such as the use of biomass briquettes and biochar production, offer alternative uses for crop residues, promoting sustainable management practices.
- **Financial incentives:** To encourage farmers to adopt sustainable practices, governments have introduced financial incentives, including subsidies for machinery and equipment, reimbursement of expenditure on stubble management, and income support schemes. These incentives aim to offset the economic burden of adopting alternative methods and provide farmers with the necessary resources to transition away from stubble burning.
- **Awareness and education programs:** Awareness campaigns and educational programs play a crucial role in changing farmers' behavior and fostering a mindset shift towards sustainable agricultural practices. These initiatives aim to educate farmers about the environmental and health hazards of stubble burning, as well as the benefits of adopting alternative management techniques.

Alternative uses of crop residues

- **Bioenergy generation:** Crop residues can be utilized to generate bioenergy through various processes, including biomass combustion, biogas production, and biofuel production. These energy sources can help reduce dependence on fossil fuels, contribute to rural electrification, and create additional revenue streams for farmers.
- **Composting and organic fertilizers:** Crop residues can be composted to produce organic fertilizers, which enhance soil fertility and promote sustainable agriculture. Composting not only reduces the need for chemical fertilizers but also improves soil structure, water retention, and nutrient availability.
- **Animal feed and bedding:** Crop residues, when processed and treated, can be used as animal feed and bedding material. By integrating crop residues into livestock farming systems, farmers can reduce their dependence on costly feed inputs while improving the overall health and productivity of their livestock.
- **Industrial applications:** Crop residues can serve as valuable resources in various industries, including paper and pulp, construction materials, and bio-based products. By exploring innovative industrial applications, the potential value of crop residues can be maximized, creating new avenues for economic growth and sustainable development.

International best practices

- **Case studies: Successful models from other countries:** Several countries have effectively addressed the issue of stubble burning and offer valuable insights. For instance, China implemented a comprehensive approach that combines legislation, technological innovations, financial incentives, and public participation to reduce stubble burning. European countries have also implemented strict regulations and promoted alternative uses of crop residues, leading to a significant reduction in the practice.
- **Lessons learned and applicability to India:** India can draw lessons from successful international models and tailor them to suit its unique agricultural landscape and socio-economic context. This includes adapting and adopting technological interventions, strengthening policy frameworks, providing financial support, and actively engaging farmers and other stakeholders in the decision-making process.

Challenges and barriers to stubble burning management

- **Economic factors:** Farmers face economic challenges in adopting alternative methods of crop residue management. The cost of machinery, lack of access to credit, and the need for additional labor or resources pose significant barriers. Addressing these economic factors and providing adequate financial support is crucial to incentivize farmers to shift away from stubble burning.
- **Infrastructure and technological limitations:** Effective stubble burning management requires infrastructure development, including the availability of advanced machinery, biomass processing units, and storage facilities. Limited access to such infrastructure, especially in remote areas, hinders the widespread adoption of sustainable practices.

- **Behavioral change and cultural practices:** Changing long-established cultural practices and ingrained behavior patterns is a complex challenge. Overcoming the cultural resistance to change requires a multi-faceted approach, including awareness campaigns, education, capacity building, and building trust among farmers.
- **Governance and policy implementation:** Ensuring effective policy implementation, monitoring, and enforcement are critical to addressing stubble burning. Strong governance, coordination between different government departments, and involvement of local bodies and communities are necessary to overcome bureaucratic hurdles and streamline efforts.

Future outlook and Recommendations:

- **Policy interventions:** Policy interventions should focus on strengthening existing policies and regulations related to stubble burning, providing clear guidelines, and integrating stubble burning management into broader environmental and agricultural policies. Governments should also consider market-based approaches, such as emissions trading schemes, to incentivize emission reductions.
- **Technological advancements:** Investing in research and development to develop advanced machinery, crop residue processing technologies, and renewable energy solutions will facilitate the transition to sustainable stubble management. Collaboration between research institutions, industry, and farmers is crucial in driving technological advancements.
- **Stakeholder collaboration and participation:** Building partnerships and collaborations between government bodies, farmers, NGOs, industry stakeholders, and research institutions is essential for developing holistic solutions. Engaging farmers in decision-making processes, incorporating their perspectives, and providing platforms for knowledge sharing and capacity building are key to successful implementation.
- **Research and development initiatives:** Increasing investment in research and development will enable the exploration of innovative and sustainable solutions for stubble burning management. This includes conducting research on crop residue valorization, impact assessment, health effects, and socio-economic studies to inform evidence-based policymaking.

Conclusion:

Stubble burning poses a significant environmental and health challenge in India. However, through concerted efforts and a multi-dimensional approach, the negative impact of stubble burning can be mitigated. By implementing effective management strategies, promoting alternative uses of crop residues, and fostering stakeholder collaboration, India can move towards sustainable agricultural practices, improve air quality, protect public health, and ensure long-term environmental sustainability.

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ECOLOGICAL IMPORTANCE OF WETLANDS

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Abstract:

Wetland also have been called as "biological super market" because of the extensive food chain and rich biodiversity that they support and play major role in the landscape by providing unique habitats for a wide range of flora and fauna. Wetlands are important because they provide habitat for thousands of species of aquatic and terrestrial plants and animals. Wetlands are valuable for flood protection, water quality improvement, shoreline erosion control, natural products, recreation, and aesthetics. Wetlands are transitional areas, sandwiched between permanently flooded deep-water environments and well-drained uplands. They include mangroves, marshes, swamps, forested wetlands, bogs, wet prairies and vernal pools. In general terms, wetlands are lands where water saturation is the dominant factor determining the nature of soil and the types of plant and animal communities living in the soil and on its surface. An immense variety of species of microbes, plants, insects, amphibians, reptiles, birds, fish and mammals forms the wetland ecosystem. Physical and chemical features such as climate, landscape shape, geology and the movement and abundance of water helps to determine the plants and animals in habitat of each wetland.

Keywords: Wetlands, water quality, flood protection, birds, mangroves, bogs and vernal pools.

Introduction:

Wetlands

Wetlands are transitional zones between permanently aquatic and dry terrestrial eco systems. According to the Ramsar convention of the IUCN at Iran in 1981, wetlands are "submerged or water saturated lands, both natural and man-made, permanent or temporary with water, that is static or flowing, fresh, brackish or salt including areas of marine water'', the depth of which at low tides does not exceed six meters. Wetland covers about 6% of the earth's land surface. There are several kinds of wetlands such as Marshes, Lagoons, Bogs, Fens, Open water bodies and Mangroves.

The Ramsar convention in wetlands is an inter government treaty with 135 contracting practices. There are 1235 wetland sites totaling 106.6 mha, designated for inclusion in the Ramsar list of wetlands of international importance. To commemorate the data of signing of the convention on wetlands, 2nd February of every year is observed as World Wetlands Day. It is celebrated first time in 1997 and this beginning was quite encouraging. Chilka Lake (Orissa) and Keoladeo National Park (Bharatpur, Rajasthan) have been designated under the convention of Wetland of international importance (Ramsar convention), as being especially significant for Water fowl habitats.

The National committee on Wetlands, Mangroves and Coral reef constitute for advising the Government, on appropriate polices and measures to be taken for conservation and management of the wetlands. It has been identified that the 93 wetlands for conservation and management on priority basis. Only 19 wetlands in India have been categorized for the Ramsar sites of India. They are as follows:

Sl. No.	Ramsar sites of India	State	Area(ha)
1	Ashtamudi Wetland	Kerala	61,400
2	Bhitarkanika Mangroves	Orissa	65,000
3	Bhoji Wetland	Madhya Pradesh	3,201
4	Chilka Lake	Orissa	1,16,500
5	Deeper Beal	Assam	4,00
6	East Calcutta Wetland	West Bengal	12,500
7	Harike Lake	Punjab	4,100
8	Kanjli	Punjab	183
9	Keoladeo National Park	Rajasthan	2873
10	Kolleru Lake	Andhra Pradesh	90,100
11	Loktrak lake	Manipur	26,600
12	Point Calimere Wildlife and Bird Sanctuary	Tamil Nadu	38,500
13	Pong Dam Lake	Himachal Pradesh	15.662
14	Ropar	Punjab	1,365
15	Sambhar Lake	Rajasthan	24,000
16	Sasthamkotta Lake	Kerala	373
17	Tosmorri	Jammu Kashmir	12,000
18	Vembana-Kol Lake	Kerala	1,51,250
19	Wular Lake	Jammu Kashmir	18,900

Wetlands of India

India has wealth of wetland ecosystems distributed in different geographical region. Most of the wetlands in India are directly or indirectly linked with major river systems, such as Ganges, Cauvery, Godavari and Tapti. India has totally 27403 wetlands of which 23444 are inland wetlands and remaining 3959 are coastal wetlands (Directory of Asian wetlands, 1989). Wetlands occupy 18.4% of the countries area (excluding river) of which 70% are under paddy cultivation. In India, it has been estimated that 4.1 million hectares are wetlands (excluding paddy fields, rivers, and streams), whereas 1.5 million hectares are natural and 2.6 million hectares are manmade. The coastal wetlands occupy 6750 sq.km and are largely determined by mangrove vegetation. In Tamil Nadu it has been estimated that 31 natural wetlands covering an area of 58,068 hectares and 20,030 manmade wetlands with an area of 2, 01,132 hectares.

Classification

The wetlands classification based on Wentz (1981), Dwyer *et al.* (1983) and Selvam (2003). Within this general definition of a wetland there are many variations. Swamps, bogs, marshes, and fens are all common types of wetlands. Marshes are generally considered to be fully inundated wetlands that contain primarily herbaceous vegetation rooted in hydric soils. Swamps, also fully inundated, are dominated by woody vegetation such as cypress or tupelo trees also rooted in hydric soils. Fens and bogs are both considered peat lands, wetlands that accumulate dry, partially decayed vegetation, or peat. Riparian wetlands adjacent and often connected to rivers, streams, and lakes are a common type of wetland that may undergo periods of drying and re-wetting as the adjacent water body levels rise and fall. These systems are not distinctly different from one another and, thus, there are many other terms (e.g., sedge meadow, pocosin, and bottom land) used to describe variations of these wetland types (Mitsch and Gosselink, 2000).

The inland wetlands, the freshwater wetland includes river system, streams, irrigation canals as well as reservoirs, lakes, ponds and marshes including rice fields, tanks, freshwater lakes, stagnant as lentic ecosystem and the running water bodies. There are 32 river system, 11 major reservoirs, 2679 canals and 38863 tanks in Tamil Nadu. The rivers of Tamil Nadu flow eastwards from the Western Ghats and are entirely reined. The perennial rivers are Cauvery, Palar, Cheyyar, Moyar, Bhavani, Amaravathi, Vaigai, Noyal, Suruli, Guhar, Vaipar, Valparai and Varshali. The 760 km long Cauvery is the longest river of the state. The total length of the rivers of Tamil Nadu is 7420 km, the area of reservoirs is 0.52 lakh ha the area of tanks and ponds are 6.92 lakh ha and 63,000 ha back waters and swamps (Venkatraman, 2005). Tamil Nadu has 31 natural wetlands covering an area of 58,068 ha and 20,030 manmade wetlands with an area of 201132 ha.

Functions and values

Wetlands are the most productive ecosystems in the world, comparable to rain forests and coral reefs. Wetland also have been called as "biological super market" because of the extensive food chain and rich biodiversity that they support and play major role in the landscape by providing unique habitats for a wide range of flora and fauna. An immense variety of species of microbes, plants, insects, amphibians, reptiles, birds, fish and mammals forms the wetland ecosystem. Physical and chemical features such as climate, landscape shape (topology), geology and the movement and abundance of water helps to determine the plants and animals in habitat of each wetland. The complex dynamic relationships among the organisms inhabiting the wetland environment are referred as food webs (Wrona, 2006). Wetlands are the essential component of the environment. The function of a wet land and the value of those functions to human society depend on a complex set of relationship between the wetland and the other ecosystems in the water shed. Water shed is a geographic area in which water, sediments and dissolved materials drain from higher elevations to a common low lying outlet or basin, a point on a larger stream, lake, underlying aquifer or estuary.

Wildlife habitat

Wetlands play an integral role in the ecology of the water shed. The combination of shallow water with high levels of the nutrients and primary productivity is ideal probe for the development of organisms that form the base of the food web and feed many species of fish, amphibians, shell fish and insects. Many species of birds and mammals rely on wetlands for food, water and shelter especially during the migration and breeding. Diverse species of mammals, plants, insects, amphibians, reptiles, birds and fish rely on wetlands for food, habitat or shelter. Wetlands are one of the most biologically productive natural ecosystems in the world, comparable to tropical rain forests or coral reefs in the number and variety of species they support. Although wetlands occupy only about 5 percent of the land area of the lower 48 states, more than one third of threatened and endangered species live only in wetlands. In addition, 20% of the country's threatened and endangered species use or inhabit wetlands at some time in their life. Some species use wetlands for their reproduction. Migrating waterfowl rely on wetlands for resting, eating and breeding areas, leading to increased populations. As noted, the appeal of wetlands and the diversity of plant and animal life, attract to contribute or support many businesses.

Water quality

Wetlands improve water quality in nearby rivers and streams and thus have considerable value as filters for future drinking water. When water enters a wetland, it slows down and moves around wetland plants. Much of the suspended sediment drops out and settles to the wetland floor. Plant roots and microorganisms on plant stems and in the soil absorb excess nutrients in the water from fertilizers, manure, leaking septic tanks and municipal sewage. While a certain level of nutrients is retained in water ecosystems and the excess nutrients can cause algal growth that's harmful to fish and other aquatic life. A wetland's natural filtration process can remove excess nutrients before water leaves a wetland, making it healthier for drinking, swimming and supporting plants and animals.

Hydrology

The hydrologic regime, or hydro period, is a major component of overall wetland ecosystem functioning. It is a wetland descriptor that is based on the fluctuation in water depth, duration, and frequency on a yearly basis (Keddy, 2000). Hydro periods among different wetlands are highly variable. In climates in which precipitation is variable from year to year such as the Midwestern U.S., hydro periods can be unpredictable and highly variable on an annual basis. In climates with reliable weather patterns, hydro periods maybe predictable and consistently respond to seasonal changes.

In other cases, hydro periods may be responsive in the short term – rising and falling in direct response to local rainfall events (e.g., riparian wetlands of the south eastern U.S.). In open wetland systems the hydro period is likely to be directly related to the duration and frequency of high flows in the connected stream or river or the amount of runoff from the adjacent landscape; thus, these open systems, especially those connected to hydrologically flashy streams or rivers, are likely to exhibit frequent changes in water levels. In these open systems, the direction and velocity of flow can be especially important, influencing the kinds and amounts of materials that are transported between the adjacent terrestrial or aquatic systems and wetlands. These inputs to open wetlands can contain nutrients, toxicants, organic material, and sediment all of which can affect the structure and function of the wetland. Likewise, the outflows from these wetlands, depending on the biogeochemical processes that occur in the wetland, can have a major impact on the receiving water body (Murphey *et al.*, 1984).

Low nutrient levels, different pH levels, and decreased organic material are all common characteristics of many natural wetland outflows. In closed systems or groundwater fed systems, the hydro period is likely to be less responsive to short, local weather events and, instead, may exhibit reliable seasonal responses based on broad annual weather patterns (Gibbs *et al.*, 1991).

Shoreline stabilization and soil erosion control

The ability of wetlands to control soil erosion is so valuable. It states that restoring wetlands in coastal areas are to buffer the storm surges from hurricanes and tropical storms. Wetlands at the margins of Lakes, Rivers, bays and the oceans protect shorelines and stream banks against erosion. Wetland plants hold the soil with their roots which absorbs the energy waves and break up the flow of stream or river currents. Many other animals and plants depend on wetlands for their survival. Estuarine fish, marine fish and shell fish, various birds and certain mammals depended on coastal wetlands for their survival. Most commercial and Game fish breed and raise their young in coastal marshes and estuaries. Migratory water fowl use coastal and inland wetlands for resting, feeding and breeding or nesting grounds for least part of the year. An international agreement to protect wet lands of international importance had been developed, because some species of migratory birds were completely dependent on certain wetlands and would become extinct if those wetlands were destroyed.

Flood control

Many wetlands are associated with the floods, plains surrounding rivers. When these rivers swell in times due to heavy rainfall or spring runoff, the wetlands store excess of water which gradually increases the level of ground water resources rather than flowing overland. Unfortunately, many flood plain and coastal areas have been developed where the wetlands no longer exist, when the ocean, lake or river level rises and the excess water in to houses, beach and farm land. In order to control river or lake levels to reduce flooding, dams and dykes are to be built. However, people are greatly realize the values of these wetlands and trying to pressure them. Many communities are attempting to restore natural wetlands to reduce damage from rising water levels. Wetlands can play a role in reducing the frequency and intensity of floods by acting as natural buffers, soaking up and storing a significant amount of flood water. Coastal wetlands serve as storm surge protectors when hurricanes or tropical storms come ashore. In the Gulf coast area, barrier islands, shoals, marshes, forested wetlands and other features of the coastal landscape can provide a significant and potentially sustainable buffer from wind wave action and storm surge generated by tropical storms and hurricanes.

Food web

Decomposition occurring in the soils of wetlands recycles dead primary and secondary producer material. Microbial respiration (both aerobic and anaerobic) mobilizes energy from organic carbon sources (e.g., plant detritus) allowing these populations to flourish in wetland soils. Microbial processes often transform chemicals into forms that are more useable by organisms at higher trophic levels. In addition to altering wetland chemical characteristics, microbes can also be directly associated with other types of organisms. Cyanobacteria, or blue-green algae, form complex mats with algae and bacteria in some wetlands and serve as integral components in some wetland food webs (Rejmankova *et al.,* 2004).

Primary production in wetlands can be highly variable depending on the amount of nutrients and sunlight available to algae, as well as other characteristics such as pH and water clarity. Wetland plants have developed various other adaptations both structural and physiological in nature that allow them to flourish in these unique environments. Common structural plant adaptations include shallow root systems, parenchyma, buttressed trunks, pneumatophores, and lenticels on the stem. These types of adaptations allow oxygen to be transported from the shoots of plant to the roots where respiration occurs (Lehman, 1980).

Additionally, mycorrhizae, fungi associated with plant root systems, provide the plant with nutrients generated through anaerobic decomposition of dead plant material and compounds less useable to plants. Secondary producers (i.e., invertebrates, fish, birds, amphibians, and mammals) are dependent and intricately linked to primary producers (Lougheed, 1998 and Angeler *et al.,* 2001).

Algae and plants can act as a food source an also provide critical habitat and nesting material for these secondary producers. Additionally, photosynthesis and respiration by primary producers affect water and soil chemical conditions (e.g., low dissolved oxygen, high pH) that influence the behaviour and survival of secondary producers (McComb and Davis, 1993 and Gabor *et al.,* 1994).

Sediment trapping and nutrient removal

Wetlands trap pollutant and sediment that might contaminate stream and reservoirs. They can prevent toxins that have been dumped on the ground from seeping into ground water. Plants are one of the important components of this function, which slows down the flow of water, allowing silt to settle and also able to absorb nutrients and toxins. These nutrients are broken down and cycled through the food web as animals consume the plants. Plants use photosynthesis to provide food for them. This process supplies oxygen to the ecosystem and the plants become food for other life forms.

In addition to their use as filters for polluted waters, wetlands are used by humans for drinking water, aquatic life use (as described in the USEPA Clean Water Act) and recreational activities such as wildlife viewing, fishing and swimming. Nutrient enrichment can negatively affect these uses through a variety of means. For example, drinking water uses can be threatened by nutrient enrichment through excess nitrate as well as proliferation of eutrophic plant and algal taxa that contribute to taste and odour problems or produce toxic compounds. Aquatic life uses are threatened by nutrient enrichment through ammonium toxicity, effects on water chemistry (e.g., dissolved oxygen), proliferation of nuisance/non-native taxa, and loss of habitat (e.g., by proliferation of plant/algal biomass). Lastly, recreation is threatened by nutrient enrichment through the loss of habitat for recreationally targeted taxa and changes in the desirability of water contact caused by proliferation of biomass and/or nuisance taxa (Lelak, 1998).

Human impact on wetlands

Human activities cause wetlands degradation by changing the water quality, quantity and flow rates by increasing the pollutant input and changing species composition as a result of disturbance and the introduction of alien species. Wetland characteristics evolve when hydrological condition causes the water table to saturate the soil for a certain amount of time each year. Any changes in hydrology can significantly alter the soil chemistry, plant and animal communities. Although wetlands are capable of absorbing pollutants from the surface water, there is a limit to their capacity to do so. The premier pollutants causing wetland degradation are sediment, fertilizer, human sewage, animal waste, road salts, pesticides and heavy metals. Wetland plants are susceptible to degradation of subjected to hydrological change and pollution inputs.

Threats to wetlands

The wild life institute of India, survey revealed that 70-80% of individual freshwater marshes and lakes in the Gangetic flood plains have been lost in the five decades. At present, only 50% of India's wetlands remain. They are disappearing at a rate of 2 to 3% every year. Indian mangrove areas have been halved almost from 700,000 hectares to 453, 000 in the year 1987 to 1995 (Sustainable Wetlands, Environmental Governance-2, 1999). A recent estimate based on remote sensing shows only 4000 sq.km area of mangrove resource in India. The loss of wetland due to the environmental and ecological problems. Which have a direct impact on the socio-economic benefits of the associated population. Serious consequences, including increased flooding, species decline, deformity or extinction and decline in water quality could result. Wetlands are also important as a genetic reservoir for various species of plants including rice, which is staple food for $3/4^{th}$ of the world's population. The Urbanization, Anthropogenic activities, Agricultural activities, Hydrological activities, Deforestation, Pollution, Stalinization, Aquaculture, Species introduction and Climate changes, all are contributed to decline in the diversity of flora and fauna, migratory birds and productivity of wetland systems. Simultaneously several thousand species have become extinct.

Management Options

- To continue natural development processes and minimize the damaging effects of man induced factors.
- Maintain the size of the wetland at least 75% of their original size.
- Prevent the deterioration of water quality and habitat characteristics
- Improve the natural quality of the lake
- Maintain and enhance the viable population of endangered species of waterfowl and other birds
- Promote awareness of site importance among local communities
- Monitor the public use of the site
- Ensure that public use does not impair the quality of the site.
- To improve and developed the socio-economic conditions of neighbouring villages through devising conservation activities.

- Plant trees in the vicinity of lakes and on all conceivable sites
- Provide substantial amount of fodder both shrubs and full grasses through range management
- Develop ecotourism in the area
- Improve the existing hygienic conditions in the neighbouring villages.
- Provide social facilities at concerned public areas.
- Monitor all important species. Evaluate and maintain conditions suitable for migratory and breeding waterfowl and other species.
- Measure the human and other disturbances.
- Manage the visitor use regarding wildlife.
- Provide strict protection to endangered bird fauna.
- Monitor the population of endangered bird fauna.
- Conduct the research on the biology and ecology of the endangered birds and all migratory birds.
- Improve the management of endangered birds.
- Start captive breeding programmes for endangered birds and other waterfowl species.
- Establish wildlife information/education centre
- Promote the research activities in relation to safeguarding the habitat and bird fauna.
- Promote the cooperation with government and non-government organizations to share their research experiences.
- Gather and record the scientific data.
- Monitor changes in the habitat and species status.

Conclusion:

Management based on accurate knowledge and increased awareness of wetland issues involving all stake holders and all components of ecosystem help in long-term sustenance involving restoration and conservation. This would enhance the function and value of the system in terms of natural and socioeconomic factors to satisfy critical resource needs of the human population. The wetland management programme generally involves the activities to protect, restore, manipulates and provide for the functions and values emphasizing both quality and acreage by advocating sustainable usage of them. Wetland management should have integrated approach in terms of planning, execution and monitoring requiring effective knowledge on a range of subjects from ecology, economics, watershed management, and planners and decision makers, etc. All this would help in understanding wetlands better and evolving a more comprehensive solution for long-term conservation and management strategies.

The proposed management would include the management of water, vegetation and the biotic factors. This would essentially involve human management. The local population will have to be taken into confidence to help in increasing the water level, through manipulation of water use, vegetative cover improvement through planting of trees and reseeding with palatable grasses and reduction of human pressure by controlling livestock grazing and eliminating illegal hunting or poaching on the waterfowl. Increased production from trees, better livestock production and creation of job opportunities on a sustained basis would help raise the income of farmers owning the lands under and around the wetlands.

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NATIONAL EDUCATION POLICY 2020: A COMPREHENSIVE ANALYSIS AND IMPLICATIONS FOR EDUCATIONAL DEVELOPMENT

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Abstract:

The National Education Policy (NEP) 2020 is a landmark document that outlines a vision for the transformation of the education system in India. This research paper provides a comprehensive analysis of the NEP 2020, exploring its key features, objectives, and implications for educational development. It examines the policy's focus on holistic and multidisciplinary education, flexibility in curriculum and pedagogy, technology integration, teacher training, and the promotion of research and innovation. Furthermore, the paper discusses the potential challenges and opportunities in implementing the NEP 2020 and its significance in shaping the future of education in India.

Keywords: NRF, NEP, Landmark document, NPE.

Introduction:

The National Education Policy (NEP) 2020 is a historic strategy that will update India's schooling for the modern era. The Union Cabinet approved it on July 29, 2020, and it seeks to provide a high-quality, accessible education that is affordable to all students. The policy prioritizes early childhood education, an interdisciplinary approach, and learning technologies. The development of creative and innovative thinking is also emphasized through the use of practical experience, analytical reasoning, and the capacity to solve problems. The strategy also places an emphasis on developing teachers' skills and empowering them to make decisions about their own classrooms. The goal of the National Education Policy (NEP) 2020 is to create a system of education that is really transformative, empowering students with the information, skills, and values they need to thrive individually and contribute to the greater good of society and the nation.

What in the old education policy?

The National Policy on Education (NPE) 1986 in India aimed to provide universal access to education for children aged 6-14 years, eradicating illiteracy and achieving high literacy levels. The policy focused on quality improvement, vocational education, teacher education, equalization of educational opportunities, promotion of Indian languages and culture, education for social and national integration, and effective planning and management. However, the NEP 2020 was implemented to meet the demands of the twenty-first century, focusing on decentralization, community participation, and accountability in education governance. The NEP 2020 aims to bring India's educational system into the 21st century, ensuring a more inclusive and harmonious society.

Why we need the National Education Policy (NEP) 2020?

The National Education Policy (NEP) 2020 aims to revitalize the Indian education system by addressing the evolving needs and challenges. Key reasons for the NEP 2020 include comprehensive reform, holistic development, equity and access, early childhood education, multidisciplinary approach, skill development, technology integration, teacher empowerment, and cultural preservation. The policy emphasizes holistic development, equity, early childhood education, multidisciplinary approach, skill development, technology integration, teacher empowerment, and cultural preservation. It aims to bridge gaps in access to quality education, promote social inclusivity, and ensure a well-rounded education for the 21st century. The NEP 2020 is crucial for preparing learners to become responsible, skilled, and well-rounded individuals capable of contributing to the nation's progress.

What are the major difference between 1986 education Policy and 2020 education policy?

The National Education Policy (NEP) 2020 introduced several significant changes and reforms compared to the previous NPE 1986. These include a focus on holistic development, early childhood care and education, a multidisciplinary approach, skill development and vocational education, technology integration, teacher empowerment and professional development, flexibility in higher education, and a strong emphasis on research and innovation. The NEP 2020 emphasizes the importance of physical, emotional, and ethical development, while the NPE 1986 focused on academic education. The NEP 2020 also promotes a multidisciplinary approach, flexibility in choice of subjects, credit-based systems, and integration of vocational education, ensuring a well-rounded education for students. The NEP 2020 also emphasizes research and innovation, fostering a culture of research and innovation in educational institutions, fostering critical thinking and problem-solving skills.

Flexibility in higher education under the NEP 2020

The National Education Policy (NEP) 2020 introduces significant reforms to promote flexibility in higher education in India. Here are some key aspects of flexibility in higher education under the NEP 2020:

1. **Multidisciplinary approach:** The NEP 2020 encourages a multidisciplinary approach in higher education, allowing students to choose courses from different disciplines and create their own unique academic pathways. It aims to break down the traditional boundaries between disciplines and promote cross-disciplinary learning.
2. **Multiple entry and exit points:** The policy allows for multiple entry and exit points in higher education. It means that students can enter and exit degree programs at different stages, acquiring certification for the credits earned during their course of study. This

provides flexibility for students who may need to take breaks or change their educational paths.

3. **Credit transfer and Academic Bank of Credits:** The NEP 2020 promotes the transfer of academic credits between institutions, enabling students to continue their education seamlessly. It also proposes the establishment of an Academic Bank of Credits, which will digitally store academic credits earned by students for future use or transfer.
4. **Choice-based Credit System:** The policy advocates for a choice-based credit system (CBCS) in higher education, wherein students have the flexibility to choose courses from a wide range of electives. The CBCS allows students to design their own curriculum based on their interests and career goals.
5. **Flexibility in curriculum design:** The NEP 2020 encourages higher education institutions to offer flexible curricula that cater to the evolving needs of learners and the job market. It emphasizes the integration of vocational education, practical training, and industry-relevant skills into the curriculum to enhance students' employability.
6. **Online and blended learning:** The NEP 2020 promotes the use of technology-enabled learning, including online and blended learning approaches. It encourages the development of digital infrastructure and the use of online platforms to deliver courses, thereby providing students with the flexibility to learn at their own pace and from any location.
7. **Lifelong learning and continuous education:** The policy recognizes the importance of lifelong learning and encourages the provision of continuous education opportunities for individuals throughout their lives. It promotes the establishment of lifelong learning centers, adult education programs, and flexible learning pathways for individuals seeking upskilling or reskilling.

These reforms aim to provide greater flexibility and choice to students in higher education, enabling them to pursue interdisciplinary studies, explore diverse subjects, and design personalized learning pathways. The emphasis on flexibility in the NEP 2020 intends to create a dynamic and inclusive higher education system that meets the needs and aspirations of learners in the 21st century.

Focus on research and innovation in the NEP 2020

The National Education Policy (NEP) 2020 places a strong emphasis on research and innovation in education, recognizing their crucial role in fostering critical thinking, problem-solving abilities, and the overall development of individuals. Here are key aspects of the NEP 2020's focus on research and innovation:

1. **Cultivating a culture of research:** The policy aims to create a culture of research and innovation across all levels of education. It emphasizes the integration of research activities into the curriculum, encouraging students to engage in research-oriented projects, and fostering a spirit of inquiry and curiosity.
2. **Research in undergraduate education:** The NEP 2020 emphasizes the inclusion of research and research-oriented learning in undergraduate programs. It encourages institutions to provide opportunities for undergraduate students to engage in research

projects, hands-on experiments, and problem-solving activities to develop their analytical and critical thinking skills.

3. **Multidisciplinary research:** The policy promotes multidisciplinary research, encouraging collaboration and knowledge-sharing among different disciplines. It aims to break down the silos between various fields of study and foster an interdisciplinary approach to research to address complex societal challenges.
4. **Innovation and entrepreneurship:** The NEP 2020 recognizes the importance of fostering innovation and entrepreneurship among students. It emphasizes the integration of innovation and entrepreneurial thinking into the curriculum, providing students with opportunities to develop their creativity, problem-solving skills, and the ability to apply knowledge in practical settings.
5. **Research infrastructure and facilities:** The policy highlights the need for the development of research infrastructure, laboratories, and facilities in educational institutions. It aims to provide state-of-the-art equipment, resources, and support systems to facilitate research activities and create an environment conducive to innovation.
6. Research Funding and Grants: The NEP 2020 emphasizes the need for increased research funding and grants to support research activities in educational institutions. It encourages collaboration with industry, government organizations, and international institutions to enhance research opportunities and attract external funding.
7. **National Research Foundation (NRF):** The policy proposes the establishment of the National Research Foundation as an apex body to promote a culture of research and innovation in India. The NRF will provide funding, support collaborative research initiatives, and facilitate the dissemination of research findings.
8. **Intellectual Property Rights (IPR) education:** The NEP 2020 stresses the importance of IPR education and awareness. It aims to integrate IPR education into the curriculum to help students understand the value of intellectual property and encourage them to protect and commercialize their innovations.

By emphasizing research and innovation, the NEP 2020 seeks to create a vibrant ecosystem that nurtures creativity, fosters scientific temper, and promotes the development of new knowledge and solutions to address societal challenges. It aims to instill a research mindset among students, educators, and institutions, contributing to the overall growth and advancement of the nation.

Conclusion:

The National Education Policy (NEP) 2020 aims to revolutionize India's educational system by focusing on interdisciplinary and cross-curricular learning, technology integration, professional development of educators, and research and innovation. The policy emphasizes holistic development, equity, early childhood education, multidisciplinary approaches, skill development, technology integration, teacher empowerment, and cultural preservation. It promotes social inclusion, high-quality education, and adaptability in higher education. The policy encourages critical thinking, problem-solving skills, and individual growth through research and innovation in the classroom. The NEP 2020 aims to improve students' creative thinking, problem-solving skills, and real-world application of learning. It also emphasizes the importance of teaching students about intellectual property rights and promoting a culture of research among youth and academic institutions.

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PHYTOREMEDIATION: HARNESSING THE POWER OF PLANTS FOR ENVIRONMENTAL CLEANUP

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Introduction:

Phytoremediation is the use of plants to clean up contaminated environments. Industrial activities, improper waste disposal, and accidental spills have led to widespread soil and water contamination, posing significant threats to ecosystems and human health. Traditional remediation methods often involve expensive and disruptive techniques (Adeoye *et al.*, 2022). In contrast, phytoremediation offers a more sustainable and environmentally friendly alternative with low negative impacts (Sharma *et al.*, 2023; Steliga and Kluk, 2020). Phytoremediation employs various techniques to remove contaminants (Table 1).

Phytoremediation offers long-term sustainability as plant systems can self-propagate and continue the cleanup process without constant human intervention. However, the effectiveness of phytoremediation depends on factors such as pollutant type, soil conditions, and plant selection. Careful site assessment and plant species choice are critical for successful implementation.
This article aims to summarize the key aspects of phytoremediation research and highlight its potential as a viable remediation strategy.

Table 1: Techniques of phytoremediation

Phytoremediation Strategy	Specific Features
Phytoextraction	Plants absorb and accumulate contaminants from the soil into their tissues. Certain plant species, known as hyperaccumulators, can accumulate high concentrations of metals and metalloids. Harvested plant biomass can be processed to recover accumulated pollutants.
Rhizofiltration	Plant roots filter contaminants from water or wastewater. Plants absorb and immobilize pollutants, purifying the water. Effective for treating wastewater from industries such as mining, agriculture, and manufacturing.
Rhizodegradation	Plant roots release enzymes and substances that break down organic pollutants in the soil. Provides degradation and transformation of contaminants. Especially effective for organic pollutants

Phytovolatilization	Plants uptake contaminants and release them into the atmosphere through transpiration. Contaminants are transformed and released into the air. Particularly effective for volatile organic compounds
Phytostabilization	Plants reduce the mobility and bioavailability of contaminants in the soil. Roots and plant biomass bind with pollutants, preventing their movement. Suitable for areas with low to moderate levels of contamination
Phytodegradation	Plants directly degrade or metabolize contaminants through enzymatic activity. Organic pollutants are broken down by plants' metabolic processes. Particularly effective for complex organic compounds
Phytostimulation	Plants release substances that stimulate microbial activity in the soil. Enhanced microbial degradation of contaminants in the presence of plants. Synergistic effect between plants and microorganisms for remediation
Phytomining	Plants absorb and accumulate economically valuable metals in their tissues. Harvested plant biomass can be processed to recover valuable metals. Offers potential for both environmental cleanup and resource recovery

Advances in genetic engineering and plant-microbe interactions:

Genetic engineering

- Genetic engineering techniques enhance plants' pollutant uptake by increasing transporter protein expression.
- Plants can be genetically modified to withstand higher pollutant concentrations, improving their tolerance in contaminated areas.
- Genetic engineering introduces or enhances enzymes involved in pollutant degradation pathways, accelerating the breakdown of complex contaminants (Sharma *et al.* 2022).

Plant-microbe interactions

- Beneficial microbial partnerships aid in pollutant degradation, nutrient acquisition, and stress tolerance.
- Manipulating plant-microbe interactions through genetic engineering or microbial inoculation improves phytoremediation effectiveness.
- Rhizosphere engineering optimizes the microbial community in the soil influenced by plant roots, promoting synergistic interactions for contaminant degradation and plant health.

Limitations of phytoremediation

1. Limited contaminant applicability.
2. Slow remediation process.
3. Depth restrictions for treatment.
4. Plant selection and maintenance challenges.

5. Lack of standardized guidelines.

Future perspectives of phytoremediation:

In the future, phytoremediation holds promise through genetic engineering, nano-enabled techniques, plant-microbe interactions, integration with other methods, and field-scale applications to enhance its effectiveness in environmental cleanup and address a wider range of contaminants.

Conclusion:

Phytoremediation offers a promising and sustainable solution for environmental cleanup. By harnessing the unique capabilities of plants and their interactions with microorganisms, we can mitigate the impact of contaminants on ecosystems and human health. Continued research and technological advancements will further enhance the efficiency and applicability of phytoremediation, enabling its widespread adoption as a reliable remediation strategy.

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PLANT BASED BIOFUELS - A SUSTAINABLE AND ECO-FRIENDLY APPROACH TO PETROLEUM PRODUCTS DEPENDENCY

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Abstract:

Biofuel, any fuel that has made out from biomass — that is, plant, algae, material, animal waste, crops or by-product acquired from Industrial processing of farming or food products. Since analogous feedstock material can be replaced readily, biofuel is a source of renewable energy, unlike fossil energies such as petroleum, coal, and natural gas. Biofuel is generally supported as a cost-effective and environmentally benign volition to petroleum and other re-creationary fuels, particularly within the environment of rising petroleum prices and increased concern over the benefactions made by fossil energies to increased carbon emissions, plant-based biofuels offer advantages such as, readily renewable, cheaper, less inflammable and having higher lubrication properties. According to the International Energy Agency's (IEA's) report on renewable energy, world biofuel production is forecasted to increase by approximately 16% to more than by 2023. Present article focuses on plant-based biofuels and their role as frontiers for change in energy source will bring a competitive advantage to the use of alternative fuels soon with accomplishment of Sustainable Environmental goals.

Keywords: Plant based Biofuels, Fossil energies, IEA, renewable energy, Sustainable environmental goals.

Introduction:

Demand for oil and gas is in huge demand and account for oil reserves continue to rise exponentially as conventional source for energy. Petroleum oil resources are estimated to be deficient to meet global energy needs With significant rise of petroleum prices since it is a finite source, combustion of petroleum increases atmospheric CO_2 level, traces for sulphur are released in atmosphere, refining demands tedious procedures and cost, also elicit acid rain With the growing demand and limited renewable energy resources there is increased demand for sustainable, eco-friendly, renewable and relatively cost-effective alternate energy fuels.

Biofuels are any liquid fuel obtained from biological material eg-trees, grass, agricultural waste, Animal waste, Fruit waste, Industrial waste, Land fill gas, crop residues. Biofuels (biodiesel, bioethanol, and biogas) on the other hand can be manufactured from variety of materials like plants, animals and animal wastes. Biofuels obtained from plant resources have gained increased attention for environmental researchers due to advantages offered by them viz include, low maintenance cost, renewable, environmentally benign, carbon neutrality, therefore plant-based biofuels such as are the alternative energy source since they are readily available and can be conveniently converted to biofuels. With the technological advancements, the global market for Plant based biofuels continues to rise and can be considered as a new paradigm to meet the needs of rising population of the country (1, 2).

Types of biofuels

Biofuels can be distinguished into two types viz, based on-

a) Sources of Biofuels

b) Generations of biofuels.

The following chart summarises the types of biofuels.

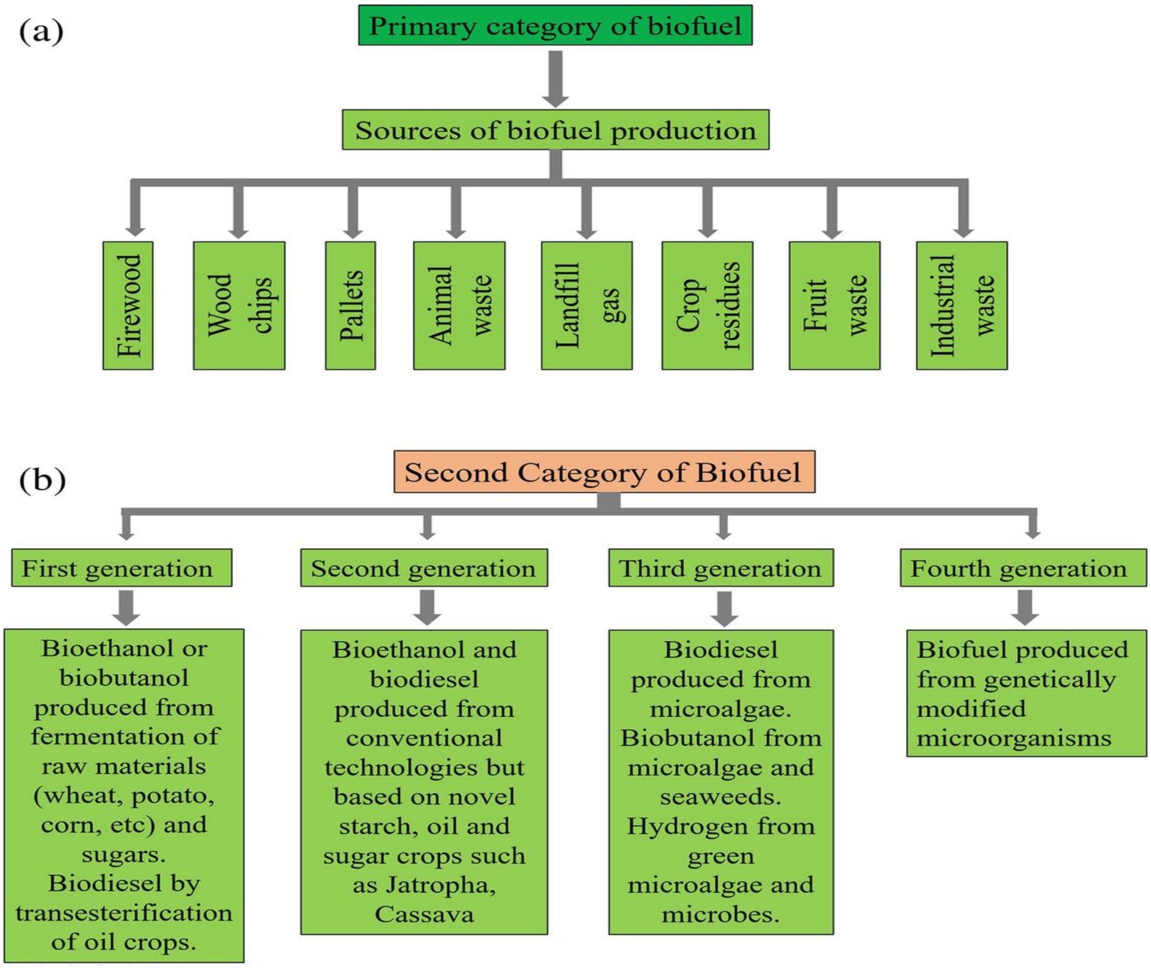

Figure 1: Types of biofuels

Typical forms of biofuels manufactured include bioethanol, biodiesel, biogas, which are known as first generation biofuels. Second generation Biofuels include cellulosic biofuel, Biomethanol and Biohydrogen. Third generation Biofuels include those produced by Macroalgae and microalgae. Fourth generation biofuels include algae which is genetically altered to improve biofuels manufacturing.

Figure 2: Generations of biofuels

Generations of biofuels

First generation biofuels (FGB)

They are also known as Conventional Biofuels. First generation biofuels are produced from crops such as, Corn, sugarcane, potatoes, karanja oil, coconut oil, soyabean oil etc. Examples of biofuels manufactured from food crops include biogas, bioethanol, biobutanol and biodiesel. They are generated by the process of fermentation and trans esterification and distillation. Since they are manufactured from food crops therefore likely to raise the prices of crops. Animal feeds are not available at cheaper rate hence production cost is increased and also compete with availability of food crops. Availability of land for production of food crops, water resources are limited. They contribute to Greenhouse emissions (GHG). they effect ecosystem and Biodiversity (5, 6).

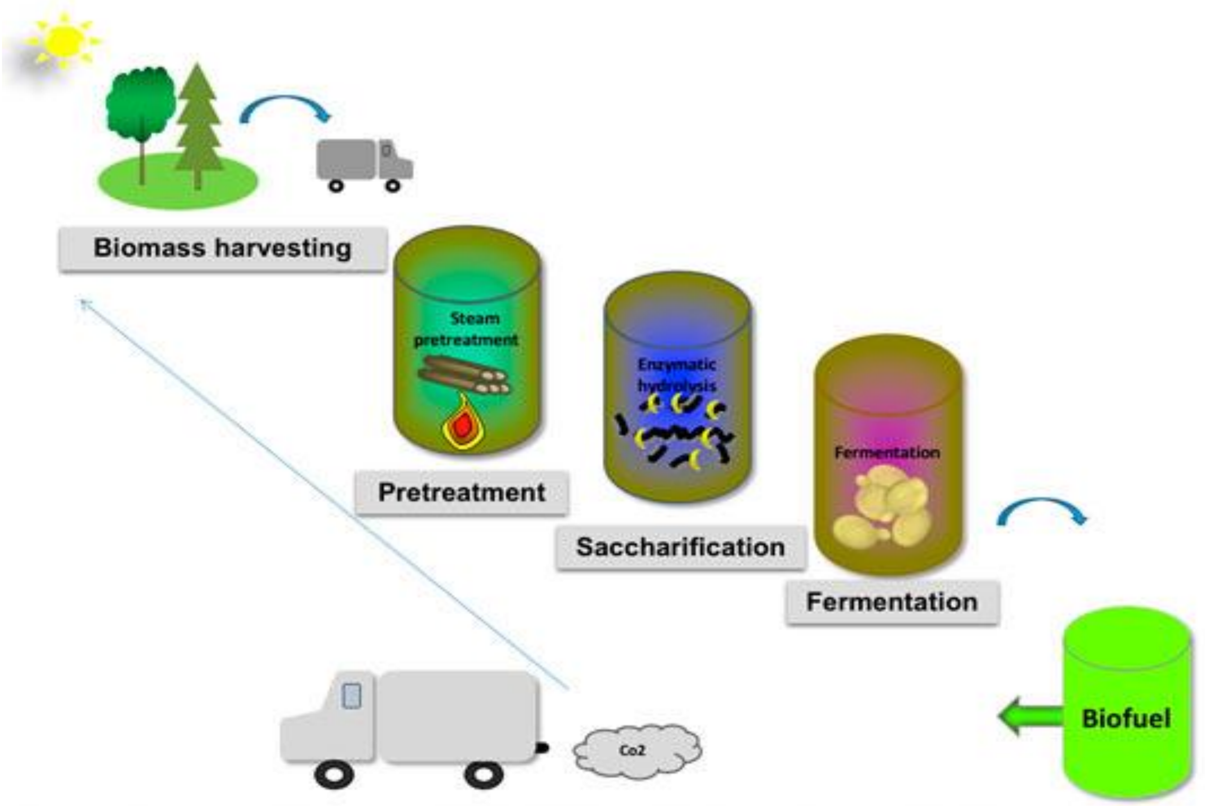

Figure 3: Production of first-generation iofuels

Second generation biofuels (SGB)/ Advanced biofuels

They are also known as Cellulosic Biofuels since they are manufactured from biomass containing cellulose and lignocellulose. Second generation biofuels utilize cellulosic biomass such as corn cubs, miscanthus, wheat straw, sugar crops for example jatropha, casava novel starch, oil, wastes, forest residues, green wastes alike parts of plants viz include, stems leaves, stalks, grass, waste generated from forests residues, farm debris which are rich in lignocellulosic content (7). SGB need pre-treatments such as enzymatic hydrolysis, and are produced by the process of fermentation, gasification, and pyrolysis. Other biomass applied for production of

SGB include, fibre wastes, fruit wastes (8). They are made from non-edible crops and oil so do not compete with availability of food resources unlike FGB. They contribute to low carbon house emissions as compared to FGB. Roland Arthur Lee and *etal* reported two processes of producing by "thermo"/thermochemical or "bio" /biochemical pathways (11). In thermochemical approach/gasification feedstock such as agricultural straw, forest residue yields syngas which is a mixture of carbon monoxide, hydrogen and hydrocarbons. Both hydrogen and hydrocarbons can be used as biofuels. Gas oil can be manufactured Hydrocarbons. In Biochemical approach fast growing crops are subjected to enzyme hydrolysis or acid hydrolysis to yield sugars which on fermentation give ethanol which can be mixed with gasoline. Fermentation yields ethanol, butanol, Biomethane and Biohydrogen Pyrolysis yields biooil, Pyrogas and char. Advantages- They utilize non-food feedstock therefore food Vs Fuel competition is not seen as compared to FGB, yields are higher, more eco-friendly as GHE is less, need less land to grow as they utilise fast growing crops and also use feedstock as animal, municipal wastes Disadvantages include viz, soil fertility is affected, difficult to commercialize since production cost is relatively high, not applicable for synthesis of biodiesel, not reliable for switch grass to harvest several times a year, generate low sulphur content (12).

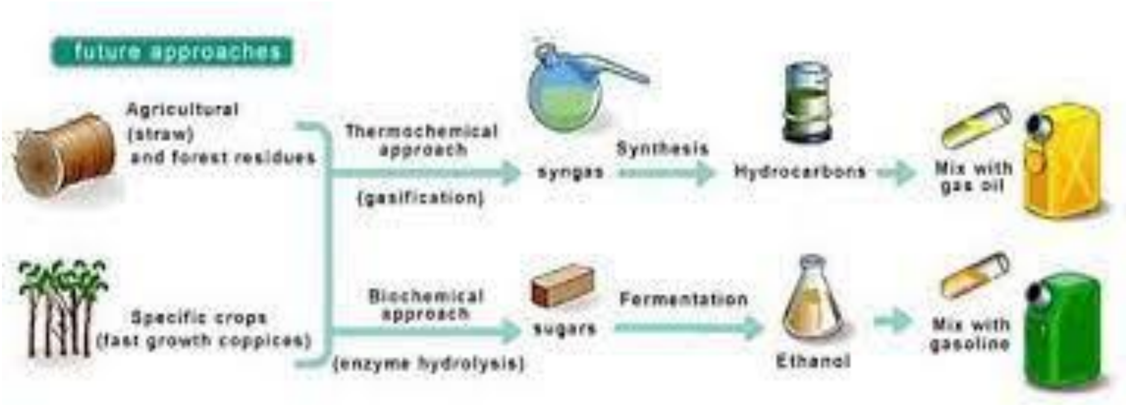

Figure 4: Production of second-generation biofuels

Third generation biofuels (TGB) / Algae biofuels

These are considered to be most promising biofuels since they utilize aquatic inedible microorganisms such as algae-microalgae, macroalgae biomass for biofuel production. Biofuels produced from algal biomass are Bioethanol, biodiesel, Biohydrogen, bio-oil, Biomethane, Biochar, Bio syngas, vegetable oil, jet oil etc. Algae biomass is subjected to various pre-treatments like chemical, Physical, enzymatic and ionic liquids. They are produced by fermentation and Trans-esterification. Various process required for algal biomass include culturing in open ponds, closed loop systema and Photobioreactors Algae are autrophs that can grow in ponds, lakes oceans river water, saline water and waste water. According to size they can be classified as Microalgae (Cyanobacteria) and Macroalgae (seaweed) (13). Basic differentiation between microalgae and Macroalgae is Microalgae is unicellular, prokaryotic and eukaryotic, small in size whereas Macroalgae is multicellular and large in size. Advantages of TGB are, they are fast growing, eco-friendly, absorb CO_2 from atmosphere, can be directly linked to powerplants and Industry., can be grown from waste water, saline water, non-arable land, hence vital need of fresh water is minimized thus enhancing the availability of water resources. Mitigate Greenhouse emissions (GHE), microalgae are high in lipid content therefore they offer high scope for production of Lipid based Biofuels. (13,14). They offer higher yield (30%) from low quantity of biomass. (15) Petroleum dependency is minimised since production rate from algal oil is high, and versatile i.e., various species can be used as biomass. Disadvantages of TGB include (16,17,18), high cost for land, for harvesting of algal biomass higher energy is required. Nutrients such inorganic compounds alike CO_2, Solar energy, salts and organic compounds are necessary for Algal Biomass.

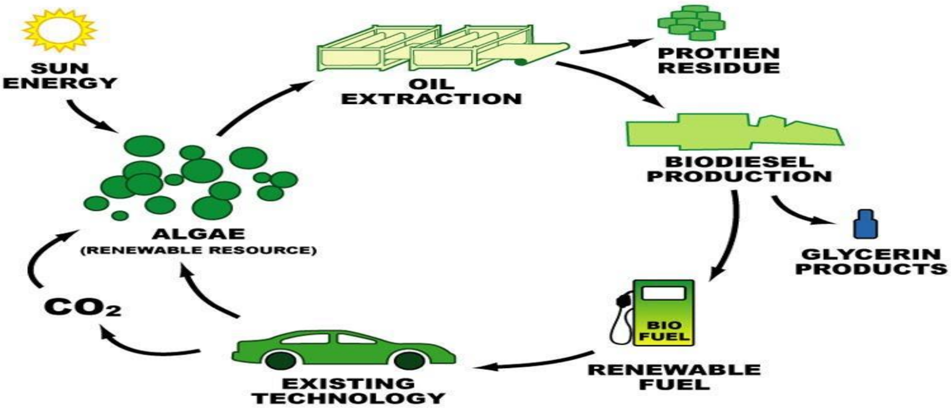

Figure 5: Production of third-generation biofuels

Fourth generation biofuels (FOGB)

Fourth generation biofuels utilize genetically modified micro-organisms such as, microalgae, yeast, cyanobacteria as feedstock and use CO_2 trapping, storing and sequestering it for efficient generation of biofuels. Carbon is captured and locked in biomass then it is sequestered form depleted oil or gases, un-mineable coal seams and saline aquafiers, thus eventually generating biofuels with neutral CO_2 emissions (19). Since agal metabolism is altered by applying genetic engineering less steps are required to generate biofuels and production rate is enhanced. The genetically engineered algae have an advantage that they possess high oil content thereby affording higher yield from non-arable land. They are prepared by pyrolysis, gasification and digestion fermentation, anaerobic digestion, Torrefaction etc. Bio-oils, Methane, Solid Fuels, Biohydrogen, biomethane, Biodiesel and synthetic biofuels are obtained from FOGB which can be used in transportation and generating electricity. Advantages of FOGB include (18), ultra-clean carbon negative clean fuel, most eco-friendly since no CO_2 emmision cheap, high yield reduced Green House emissions. Disadvantages include scarcity of Biomass since not all the species can be exploited for genetic modification also genome availability is of concern, also not possible to commercialise on large scale, Solar energy used as energy source is limited to day time also carbon and nitrogen sources are required in large amount, harvesting methods are not cheap and require initial high investments. Guidelines for Marine cultivation needs to be exploited. B. Abdullah, *et al.* reported following species of Properties of the most widely used microalgae in algal biofuel production (19).

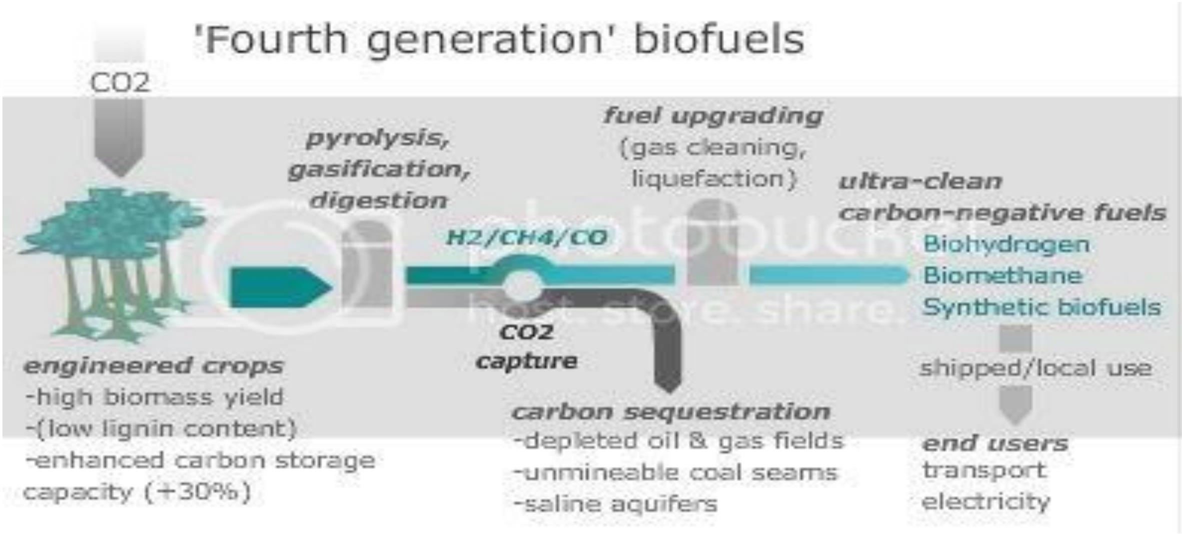

Figure 6: Fourth generation biofuels

Table 1: Biomass (Microalgae – employed for biofuel production)

Properties of the most widely used microalgae in algal biofuel production

Class	Microalgae strain	Lipids (%)	Proteins (%)	Carbohydrates (%)
Eustigmatophyceae				
	Chlorella vulgaris	41–58	51–58	12–17
	Chlorella sorokiniana	22–24	40.5	26.8
	Chlorella pyrenoidosa	2	57	26
	Chlorella protothecoides	40–60	10–28	11–15
	Chlorella minutissima	14–57	47.89	8.06
Chlorophyceae				
	Botryococcus braunii	25	–	–
	Scenedesmus obliquus	30–50	10–45	20–40
	Dunaliella tertiolecta	11–16	20–29	12.2–14
	Dunaliella salina	6–25	57	32
	Scenedesmus dimorphus	16–40	8–18	21–52
	Tetraselmis suecica	15–23	–	–
	Haematococcus pluvialis	25	–	–
	Scenedesmus quadricauda	1.9	40–47	12
Bacillariophyceae				
	Phaeodactylum tricornutum	18–57	30	8.4
	Thalassiosira pseudonana	20	–	–
Cyanophyceae				
	Spirulina platensis	4–9	46–63	8–14

Current scenario and future prospectives:

Production of Biofuels was highest reported by US, followed by Brazil and Indonesia. Global biofuels production has increased 9-fold times from 2000-2020. Greater use of renewable form of energy, use of electric cars would be a fair option to reduce dependency on petroleum products and reduce carbon footprints for sustainable ecosystem (21). Greenhouse emissions not only affect environment but also humanhealth, CO_2 released fossil fuel combustion, coal and crude oil for transportation sector, methane released from natural gas systems, landfills and agriculture nitrous oxide released from cars, agricultural soil emitted during combustion of fossil fuels and solid waste. Hydrofluorocarbons released from semiconductor manufacturing, Perfluorocarbons released from aluminium production and variety of industrial processes contribute towards climate change and global warming, depletion of ozone layer, smog and air pollution and acidification of water bodies are the current problems of environmental concern. Switching to biofuels and use of electric cars is a promising alternative reduce carbon footprints and for clean energy production. (22, 23)

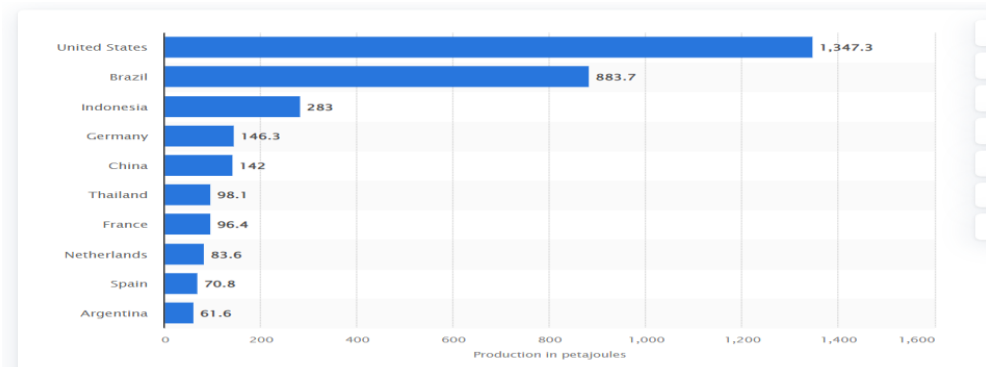

Figure 7: Giant players in biofuels production market reported in 2022 (Source-https://www.statista.com/statistics/274168/biofuel-production-in-leading-countries-in-oil-equivalent/ last accessed on 21-11-2021)

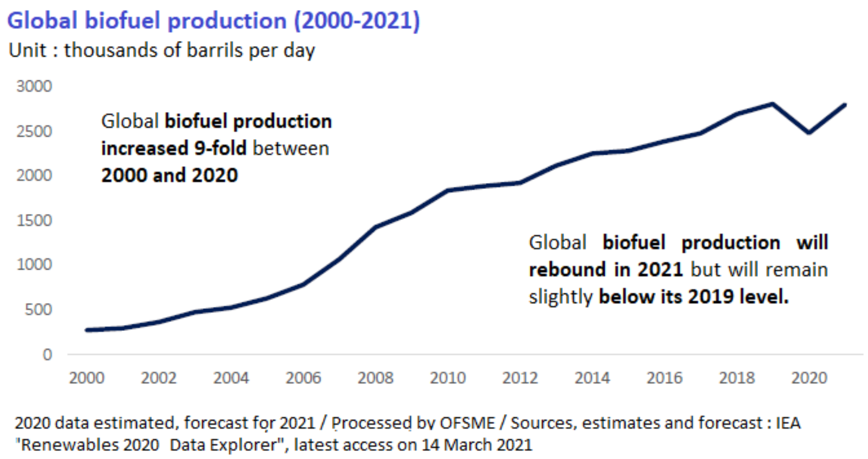

Figure 8: Global biofuel production graph
(Source: Global energy and CO_2 data)

The graph indicates the massive growth in global biofuel production from 2000 to 2020, however biofuel production was severely affected due to COVID-19 Pandemic and due to lockdowns-imposed biofuel market etched and resulted in decreased demand for transportation, also prices of feedstock suffered massive hit in 2020 due to ruptured economy, but in 2021 researchers forecasted the growth by 13% since oil demands are on hike and will continue to remain. The subsequent advantage offered by the pandemic was low Green House Emissions (GHG).

Sustainability of biofuels

Role of biofuels in sustainable environment apprehend towards Sustainable environmental goals in terms social, economic, ecological and environmental concern. these goals are achieved in terms of economic sustainability since they can be cost -effective, energy secured and self-sufficient. In terms of Environmental sustainability parameters assessed they reduce carbon emissions, changes in air, water and soil quality and biodiversity changes. Social sustainability can be assessed by economic indicators, and also by framing regulations, implementing strategies for economical biofuels production. The sustainability index for sustainable biofuel production for assessed and was reported by Silva *et al*. (2011). Standards and certification for specific emissions, certification relating to food and ecosystem preservation. India is stepping towards "Net Zero emission" by 2070. The Panchamitra policy was declared at the 26COP by Government of India which include generating energy from non-fossil source,to meet half if its energy requirement from renewable energy sources, to reduce carbon emission by 1 Billion tonnes, to decrease carbon intensity achieve it to 45% and go-green and cleaner future by net zero emission (24, 25).

Conclusion:

Continuous rise in price of petroleum products is of concern as for fuels, fossil fuels are depleting and energy experts have forecasted there would be continuous rise in price of crude oil which would cause eventual rise in prices of Petroleum and Diesel, over past month have raised by 14% in India. Also, investments on oil sector are decreased since Government is in favour of promoting renewable, commercially viable, economic, sustainable and carbon negative biofuels for green ecosystem. Biofuels offer all these advantages and possess higher lubrication properties hence can be a durable for transport system and can be used as additives in petroleum products. Hence it can be concluded that Biofuels are new paradigm as an alternative fuel in future.

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THE FUTURE OF DIGITALIZATION AND SUSTAINABLE DEVELOPMENT

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Abstract:

The future of digitalization and sustainable development holds immense potential for transforming various sectors and addressing global challenges. The future will witness increased integration of digital technologies such as AI, IoT, blockchain, and big data analytics across industries. This integration will enable more efficient resource management, data-driven decision-making, and automation for sustainable development. Digitalization will play a pivotal role in accelerating the global transition to renewable energy sources. Smart grids, advanced energy storage systems, and decentralized energy generation will enable greater efficiency, reliability, and resilience in the energy sector while reducing carbon emissions. The growth of smart cities will be driven by digital technologies, enabling the development of sustainable and livable urban environments. Smart infrastructure, intelligent transportation systems, and optimized resource management will enhance energy efficiency, waste management, and quality of life in cities. Digitalization will facilitate the transition towards a circular economy, where resources are conserved, reused, and recycled. Advanced data analytics, IoT-enabled tracking systems, and blockchain technology will enable transparent supply chains, resource optimization, and waste reduction. Digital technologies will revolutionize agriculture practices, enhancing productivity while minimizing environmental impact. Precision farming techniques, remote sensing, AI-based crop monitoring, and data-driven decision support systems will improve resource efficiency, crop yields, and food security. Ensuring digital inclusion for all is essential for sustainable development. Efforts to bridge the digital divide, promote digital literacy, and provide equal access to digital technologies and services will empower communities, foster innovation, and drive socio-economic growth. As digitalization expands, it is crucial to prioritize ethics, privacy, and security. Policies and regulations need to address data privacy, cybersecurity risks, algorithmic biases, and the ethical use of AI to ensure a fair and sustainable digital future. Achieving sustainable development in the digital era requires collaboration among stakeholders. Public-private partnerships, cross-sectoral collaborations, and international cooperation will foster innovation, knowledge-sharing, and collective action toward common sustainability goals. The digital transformation will create new job opportunities and demand a workforce equipped with digital skills. Investments in reskilling and upskilling programs will be crucial to prepare individuals for the future of work and ensure an inclusive digital society. Digitalization should align with and contribute to the achievement of the United Nations' Sustainable Development Goals (SDGs). By leveraging digital technologies, progress can be made in areas such as climate action, clean energy, responsible consumption, and affordable and clean technologies. The future of digitalization and sustainable development is dynamic and continually evolving. Embracing

digital technologies and ensuring their responsible and inclusive deployment will be instrumental in driving the transition to a sustainable and prosperous future Schneider S. (2019).

Keywords: Digitalization; sustainable development; goals; Challenges, Need

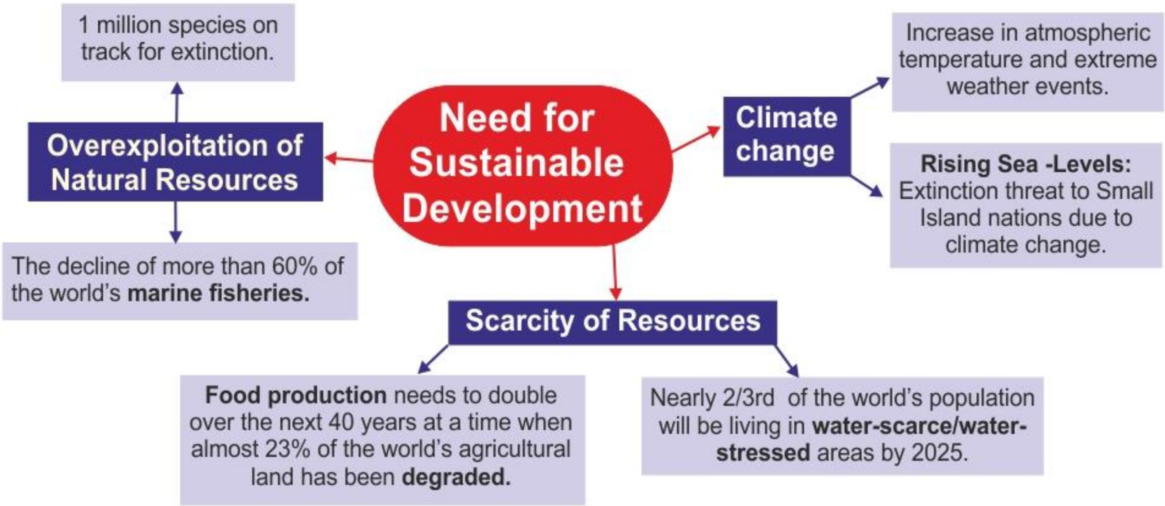
Sustainable development

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This most widely accepted definition of Sustainable Development was given by the Brundtland Commission in its report Our Common Future (1987) Sustainable development (SD) calls for concerted efforts toward building an inclusive, sustainable, and resilient future for people and the planet.

Need for sustainable development

Sustainable development is essential for the long-term well-being of both present and future generations. It recognizes that economic growth, social progress, and environmental protection are interconnected and should be pursued together to achieve a balanced and harmonious society. Sustainable development aims to preserve and protect the natural environment, including ecosystems, biodiversity, and natural resources. It promotes responsible resource management, reducing pollution and waste, and mitigating the impacts of climate change. By taking care of the environment, we ensure its sustainability for future generations. Sustainable development promotes social inclusivity and equitable access to resources, opportunities, and services. It emphasizes reducing poverty, improving education and healthcare, and fostering social justice. It seeks to address inequality, ensuring that all individuals have the chance to live fulfilling lives and participate in decision-making processes. Sustainable development recognizes the need for a robust and resilient economy that can meet the needs of the present without compromising the ability of future generations to meet their own needs. It encourages responsible business practices, innovation, and investment in sustainable industries. By transitioning to a green economy, we can create new jobs, enhance productivity, and ensure long-term economic stability.

Sustainable development acknowledges the urgent need to address climate change. It involves reducing greenhouse gas emissions, transitioning to renewable energy sources, and implementing adaptation measures to cope with the impacts of climate change. By taking proactive steps to combat climate change, we can protect ecosystems, prevent extreme weather events, and ensure the well-being of communities worldwide. Sustainable development recognizes our responsibility to future generations. It urges us to consider the long-term consequences of our actions and make decisions that promote sustainability and resilience. By adopting sustainable practices today, we can pass on a healthier, more equitable world to future generations. Achieving sustainable development requires international collaboration and partnerships. It emphasizes the importance of working together across borders to address global challenges such as poverty, hunger, and environmental degradation. By fostering cooperation, sharing knowledge, and mobilizing resources, we can accelerate progress toward a sustainable future. In summary, sustainable development is crucial for creating a world that balances environmental protection, social equity, and economic stability. It offers a holistic approach to addressing the pressing issues we face today and lays the foundation for a prosperous and resilient future.



Core elements of sustainable development

The core elements of sustainable development encompass three interconnected pillars: environmental, social, and economic. These pillars are often referred to as the triple bottom line including land, water, forests, minerals, and biodiversity. It aims to reduce pollution and waste generation, promote sustainable consumption and production patterns, and minimize the environmental impact of human activities. Sustainable development addresses the causes and impacts of climate change through efforts to reduce greenhouse gas emissions, promote renewable energy, and enhance energy efficiency. It recognizes the importance of maintaining healthy ecosystems, preserving biodiversity, and restoring degraded areas to ensure the long-term functioning and resilience of ecosystems. Sustainable development seeks to eradicate poverty by ensuring equitable access to resources, opportunities, and basic services such as education, healthcare, and clean water. It aims to create inclusive societies by addressing inequality, promoting social justice, and ensuring that marginalized groups and vulnerable populations have equal rights and opportunities. Sustainable development promotes gender equality and empowerment, ensuring that women and girls have equal access to education, healthcare, employment, and decision-making processes. It focuses on improving healthcare systems, promoting healthy lifestyles, and providing access to quality healthcare services for all individuals (Xu *et al.*, 2022)

Sustainable development emphasizes the need for economic growth that is environmentally sustainable, socially inclusive and respects ethical business practices. It promotes efficient use of resources, reduces waste generation, and optimizes production processes to minimize environmental impact. Sustainable development encourages research, development, and adoption of innovative technologies that support sustainable practices and enhance productivity. It calls for businesses to adopt responsible and ethical practices, including corporate social responsibility, fair trade, and adherence to labor and human rights standards. It's important to note that these elements are interconnected and mutually reinforcing. Sustainable development recognizes that addressing environmental challenges, promoting social well-being, and achieving economic prosperity are all essential for a sustainable and thriving future.

Global issues related to sustainable development

Several global issues are closely related to sustainable development. These issues pose significant challenges to achieving sustainability and require international cooperation and collective action. Climate change is one of the most pressing global challenges. It poses significant risks to ecosystems, communities, and economies worldwide. Addressing climate change involves reducing greenhouse gas emissions, transitioning to renewable energy sources, and implementing adaptation measures to mitigate its impacts. The loss of biodiversity threatens the functioning of ecosystems and the services they provide. Habitat destruction, pollution, climate change, and unsustainable exploitation of natural resources contribute to biodiversity loss. Preserving biodiversity is crucial for maintaining ecosystem resilience and long-term sustainability. Poverty and inequality remain pervasive global issues. Sustainable development aims to eradicate poverty, reduce inequality, and ensure access to basic services, education, and healthcare for all individuals. Bridging the poverty gap and promoting inclusive growth is fundamental to achieving sustainability. Many regions face water scarcity, with a growing population and increasing water demands exacerbating the problem. Sustainable development entails efficient water management, promoting water conservation, and ensuring equitable access to clean water and sanitation services.

Transitioning to a sustainable energy system is vital for reducing greenhouse gas emissions and mitigating climate change. Promoting renewable energy sources, improving energy efficiency, and enhancing access to clean and affordable energy are crucial elements of sustainable development. Rapid urbanization poses significant challenges to sustainability. Creating sustainable cities involves promoting compact and efficient urban development, improving public transportation, ensuring access to affordable housing, and enhancing urban resilience to climate change. Ensuring global food security while minimizing environmental impact is a critical challenge. Sustainable agriculture practices, reducing food waste, promoting resilient farming systems, and enhancing smallholder farmers' livelihoods are essential for achieving sustainable food production and distribution. Unsustainable consumption and production patterns deplete natural resources, contribute to pollution, and exacerbate climate change. Shifting toward sustainable consumption and production involves promoting circular economy approaches, reducing waste, and adopting sustainable lifestyles and consumption patterns (Salvia *et al.*, 2019).

Health challenges, such as pandemics, diseases, and inadequate healthcare systems, affect sustainable development. Strengthening healthcare infrastructure, ensuring universal health coverage, and addressing emerging health risks is crucial for sustainable development. Peace, security, and justice are fundamental prerequisites for sustainable development. Reducing conflicts, promoting inclusive governance, upholding human rights, and ensuring access to justice and the rule of law contributes to a sustainable and peaceful world. These global issues highlight the interconnectedness and complexity of sustainable development. Addressing them requires coordinated efforts, partnerships, and the integration of social, economic, and environmental considerations into policies and actions at global, national, and local levels.

Sustainable development goals

The Sustainable Development Goals (SDGs) are a set of 17 global goals established by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development. These goals serve as a blueprint for addressing the world's most pressing social, economic, and environmental challenges, aiming to achieve a more sustainable and equitable future. The 17 SDGs encompass a broad range of interconnected issues.

Here is an overview of the Sustainable Development Goals (Jones *et al.*, 2017).

Challenges of sustainable development

Sustainable development faces several challenges that hinder progress and the achievement of the Sustainable Development Goals (SDGs). These challenges arise from complex and interrelated factors. Poverty and inequality persist as significant challenges worldwide. Addressing poverty and reducing inequality requires comprehensive strategies that encompass access to basic services, inclusive economic growth, social protection, and empowerment of marginalized populations. Climate change poses a grave threat to sustainable development. Rising greenhouse gas emissions, deforestation, pollution, and loss of biodiversity contribute to environmental degradation. Mitigating climate change, adapting to its impacts, and promoting sustainable environmental practices are critical challenges (George *et al.*, 2020).

Meeting the growing demands for resources, energy, and food in a sustainable manner is a challenge. The overexploitation of natural resources, unsustainable production and consumption patterns, and waste generation strain ecosystems and contribute to environmental degradation. Shifting towards sustainable resource management and promoting circular economy practices are crucial for addressing these challenges. Ensuring universal access to quality education and healthcare remains a challenge, particularly in developing countries. Barriers such as inadequate infrastructure, limited funding, gender disparities, and social inequalities hinder progress in achieving these fundamental goals.

Sustainable development requires strong political will and effective governance at all levels. Challenges include corruption, lack of transparency, weak institutions, and limited capacity for policy implementation. Strengthening governance mechanisms, promoting participatory decision-making processes, and fostering accountability are necessary for overcoming these challenges.

Mobilizing adequate financial resources for sustainable development is a significant challenge. Insufficient investment, limited access to capital, and a lack of innovative financing mechanisms hinder progress in implementing sustainable projects and initiatives. Bridging the financing gap and attracting investments that align with sustainable development objectives is essential. Balancing economic growth, social progress, and environmental protection can be challenging due to competing priorities and trade-offs. Decision-making processes often involve complex trade-offs between short-term gains and long-term sustainability. Achieving consensus and striking a balance among different objectives is crucial for sustainable development.

Insufficient data availability, especially in developing countries, limits the ability to track indicators, measure impacts, and make informed policy decisions. Improving data collection, monitoring systems, and capacity-building efforts are necessary to address these challenges. Sustainable development requires global cooperation and collaboration, yet implementation gaps persist. Unequal distribution of responsibilities, limited international cooperation, and fragmented approaches hinder progress. Strengthening international partnerships, fostering knowledge sharing, and ensuring effective implementation of commitments are critical for addressing this challenge. Addressing these challenges requires a comprehensive and integrated approach, with coordinated efforts from governments, civil society, businesses, and international organizations. It calls for innovative solutions, transformative policies, and collective action to ensure sustainable development for present and future generations.

Progress of sustainable development

Tracking the progress of sustainable development is essential to assess the implementation of the Sustainable Development Goals (SDGs) and identify areas that require further attention and action. Voluntary National Reviews (VNRs): Member states of the United Nations present Voluntary National Reviews during the annual High-Level Political Forum on Sustainable Development. VNRs provide a comprehensive assessment of a country's progress in implementing the SDGs, including successes, challenges, and lessons learned. The United Nations developed a set of indicators to measure progress toward each of the SDGs. These indicators provide quantitative and qualitative data to track advancements in specific areas of sustainable development, allowing for comparison across countries and regions. The Sustainable Development Report, formerly known as the Global SDG Index, provides an annual assessment of countries' performance on the SDGs. It ranks countries based on their progress towards achieving the goals, highlighting areas of strength and areas that require improvement.

Governments, international organizations, and other stakeholders collect and report data on various indicators related to the SDGs. This data collection process helps monitor progress, identify trends, and inform policy decisions. Efforts are being made to improve data availability, quality, and disaggregation to ensure accurate and inclusive monitoring. Regional organizations and local authorities often conduct assessments to track sustainable development progress at the regional or subnational level. These assessments provide a more localized perspective and help identify regional disparities and challenges. Civil society organizations, academia, businesses, and other stakeholders play a crucial role in monitoring and reporting progress on sustainable development. They contribute through research, data analysis, and advocacy, holding governments accountable and ensuring that progress is tracked comprehensively (Hellemans *et al.*, 2021).

International cooperation and knowledge sharing play a vital role in monitoring progress. Collaboration between countries, organizations, and stakeholders allows for sharing best practices, exchanging experiences, and learning from each other's successes and challenges. While progress has been made since the adoption of the SDGs in 2015, significant challenges remain, and progress is uneven across countries and goals. Efforts to monitor progress and address gaps and obstacles are ongoing to ensure that sustainable development remains a priority and that action is taken to achieve the goals by 2030.

Digital development

Digital development refers to the use and application of digital technologies to foster social, economic, and human development. It encompasses the use of digital tools, infrastructure, and services to address development challenges and create opportunities for individuals, communities, and nations. Digital development relies on robust and accessible digital infrastructure, including broadband networks, internet connectivity, and telecommunications infrastructure. Building and expanding digital infrastructure is crucial for enabling digital access, communication, and the delivery of digital services.

Digital development aims to ensure that all individuals and communities have equal opportunities to access and benefit from digital technologies. It involves bridging the digital divide by providing affordable and reliable internet access, digital literacy training, and access to digital devices. Promoting digital inclusion helps reduce inequalities and empower marginalized groups. Digital development includes the digitalization of government services and the adoption of e-government practices. Digital platforms and services can improve the efficiency, transparency, and accessibility of public services, such as online portals for citizen engagement, digital identity systems, and electronic payment systems. Digital development recognizes the importance of digital education and skills development. It involves integrating digital literacy and technology skills into formal education systems and providing training opportunities to enhance digital competencies for individuals, workers, and entrepreneurs. Digital skills are crucial for accessing employment, participating in the digital economy, and fostering innovation.

Digital technologies provide opportunities for entrepreneurship and innovation, particularly in emerging economies. Digital development focuses on creating an enabling environment for digital entrepreneurship, supporting startups and small businesses, promoting digital innovation hubs, and fostering a culture of innovation and creativity. Digital technologies have the potential to transform healthcare delivery and improve health outcomes. Digital development initiatives include the use of telemedicine, mobile health applications, electronic health records, and data analytics to enhance access to healthcare, remote diagnosis, monitoring, and health information dissemination. Digital development promotes the use of digital financial services, such as mobile banking, digital payments, and fintech solutions. Digital financial inclusion enables access to formal financial services, improves financial management, supports entrepreneurship, and promotes economic growth.

Digital development necessitates robust data governance frameworks to protect privacy, ensure data security, and promote responsible data use. It involves establishing regulations and policies that govern data collection, storage, sharing, and usage to protect individuals' rights and promote trust in digital systems. Digital development requires collaboration and partnerships among governments, private sector entities, civil society organizations, and international institutions. Collaborative efforts help leverage resources, expertise, and knowledge-sharing to address common challenges and ensure sustainable and inclusive digital development. Digital development is an ongoing process that adapts to technological advancements, societal needs, and development priorities. It requires an inclusive, participatory approach that involves stakeholders at all levels to harness the full potential of digital technologies for the betterment of societies and economies.

Critical challenges for governing digitalization

Governing digitalization poses several critical challenges that need to be addressed to ensure its responsible and sustainable implementation. With the increasing digitization of personal, commercial, and government data, safeguarding privacy and ensuring data security has become a significant challenge. Governments must establish robust regulations and frameworks to protect individuals' data rights, prevent unauthorized access, and address issues such as data breaches and cyber threats. Striking a balance between facilitating data-driven innovation and maintaining privacy rights is crucial.

As AI technologies advance, concerns about ethical implications arise. The use of AI algorithms in decision-making processes can have far-reaching consequences, such as biases, discrimination, and infringement of human rights. Governments must establish ethical guidelines and regulations to ensure transparency, fairness, and accountability in the development and deployment of AI systems. This includes addressing issues like algorithmic bias, ensuring explainability and fairness in AI decision-making, and establishing frameworks for AI governance. The digital divide remains a critical challenge, with disparities in access to digital technologies and connectivity between regions, socioeconomic groups, and marginalized communities. Ensuring digital inclusion and equity is crucial for harnessing the benefits of digitalization and preventing the exacerbation of existing inequalities. Governments need to invest in infrastructure development, affordable broadband access, digital skills training, and support programs to bridge the digital divide and ensure equal opportunities for all (World Economic Forum, 2021)

Digitalization transcends national boundaries, and governing it effectively requires global cooperation and harmonization of regulations. The Internet and digital technologies operate on a global scale, making it challenging for individual countries to regulate them independently. International collaboration is needed to address issues such as cross-border data flows, jurisdictional challenges, intellectual property rights, and cybersecurity. Establishing frameworks for global governance and collaboration is essential to address these challenges collectively. Addressing these challenges requires a multi-stakeholder approach involving governments, private sector entities, civil society organizations, and academia. It involves the development of agile and adaptive governance frameworks that can keep pace with the rapid advancements in digital technologies while upholding ethical principles, ensuring inclusivity, and protecting individual rights and societal well-being.

Digital sustainability

Digital sustainability refers to the practice of ensuring that digital technologies and processes are designed, deployed, and used in a manner that promotes environmental, social, and economic sustainability. It involves considering the environmental impact of digital technologies, addressing issues of electronic waste, promoting energy efficiency, and leveraging technology for sustainable development. Green information technology focuses on reducing the environmental impact of digital technologies. This includes designing energy-efficient hardware, optimizing data centers for reduced energy consumption, and adopting sustainable practices in IT operations.

The proper disposal and recycling of electronic waste (e-waste) are crucial for digital sustainability. This involves implementing recycling programs, promoting responsible disposal practices, and encouraging the reuse and refurbishment of electronic devices. Digital sustainability emphasizes the importance of energy-efficient technologies and practices. This includes optimizing energy consumption in data centers, using energy-efficient devices and appliances, and employing smart energy management systems. Sustainable software development focuses on creating applications and platforms that minimize their environmental impact. This involves optimizing code efficiency, reducing energy consumption, and considering the full lifecycle of software, including maintenance and updates.

Managing one's digital footprint is essential for digital sustainability. It involves being mindful of the energy consumption and environmental impact associated with digital activities such as online streaming, cloud storage, and data transmission. Ensuring equal access to digital technologies and bridging the digital divide are critical aspects of digital sustainability. This involves promoting digital literacy, providing affordable internet access, and addressing barriers to technology adoption for marginalized communities. Effective data management plays a role in digital sustainability. This includes optimizing data storage and retrieval processes, implementing data compression techniques, and adopting responsible data governance practices.

Digital technologies can be harnessed to create sustainable and efficient urban environments. Smart city initiatives leverage digital solutions for energy management, waste management, transportation optimization, and resource allocation, leading to more sustainable and livable cities. Digital sustainability includes considering ethical implications and social impacts. This involves addressing issues of privacy, data security, algorithmic biases, and promoting responsible use of digital technologies. Achieving digital sustainability requires collaboration among various stakeholders, including governments, businesses, civil society, and individuals. Collaboration fosters knowledge-sharing, innovation, and collective action toward common sustainability goals. By integrating digital technologies with sustainable practices, digital sustainability aims to mitigate the environmental impact of technology while harnessing its potential to address global challenges and contribute to a more sustainable future.

Digital sustainable development as an emerging concept

Digital sustainable development is an emerging concept that highlights the intersection between digital technologies and sustainable development. It recognizes the potential of digital transformation to address sustainability challenges and leverage digital tools and innovations to achieve the Sustainable Development Goals (SDGs) (Baiba Šavriņa, 2022). Digital sustainable development focuses on harnessing the power of digital technologies to drive positive change. It explores how technologies such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, big data analytics, and cloud computing can be applied to address environmental, social, and economic challenges.

Digital sustainable development encourages the development and implementation of innovative solutions that integrate digital technologies with sustainable development principles. It involves leveraging digital tools and data to design and implement interventions that contribute to sustainability goals, such as resource efficiency, renewable energy adoption, sustainable mobility, and circular economy practices. Digital sustainable development emphasizes the importance of data-driven decision-making in advancing sustainability objectives. It recognizes that the availability of vast amounts of data, combined with advanced analytics and artificial intelligence, can provide valuable insights for evidence-based policymaking, planning, and monitoring progress toward the SDGs. Digital sustainable development strives to ensure that digital transformation is inclusive and leaves no one behind. It focuses on bridging the digital divide, promoting digital literacy and skills development, and ensuring equitable access to digital technologies and services. It also addresses the potential risks and challenges associated with digitalization, such as privacy concerns, cybersecurity, and ethical considerations (Sparviero *et al.*, 2021).

Digital sustainable development encourages collaboration and partnerships among different stakeholders, including governments, businesses, civil society organizations, academia, and technological innovators. It recognizes the need for multi-stakeholder cooperation to leverage expertise, resources, and knowledge to drive sustainable development outcomes. Digital sustainable development emphasizes the importance of monitoring and evaluating the impact of digital interventions on sustainable development. It involves tracking relevant indicators, measuring outcomes, and assessing the effectiveness and efficiency of digital solutions in contributing to the SDGs. This monitoring and evaluation process helps identify successful approaches, lessons learned, and areas for improvement. Digital sustainable development is an evolving concept that requires ongoing exploration, innovation, and adaptation to the changing technological landscape. It provides a framework for leveraging digital technologies to accelerate progress toward sustainable development and achieve the 2030 Agenda. By embracing digital transformation and integrating it into sustainable development strategies, societies can unlock new opportunities for positive change and drive inclusive and sustainable development outcomes.

The link between digitization and the sustainable

Digitization, or the process of utilizing digital technologies and data, has a strong link to sustainable development. It can contribute to advancing sustainability goals and addressing various environmental, social, and economic challenges. Digitization enables the optimization of resource use through technologies such as smart grids, smart buildings, and precision agriculture. It helps monitor and manage energy consumption, water usage, and waste generation, leading to more efficient resource utilization. Digital technologies facilitate the integration of renewable energy sources into the grid, enabling better management of decentralized energy systems and promoting the transition to a low-carbon energy sector.

Digital tools like remote sensing, satellite imagery, and sensors enable real-time environmental monitoring, helping track deforestation, air quality, biodiversity, and climate change. This data can inform decision-making and support conservation and environmental protection efforts. Digitization improves access to education and information, bridging the digital divide and providing learning opportunities to underserved communities. Online platforms, e-learning, and digital libraries enhance educational access and promote lifelong learning (Liliana Ionescu-Feleagă *et al.*, 2023).

Digital technologies can empower marginalized communities and individuals by providing access to financial services, healthcare information, government services, and employment opportunities. It supports social inclusion, enhances digital literacy, and enables participation in the digital economy. Digital health solutions, telemedicine, and mobile applications facilitate remote healthcare services, improving access to quality healthcare in underserved areas. It enables remote consultations, health monitoring, and efficient healthcare delivery systems.

Digitization fosters the development of sustainable business models, such as circular economy practices, sharing economy platforms, and online marketplaces for sustainable products and services. It promotes resource efficiency, reduces waste, and supports the transition to a greener economy. Digital technologies enable entrepreneurship and innovation, empowering individuals and small businesses to enter global markets. It fosters economic growth, job creation, and income generation, particularly in the digital and technology sectors.

Digital tools like blockchain and the Internet of Things (IoT) enable supply chain transparency, facilitating traceability and accountability in product sourcing, reducing environmental and social risks, and supporting ethical business practices. Data-Driven Decision-Making: Digitization provides access to vast amounts of data that can inform evidence-based decision-making processes. It enables governments and policymakers to design and implement effective policies and interventions addressing sustainable development challenges. Digital technologies support real-time monitoring and reporting of progress toward sustainable development goals. It enhances accountability, facilitates reporting on environmental indicators, and enables the tracking of social and economic impacts. It's important to note that while digitization has the potential to contribute to sustainability, it can also have negative environmental and social impacts, such as electronic waste generation, energy consumption, and privacy concerns. Therefore, the responsible and ethical use of digital technologies is crucial to maximizing the positive impact on sustainability.

Digitalisation and impacts on sustainability

Digitalization has had significant impacts on sustainability across various sectors and aspects of our lives. Digital technologies have enabled greater energy efficiency by optimizing energy consumption and reducing waste. Smart grids, for example, use sensors and data analytics to optimize energy distribution, resulting in reduced energy losses and lower greenhouse gas emissions. Digitalization has facilitated the integration of renewable energy sources into the grid. Through advanced monitoring and control systems, renewable energy generation, such as solar and wind, can be managed more effectively, increasing their reliability and reducing the reliance on fossil fuels. Digital technologies, including Internet of Things (IoT) devices and artificial intelligence (AI), have enhanced resource management. Smart sensors and connected devices enable real-time monitoring and control of resources like water, electricity, and waste. This allows for better optimization, reduced waste, and improved overall resource efficiency.

Digitalization plays a crucial role in enabling the transition to a circular economy, where resources are recycled, reused, or repurposed rather than discarded. Technologies such as blockchain can track and trace products throughout their lifecycle, enabling better management of material flows and facilitating circular supply chains. The rise of e-commerce has altered traditional retail models and reduced the need for physical stores. This shift has the potential to lower carbon emissions associated with transportation, as online shopping can be more energy-efficient and result in fewer vehicle miles traveled.

Digitalization has enabled increased telecommuting and remote work opportunities, reducing the need for daily commuting and associated greenhouse gas emissions. This shift towards flexible work arrangements can contribute to lower carbon footprints for individuals and organizations.

Digital technologies generate vast amounts of data that can be analyzed to inform sustainable decision-making. By leveraging data analytics and AI, businesses and governments can identify areas of improvement, optimize processes, and develop sustainable strategies based on evidence and insights (Schneider, 2019).

Despite the positive impacts, it's essential to consider the potential negative effects of digitalization on sustainability. These include electronic waste, the energy consumption of data centers, the digital divide, and privacy concerns. It is crucial to adopt responsible digital practices and invest in sustainable infrastructure to mitigate these challenges and maximize the benefits of digitalization for sustainability.

The role of digitalization in sustainable development

Digitalization plays a significant role in promoting sustainable development by leveraging digital technologies and data to address social, economic, and environmental challenges (Xu *et al.,* 2022). Digital technologies improve access to information and essential services, particularly in underserved areas. It enables digital literacy, e-learning, and online educational resources, promoting inclusive and lifelong learning opportunities. Digital platforms also provide access to healthcare information, telemedicine services, and financial services, empowering individuals and communities.

Digitalization facilitates the integration of renewable energy sources, improves energy efficiency, and enables smart grids. It allows for real-time monitoring and optimization of energy consumption, leading to reduced greenhouse gas emissions and better resource management. Smart meters, sensors, and energy management systems contribute to energy conservation and sustainability. Digitalization supports sustainable transportation systems by promoting alternatives to private vehicles, such as ride-sharing and public transport apps. It facilitates the optimization of routes, reduces traffic congestion, and promotes efficient logistics and supply chain management. Intelligent transportation systems, electric vehicle infrastructure, and mobility apps contribute to reducing emissions and improving air quality.

Digital technologies enable the implementation of circular economy practices. It supports recycling and waste management through digital tracking and tracing of materials, promoting resource efficiency and reducing waste generation. Digital platforms facilitate sharing and collaborative consumption models, extending the lifespan of products and reducing the need for new resource extraction. Digital tools like remote sensing, satellite imagery, and IoT devices enhance environmental monitoring and conservation efforts. They enable real-time data collection on deforestation, biodiversity, air quality, and climate change, informing evidence-based decision-making and supporting conservation initiatives. Digitalization also contributes to citizen science, engaging the public in data collection and environmental monitoring.

Digitalization promotes the development of smart and sustainable cities. It enables efficient energy and water management, intelligent transportation systems, smart buildings, and effective waste management. Digital platforms and data analytics support urban planning, resource optimization, and the delivery of citizen-centric services, enhancing the quality of life in urban areas. Digitalization fosters entrepreneurship and innovation, particularly in the technology sector. It enables digital startups and social enterprises to develop innovative solutions to sustainability challenges. Digital platforms and e-commerce provide opportunities for small businesses and artisans to reach global markets, contributing to economic growth and job creation.

Digital technologies generate vast amounts of data that can inform evidence-based decision-making and policy development. Data analytics, artificial intelligence, and machine learning enable policymakers to gain insights, monitor progress, and evaluate the impact of interventions. It supports the development of targeted and effective policies and strategies for sustainable development. Digitalization, when combined with appropriate policies, regulations, and capacity-building efforts, has the potential to accelerate progress towards the Sustainable

Development Goals (SDGs) by fostering innovation, enhancing efficiency, and promoting inclusive development. However, it is essential to address digital divides, and privacy concerns, and ensure the ethical and responsible use of digital technologies to maximize their benefits for sustainable development (Kondratenko *et al.*, 2022).

The digital revolution and sustainable development opportunities

The digital revolution presents significant opportunities for sustainable development. Digital technologies enable organizations to optimize their resource use and operational efficiency. Through the use of data analytics, IoT devices, and automation, businesses can identify inefficiencies, reduce waste, and optimize processes. This leads to improved energy efficiency, reduced emissions, and minimized resource consumption, contributing to sustainable development goals. Digital technologies bridge the gap in accessing essential services, particularly in underserved areas. Internet connectivity and mobile technologies enable access to education, healthcare, finance, and other essential services, empowering individuals and communities. This enhances social inclusion and reduces inequalities, which are core principles of sustainable development (The World in 2050, 2019).

The digital revolution creates opportunities for innovation and entrepreneurship. Digital technologies provide a platform for developing and scaling sustainable solutions. Startups and social enterprises can leverage digital tools to address environmental and social challenges, creating new business models that drive economic growth while contributing to sustainable development. The availability of vast amounts of data and advanced analytics tools supports data-driven decision-making. Governments, organizations, and individuals can leverage data to gain insights into social, economic, and environmental issues. This enables evidence-based policymaking, targeted interventions, and better monitoring of progress toward sustainable development goals. Digital technologies enable greater citizen engagement and participation in decision-making processes. Through online platforms, social media, and digital tools, individuals can voice their opinions, contribute to policy discussions, and participate in sustainable development initiatives. This fosters transparency, inclusivity, and accountability in governance, strengthening the democratic process.

Digital tools such as remote sensing, satellite imagery, and geospatial data enable more effective environmental monitoring and conservation efforts. Real-time data collection, analysis, and visualization facilitate the identification of environmental hotspots, monitoring of biodiversity, and tracking of deforestation or pollution. This supports evidence-based conservation strategies and enhances environmental protection. Digital technologies facilitate global collaboration and knowledge sharing among stakeholders. Online platforms, virtual conferences, and social networks connect individuals, organizations, and governments worldwide. This enables the sharing of best practices, lessons learned, and innovative solutions, fostering collaboration toward achieving sustainable development goals at a global scale.

The digital revolution offers opportunities for climate change mitigation and adaptation. Digital solutions enable the monitoring and management of greenhouse gas emissions, renewable energy integration, and climate risk assessment. Climate models and data analytics support the development of climate action plans, resilience strategies, and informed decision-making to address the impacts of climate change. It is important to note that while the opportunities presented by the digital revolution are significant, they must be harnessed responsibly and ethically. Digital inclusion, data privacy, cybersecurity, and addressing digital divides are critical considerations to ensure that the benefits of digital technologies are accessible to all and do not exacerbate existing inequalities. By leveraging digital tools and approaches, sustainable development can be accelerated, leading to a more inclusive, prosperous, and environmentally conscious future.

Main challenges of digital sustainability

Digital sustainability faces several challenges that need to be addressed to ensure its successful implementation. The rapid growth of digital technologies, including data centers, cloud computing, and the Internet of Things, has led to increased energy consumption. Balancing the demand for digital services with energy efficiency and renewable energy sources is a significant challenge. The proliferation of electronic devices and the rapid pace of technological advancement contribute to a growing problem of electronic waste. Proper disposal, recycling, and responsible lifecycle management of electronic devices pose challenges in terms of infrastructure, regulations, and consumer awareness (The World in 2050, 2019).

Digital products, such as smartphones and computers, involve complex global supply chains with numerous components and materials. Ensuring transparency and responsible sourcing of these components, including rare minerals, presents challenges in terms of traceability and ethical practices throughout the supply chain. As digitalization expands, protecting personal data and ensuring cybersecurity become critical challenges. Safeguarding user privacy, preventing data breaches, and building secure digital infrastructure requires robust policies, regulations, and technological measures. Bridging the digital divide and ensuring equitable access to digital technologies pose challenges, particularly in underserved communities and developing regions. Limited internet connectivity, affordability issues, and lack of digital literacy hinder equal participation in the digital economy.

Rapid technological advancements and short product lifecycles contribute to a culture of planned obsolescence, where devices become outdated quickly. This leads to increased electronic waste and challenges in managing the disposal and recycling of outdated technologies. The ethical use of digital technologies, including AI, automation, and data analytics, presents challenges in terms of biases, fairness, accountability, and potential social implications. Developing ethical frameworks and guidelines for responsible and inclusive technology deployment is crucial. Achieving digital sustainability requires a cultural shift and widespread awareness. Encouraging individuals, businesses, and governments to adopt sustainable digital practices, understand the environmental and social impact of digital technologies, and make informed choices remains a challenge (Ortwin *et al.*, 2021)

Developing appropriate regulations and policies to address the environmental impact, energy efficiency, e-waste management, and privacy concerns related to digital technologies can be complex. Balancing innovation, economic growth, and sustainability goals requires effective and adaptable regulatory frameworks. Promoting collaboration among various stakeholders, including governments, businesses, civil society, and individuals, is vital for addressing the challenges of digital sustainability. Encouraging partnerships, knowledge-sharing, and collective action is necessary to drive systemic change. Addressing these challenges requires a multi-faceted approach, involving technological advancements, policy interventions, public awareness, and cross-sector collaboration. By actively tackling these challenges, the path toward achieving digital sustainability becomes more feasible.

Steps to enable sustainable digital organization

Enabling sustainable digital transformation involves adopting strategies and practices that prioritize environmental, social, and economic sustainability. Define specific sustainability objectives that align with your organization's values and overall sustainability strategy. These goals could include reducing carbon emissions, minimizing e-waste, increasing energy efficiency, and promoting digital inclusion. Assess your current digital infrastructure, operations, and practices to identify areas for improvement. Evaluate energy consumption, resource usage, waste management, and the environmental impact of your digital technologies.

Optimize the energy efficiency of your digital infrastructure by implementing measures such as virtualization, server consolidation, and power management systems. Choose energy-efficient hardware and prioritize energy-saving settings across devices. Utilize cloud computing and virtualization technologies to optimize resource utilization, reduce physical infrastructure, and enable scalability. Cloud-based services can provide energy-efficient and shared resources, reducing the need for on-site hardware. Incorporate circular economy principles into your IT practices. This includes extending the lifespan of devices through repair and upgrades, promoting device recycling and responsible e-waste management, and considering sustainable sourcing of IT components. Improve the energy efficiency of your data centers by employing efficient cooling systems, implementing virtualization and consolidation strategies, and monitoring and optimizing power usage effectiveness (PUE) metrics.

Embrace remote and flexible work options to reduce commuting-related carbon emissions and energy consumption. Encourage virtual meetings and collaborative digital tools to minimize travel and support remote work practices. Promote digital literacy programs to empower individuals, especially marginalized communities, with the necessary skills to access and utilize digital technologies. Ensure equitable access to digital resources, bridging the digital divide and promoting digital inclusion. Prioritize data privacy, security, and ethical use. Comply with data protection regulations, implement strong security measures, and consider the ethical implications of data collection, processing, and sharing. Minimize data storage and ensure responsible data governance practices.

Engage with industry peers, sustainability organizations, and technology providers to share knowledge and best practices in sustainable digitalization. Collaborate on research, initiatives, and standards development to drive collective action and innovation. Establish key performance indicators (KPIs) and metrics to track your organization's progress toward sustainable digitalization. Regularly assess and report on your sustainability initiatives to demonstrate transparency and accountability. Embrace a culture of continuous improvement and innovation in sustainable digitalization. Stay informed about emerging technologies and practices that can further enhance sustainability in your digital operations. By following these steps, organizations can enable sustainable digitalization, minimize environmental impact, maximize resource efficiency, and contribute to a more sustainable future.

Digitizing a sustainable future

Digitizing a sustainable future involves leveraging digital technologies and approaches to drive transformative change and address sustainability challenges. Digitization enables the development of smart and sustainable infrastructure systems. It involves integrating digital technologies into areas like energy, transportation, buildings, and waste management to enhance efficiency, optimize resource use, and reduce environmental impacts. Smart grids, intelligent transportation systems, energy-efficient buildings, and waste management systems are examples of digitized infrastructure that contribute to sustainability.

IoT connects devices, sensors, and systems to enable data collection, analysis, and real-time monitoring. By utilizing IoT, various sectors can optimize resource use, improve energy efficiency, enhance environmental monitoring, and support sustainable practices. For instance, smart agriculture systems can monitor soil moisture, weather conditions, and crop health to optimize irrigation and reduce water consumption. Digitization generates vast amounts of data that can be analyzed to gain insights and inform decision-making. Data analytics techniques, including machine learning and artificial intelligence, can be applied to identify patterns, trends, and correlations that help address sustainability challenges. For example, analyzing energy consumption patterns can guide efforts to reduce energy waste and optimize energy usage.

Digital platforms and online tools facilitate collaboration, knowledge sharing, and collective action for sustainability. These platforms bring together diverse stakeholders, including governments, businesses, civil society organizations, and individuals, to exchange ideas, share best practices, and collaborate on sustainable initiatives. They enable collective problem-solving and promote partnerships to achieve common sustainability goals. Digitization plays a crucial role in transitioning to a circular economy, where resources are used efficiently and waste is minimized. Digital technologies enable traceability, tracking, and management of materials throughout their lifecycle. By digitizing waste management systems, it becomes possible to optimize waste collection, recycling, and repurposing efforts, reducing landfill waste and promoting a more sustainable approach to resource management (Lucia *et al*., 2021).

Digitizing a sustainable future requires equipping individuals with the necessary digital literacy and skills. It involves providing training and education to enhance digital competency, data literacy, and understanding of sustainable practices. Building digital skills empowers individuals to participate actively in the digital economy and contribute to sustainable development efforts. Digitization enables improved monitoring and reporting of progress toward sustainability goals. Through digital platforms, data collection tools, and reporting mechanisms, it becomes easier to track indicators, measure impact, and communicate achievements and challenges related to sustainability. Transparent and accessible reporting contributes to accountability and drives further action. Digitization fosters innovation and entrepreneurship by providing opportunities for developing and scaling sustainable solutions. Entrepreneurs can leverage digital technologies to create innovative products, services, and business models that address sustainability challenges. This encourages economic growth, job creation, and the advancement of sustainable development.

By embracing digitization and leveraging digital technologies responsibly and inclusively, we can accelerate progress toward a sustainable future. It requires collaboration, investment, and the integration of digital approaches into sustainable development strategies and policies. Digitizing a sustainable future offers immense potential to address global challenges and create a more prosperous and environmentally conscious world.

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CURRENT UNDERSTANDING OF MICROPLASTICS IN THE ENVIRONMENT: OCCURRENCE, FATE, RISKS, AND WHAT WE SHOULD DO

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Abstract:

The occurrence of microplastics, defined as plastic particles with dimensions smaller than 5 mm, has attracted considerable interest in the scientific community and society at large in recent times. Microplastics have been detected in aquatic environments and sedimentary deposits spanning various continents and oceans. Numerous instances of microplastic pollution have been well-documented across diverse global environments, including marine and freshwater ecosystems, as well as atmospheric deposition. The phenomenon of organisms consuming microplastics has been observed and has attracted increasing attention. The presence of microplastics can be attributed to their dual role as both a potential origin and storage site for hazardous substances. To enhance our comprehension of the notable issues about microplastics and the potential exposure of organisms to toxic chemicals, it is advantageous to investigate the prevalence, destiny, and hazards associated with microplastics in the natural environment. Furthermore, numerous studies have documented that the chemical composition of microplastics and the pollutants they accumulate may harm marine organisms. The complete understanding of the potential consequences on human health from consuming aquatic products contaminated with microplastics remains limited. Therefore, future research should prioritize the investigation of the transfer, accumulation, and potential consequences of microplastics within the food chain.

Keywords: Microplastics, environment, pollution, polymer.

Introduction:

Microplastics are frequently characterized as diminutive plastic particles with a size smaller than 5mm. The origin of these particles can be attributed to a range of sources, encompassing both primary and secondary sources, as indicated by scholarly investigations conducted (Cole *et al.*, 2011; Horton *et al.*, 2017).Horton *et al.* (2017) have identified primary source microplastics in cosmetic and medical products, specifically in the form of polyethylene (PE), polypropylene (PP), and polystyrene (PS) particles. Secondary microplastics are hypothesized to be produced through a range of mechanisms, encompassing physical, chemical, and biological processes, resulting in the fragmentation of plastic waste(Ryan *et al.*, 2009) as shown in figure 1.

Based on the research conducted by (Gregory, 1978 and 1996), it is proposed that primary microplastics have the potential to enter the aquatic environment through the discharge of household sewage or the unintentional release of plastic resin powders or pellets commonly used for airblasting. An additional significant factor contributing to the prevalence of primary microplastics is the incorporation of sewage sludge, which may contain synthetic fibers or sedimented microplastics from personal care or household products, into land application practices(Horton *et al.*, 2017). (Duis *et al.*, 2016) have identified secondary sources of microplastics as major contributors to microplastic pollution, primarily due to the significant influx of microplastic waste into the environment. Secondary microplastics are thought to originate from human activities, specifically those associated with littering, as well as being released during the collection and disposal of municipal solid waste.

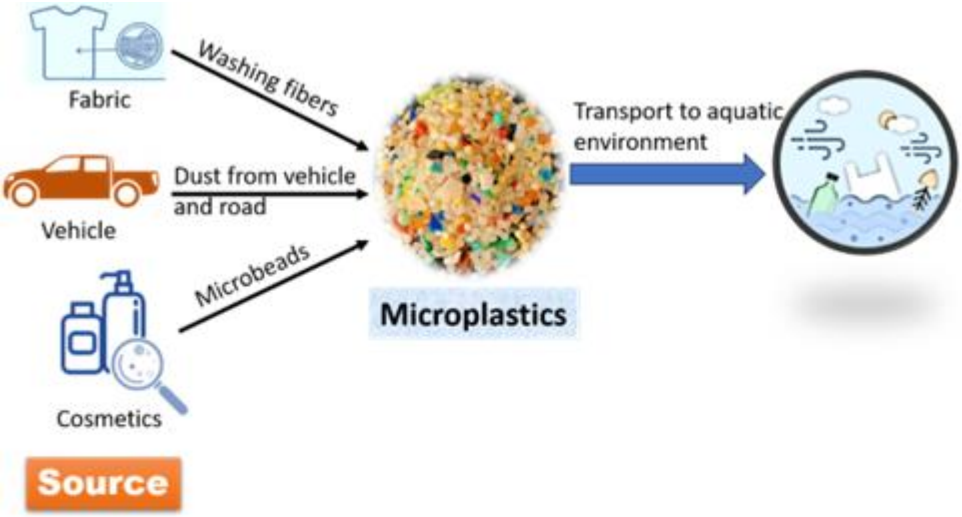

Figure 1: Sources and transport of microplastics into the aquatic environment

Microplastics, which are plastic particles measuring less than 5mm in size, have received considerable attention in recent times due to their significant prevalence in the natural surroundings. According to several studies (Jambeck *et al.*, 2015; Phuong *et al.*, 2016; Auta *et al.*, 2017) (Carbery *et al.*, 2018)the annual discharge of microplastics into the ocean is estimated to be around 8 million tons. The presence of microplastics has been widely documented in marine and coastal ecosystems, including sediments (Dekiff *et al.*, 2014; Vaughan *et al.*, 2017)), beaches (Van *et al.*, 2012), seawater (Woodall *et al.*, 2014; Zhou *et al.*, 2018), river water (Dong *et al.*, 2017), and polar regions (Kanhai *et al.*, 2018). The small dimensions and high surface to volume ratio of microplastics render them susceptible to the sorption and accumulation of pollutants present in the surrounding water (Holmes *et al.*, 2012; Hodson *et al.*, 2017; Holmes *et al.*, 2014; Brennecke *et al.*, 2016; Karapanagioti *et al.*, 2011; Fries *et al.*, 2012; Bakir *et al.*, 2014). The variability of pollutant concentrations on microplastics has been observed in various studies conducted (Ashton *et al.*, 2010; Turner, 2016; Vedolin *et al.*, 2018). According to the

2014 United Nations Environment Programme (UNEP) yearbook, the issue of microplastics pollution has been recognized as one of the ten emerging global concerns. This acknowledgment elevates the issue of microplastics pollution to a level of importance comparable to that of climate change. Given the enduring presence of microplastics in the environment, it is crucial to acknowledge and tackle the problem of contamination they present. Furthermore, the identification of the suitable course of action requires a thorough comprehension of the occurrence, destiny, and potential hazards linked to microplastics.

Multiple studies have provided insight into the adverse effects of microplastics on both the natural environment and human well-being. A research study was undertaken to examine the potential toxic effects of polystyrene microplastics (PSMPs) on earthworms (Eisenia fetida). The study's findings indicate that PSMPs possess the capacity to induce oxidative stress, histopathological changes, and significant DNA damage in the Eisenia fetida. Based on the findings of (Ying *et al.*, 2020), it was observed that the toxicity of 1300 nm PSMPs was considerably higher in comparison to that of 100 nm PSMPs. This difference in toxicity was primarily attributed to the increased bioaccumulation of the 1300 nm PSMPs. Microplastics have been found to have a widespread presence and are known for their long-lasting nature, high durability, tendency to break down into smaller pieces, and ability to absorb other pollutants (Padervand *et al.*, 2020). Previous research has also highlighted the presence of organic pollutants, such as polyamide, polyester, polymerizing vinyl chloride, and acrylics, within microplastics (Van *et al.*, 2012). Therefore, it is crucial to prioritize conducting a thorough investigation and developing effective strategies aimed at addressing the presence of microplastics in the aquatic environment.

Types, properties, and distribution of microplastics

The predominant microplastics found in marine environments are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyamide (PA), and polyethylene terephthalate (PET), as documented in the studies conducted by (Andrady, 2017; Hidalgo-Ruz *et al.*, 2012). The concept of crystallinity refers to the proportion of crystalline regions within polymers, characterized by the alignment of polymer chains. The spatial distribution of microplastics within the water column is influenced by the density characteristics of these particles. In a general context, it is commonly observed that polyethylene (PE) and polypropylene (PP) can be categorized as floating microplastics due to their densities typically being lower than that of water. Polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), and polyamide (PA) exhibit a greater density than water, resulting in their propensity to submerge in aqueous environments. It is important to acknowledge that the properties of microplastics, such as crystallinity and density, may not be regarded as inherent characteristics, as they have the potential to undergo changes over time as a result of weathering and aging processes.

Properties changes of microplastics after degradation

Macroscopic plastics and microplastics found in marine and coastal environments experience a range of weathering and aging phenomena. These include exposure to sunlight, thermal aging, the growth of bio-films, and oxidation. These processes contribute to the degradation of plastic polymers. Degradation encompasses a range of chemical reactions that result in the breakdown of plastic polymers. This breakdown can be categorized into various types, including photo degradation, thermal degradation, biodegradation, and thermos-oxidative degradation. These classifications are based on the distinct weathering processes involved. The process of degradation results in the fragmentation of macroscopic plastic waste, thereby introducing secondary microplastics into various environments. The degradation of primary and secondary microplastics primarily alters their physical and chemical characteristics, including color, surface morphology, crystallinity, particle size, and density (Rincon-Rubio *et al.,* 2001; Lambert *et al.,* 2016; Zhao *et al.,* 2018; Zettler *et al.,* 2013; Fazey *et al.,* 2016; Rouillon *et al.,* 2016).

Source and transport of microplastics

Based on a review published by the Scientific Advice Mechanism of the European Union in 2019, it has been observed that microplastics are found extensively across the environment, suggesting their prevalent presence and dispersal. The primary sources of microplastics include domestic discharge, which includes polymeric plastic derived from cosmetics and cleaning products, as well as the feedstocks used in the production of these items. In addition, the plastic powder or pellets used for air blasting significantly contribute to the total amount of microplastics, estimated to be between 5000 and 80,000 tons (Zhao *et al.,* 2018) (Figure 1). In the current atmospheric conditions, various factors such as mechanical degradation or exposure to UV light contribute to the continuous degradation of larger plastic particles, which typically range in size from 1.1 to 41.8 mm. This degradation process results in the significant release of microplastics into the surrounding environment. The microplastics mentioned can be categorized as secondary sources of microplastic pollution.

A considerable amount of microplastics that come from land sources can find their way into water bodies through the release of effluent from wastewater treatment plants or industrial sources. Based on the findings of (Liu *et al.,* 2006) Huang *et al.* (2021), it has been observed that smaller or lighter debris tends to be present on the surface of water bodies, while larger or heavier debris (with a median size of 3.6 mm) tends to be found on the beds of these water bodies.

Occurrence of microplastics in aquatic environment

According to a comprehensive report published by the International Union for Conservation of Nature (IUCN) in 2017, it has been observed that microplastics have a substantial impact on the composition of the Great Pacific Garbage Patch. Consequently, this contributes to the persistent pollution of our valuable marine ecosystems. In numerous developed nations, there is a notable observation that smaller fragments of marine debris make a substantial contribution to the issue of marine plastics pollution, in addition to the more conspicuous larger pieces. Wastewater treatment plants (WWTPs) have been recognized as a notable source of microplastic discharge into aquatic ecosystems. While the existing treatment processes are successful in removing larger plastic particles, it is important to acknowledge that microplastics can occasionally evade these units and enter the aquatic environment. It is important to consider that numerous wastewater treatment plants (WWTPs) are located near water bodies, such as oceans or seas. This proximity can lead to the release of a relatively higher amount of microplastics (Murphy *et al.,* 2016). Based on a recent study, it has been observed that the drainage system experiences an overflow during wet weather conditions, commonly referred to as wet weather flow (WWF). This overflow has been found to contribute an estimated annual total of approximately 8.50 × 1014 microplastic particles to the watershed. It is noteworthy that this particular contribution is discovered to be approximately six times greater than the amount contributed by wastewater treatment plants (WWTPs).

The plastics found along the coast of water bodies may have experienced either chemical weathering or mechanical erosion due to the surface textures of the plastics. Based on a study, it has been suggested that there may be a significant number of particles, estimated to be in the trillions, with a weight of approximately 270 tons, situated beneath the sea surface at depths ranging from 0.5 to 2 meters. According to Corcoran *et al.,* (2009), beaches have been identified as a location where plastic contaminants tend to accumulate. Another factor that has been observed to contribute to the increased presence of microplastics in aquatic environments is the growing number of tourists and the activities associated with tourism. This includes the discharge of sewage from moored cruise ships and hotels, as highlighted.

Toxicity and human health effects chemical

Chemical additives, such as plasticizers, heat stabilizers, antioxidants, and colorants, are commonly utilized in the manufacturing process of polymers to improve the performance of the end product. The potential long-term risks may arise from the presence of these compounds when they are exposed to the environment. Based on the findings of Rehse *et al.,* (2016) there is empirical evidence indicating that plasticizers may have adverse effects on both animal and plant species. Another aspect that should be considered is the potential existence of chemicals associated with microplastics, including unbound plastic precursors and various additives. There is a potential for monomers and oligomers to migrate from food packaging materials. The potential contribution of unreacted leaked fractions of plastics, such as monomers, oligomers, and chemical additives, to the toxicity of microplastics has been identified. At present, plastic litter is widely acknowledged as a significant concern for the aquatic environment, alongside other pressing issues such as climate change and ozone depletion. Microplastics possess the capacity to induce detrimental impacts on both human health and the environment through multiple mechanisms, including entrapment, ingestion, accumulation of harmful substances, and facilitation of the spread of invasive species. Another issue related to microplastics is their capacity to retain these compounds on their surface, which could potentially result in their transportation into diverse ecosystems.

Toxic effects on the environment

Microplastics have been found to enter the bodies of aquatic organisms through ingestion, which can result in their accumulation. Furthermore, it is possible for these microplastics to find their way into the food chain. The process of trophic exchange is known to have an impact on the ingestion of microplastics by fish. They have been observed to consume mysids, which in turn leads to the breakdown of microplastics as a byproduct of their metabolic processes. According to Hasegawa *et al.,* (2021), there is evidence suggesting that fish may consume a higher amount of microplastics from mysids compared to the surrounding aquatic environment, with estimates ranging from 3-11 times more. Different species of fish demonstrate different levels of microplastic consumption, with carnivorous fish typically consuming relatively fewer plastics compared to omnivorous fish. It has been observed that omnivorous fish often contain higher concentrations of microplastics, which can be attributed to their limited excretion capacity (Zhang *et al.*, 2021; Pan *et al.*, 2020).

Analytical methods of microplastics (MP) in the environment

Microplastics (MP) can be found in various forms and concentrations within the environment, with densities ranging from 0.9 to 2.3 g/cm3. The material can be classified into two categories based on its density: light or heavy. Additionally, it can also be categorized based on its flexibility as either hard or soft, according to its physical properties (Hidalgo-Ruz *et al.*, 2012; Lima *et al.,* 2014). The physiochemical properties of plastics may exhibit variations as a result of their diverse origins. Microplastic (MP) particles display a variety of colours, including red, white, clear, blue, green, black, purple, yellowish, and brown, as observed through microscopic examination (Song *et al.*, 2017). According to the literature, MP particles exhibit a wide range of shapes, such as elongated or shortened fibers, two-dimensional triangular or rectangular shapes, two-dimensional polygonal shapes, three-dimensional column-like or spherical shapes, three-dimensional pellet-shaped or cuboid shapes, as well as three-dimensional cone-shaped, pyramidal, and other irregular shapes (Xu *et al.,* 2020). The MP particles are composed of a variety of chemical constituents, including polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (PA), polyethylene terephthalate (PET), polyvinyl chloride (PVC), cellulose acetate (CA), polystyrene foam, and foamed polystyrene.

Extraction and separation methods

The extraction process is of great importance and shows variations when applied to both sediment and seawater samples. There are two methods available for effectively separating large microplastics in water. Firstly, one possible approach could involve utilizing a net to effectively separate them from the water. In another approach, one can consider filtering the large microplastics by utilizing filters or sieves after collecting a predetermined volume of water. These can then be visually sorted for further analysis. Microplastics (MP) typically have a density range of 0.9 to 2.3 g/cm^3. When dealing with sediment and soil that have higher densities in the range of 2.6 to 2.7 g/cm^3 (Dekiff *et al.,* 2014), flotation is a widely used technique. This method entails the extraction of MP by utilizing a salt solution with a comparatively higher density. A higher solution density can provide a broader range of density measurements for the melting point analysis. In order to achieve optimal separation of the flotation components (plastics and organic matter) from the mineral components in the mixture solution after centrifugation, it is recommended to gently place a rubber disc in the central area of the centrifugal tube. This measure has the potential to effectively minimize the resuspension of mineral particles, leading to a notable decrease in separation time (Scheurer *et al.,* 2018).

Identification and quantification of micro- and nanoplastics

After the completion of sample preparation, it is feasible to extract microplastics from environmental samples and subsequently employ diverse techniques to identify and quantify them. Although a universally accepted protocol for sampling and quantifying microplastics in the environment does not currently exist, it is possible to compile the commonly mentioned techniques documented in scientific literature. The utilization of established analytical techniques for other substances is often involved in these grouped sampling approaches. A frequently employed technique for the detection of microplastics entails initial visual identification of potential plastic particles, followed by subsequent confirmation of their composition through chemical analysis. This approach commonly integrates optical and spectroscopic techniques to minimize the occurrence of inaccurate positive or negative outcomes. However, it is imperative to acknowledge that there are specific constraints associated with this methodology, as highlighted by (Eriksen *et al.,* 2013). It was discovered that approximately 20% of the particles initially classified as microplastics based on visual observation were subsequently identified as aluminium silicate originating from coal ash upon examination using scanning electron microscopy (SEM). In previous studies, it was discovered that a subset of visually observed microplastic particles measuring less than 100 mm were not definitively identified as microplastics following the application of micro-Raman analysis (Lenz *et al.,* 2015). Furthermore, there have been cases where as much as 70% of particles were erroneously classified as microplastics during FTIR analysis (Hidalgo-Ruz *et al.,* 2012).

Risks of microplastics

Carson *et al.* (2011) suggest that the presence of considerable amounts of microplastics may have the potential to influence the physical characteristics of beach sediments. This modification may potentially have consequences for a range of organisms, including crustaceans and sea turtles, as well as their eggs. The presence of floating microplastics in water may have the potential to influence the distribution of sunlight that organisms can access, which could potentially affect their regular biological activities. It has been noted in scientific studies (Goldstein *et al.,* 2012; Majer *et al.,* 2012) that the presence of microplastics in the environment can potentially contribute to the formation of new habitats for organisms and encourage microbial colonization (Zettler *et al.,* 2013). These factors have the potential to impact the abundance and distribution of these organisms. On the other hand, it is worth considering that organisms residing on the surface of floating microplastics have the potential to exhibit invasive species-like behavior when they are transported to unfamiliar environments.

What we should do?

Further research

There remains a substantial amount of work that needs to be undertaken to effectively address data gaps, resolve lingering inquiries, and reconcile conflicts surrounding the issue of microplastic pollution in the environment. An exemplary study conducted by Lenz *et al.* (2015)

offers significant insights into the effects of microplastic ingestion and the resulting toxicity on organisms. Furthermore, an accompanying study conducted by Huvet *et al.* in 2016 provides additional insights into the individual and collective impacts of these factors. Lenz *et al.* (2016) suggest that future studies examining the impacts of microplastics on organisms should incorporate lower concentrations of microplastics. This suggestion is based on the observation that certain laboratory experiments employed concentrations of microplastics that exceeded those reported in field studies. Nevertheless, Huvet *et al.* (2016) underscored the significance of improving the analytical techniques for microplastics to precisely evaluate their prevalence in the environment. There is a scarcity of studies pertaining to microplastics in the water column and seafloor, in contrast to a substantial body of research focused on microplastics in the water surface. Further investigation is necessary to accurately evaluate the degree of bioaccumulation and biomagnification of plastics, along with the accompanying toxic chemicals, in diverse wildlife species and human populations.

Conclusions:

Recent studies have summarized three primary approaches: chemical, biological, and physical methods for removing microplastics from the environment. These studies were conducted after a brief survey on microplastics' sources, occurrence, and transport pathways. Combining sorption and filtration processes within membrane bioreactors is highly effective for removing a substantial portion of the microplastics in the influents that enter water treatment plants. Nevertheless, it is crucial to acknowledge that these systems unintentionally play a role in disseminating microplastics into aquatic ecosystems, as the wastewater is discharged daily. Microplastics in the soil give rise to apprehensions regarding potential, yet undiscovered, hazards to human health, particularly because many edible vegetables are derived from the soil. Furthermore, it has been observed that microplastics have been detected in atmospheric fallouts, as documented. Direct exposure to ambient air can expose individuals to substantial health risks. Therefore, forthcoming studies should prioritize examining the impacts of microplastics on human health across different environmental contexts, including soil and the atmosphere.

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DELETERIOUS EFFECTS OF HEAVY METALS ON THE HEALTH OF HUMAN AND AQUATIC ENVIRONMENT

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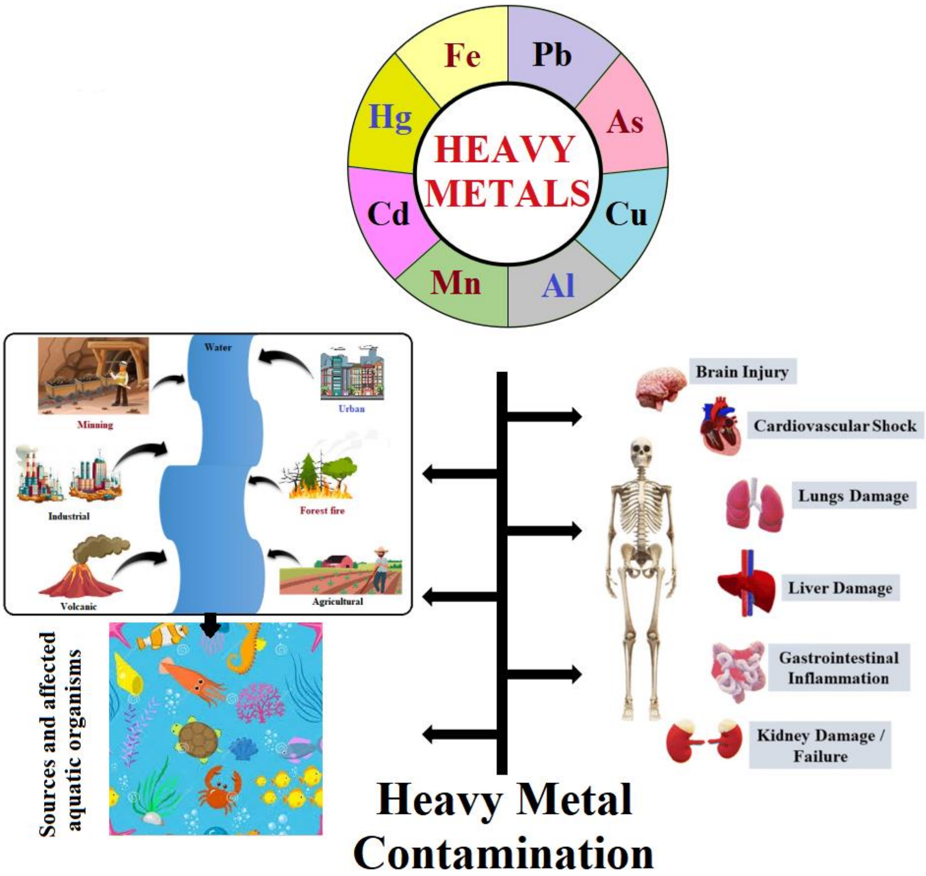
Abstract:

The chapter describes the occurrence, exposure and harmful effects of heavy metals on human health and aquatic environment. This chapter also discusses their metabolic element, primary entry points, and the relative size of such instances. Eventually, heavy metals put the living things under a lot of stress, which raises mortality. As a result, this study comments on and clarifies how heavy metal exposure to aquatic food affects human health risks. In many places of the world, the main instances are mostly associated with the negative effects of mercury, lead, arsenic and other heavy metals on human health. Last but not least, remediation is advised to bring about stability in aquatic ecosystems and human health.



Graphical representation of heavy metal contamination and their effect on human health and aquatic environment

Introduction:

Globally, heavy metal contamination is known to be the root cause of a number of ailments, including arsenic poisoning, organic mercury poisoning (minamata sickness), cadmium poisoning (itai-itai disease) and asthma due to air pollution. The interactions between internal and external factors in marine ecosystems are many, dynamic, and prone to change over time. Pollutants that enter estuaries and inshore waters do significant harm to the existence and activities of aquatic animals, even resulting in mass extinctions [1]. The buildup of heavy metals in marine environments is one of the pollutants with the greatest worldwide impact. Regarding the distribution of different heavy metals along the coast and in the water, significant contributions have been made. According to Velez and Montoro (1998), heavy metals emitted by household, industrial, and other human-made activities may significantly contaminate natural water systems. The biological balance of the recipient environment and a variety of aquatic creatures may be severely harmed by heavy metal contamination. Fish are the dwellers that are most vulnerable to the negative effects of these contaminants among animal species [2]. Because toxins accumulate in the food chain and create negative impacts and death in aquatic systems, fish are frequently employed to assess the health of aquatic ecosystems. The majority of the time, anthropogenic activities such asmining wastes, home sewage and industrial effluents cause heavy metals to enter the aquatic environment through air deposition, erosion of the geological matrix or both. In aquatic systems, metal pollutants typically persist in soluble or suspension form before either settling to the bottom or being ingested by creatures. Because of their toxicity, the cumulative and irreversible accumulation of heavy metals in various organs of marine organisms eventually results in metal-related disorders, putting the aquatic biota and other organisms in peril. Fish, which are important aquatic species in the food chain, frequently accumulate significant levels of particular metals [1,3].

Metals including lead, iron, copper, zinc, cadmium and manganese, which act either directly or synergistically, are frequent hazardous contaminants for fish. The processes and paths of these (potential) pollutants from one trophic level to the next are described by the bioaccumulation of trace elements in living species and biomagnification in them, demonstrating the higher bioaccumulation ability in the organisms in question. The retention duration of dangerous compounds was longer as concentrations rose up the food chain than it was for the other regular dietary ingredients. Individual metals and metal complexes that have been proved to have a detrimental effect on people's health are referred to as "toxic metals," including "heavy metals." Many of these metals are essential to life in extremely small quantities. But in bigger quantities, they turn toxic. They could accumulate in biological systems and pose a serious health risk [4].

Heavy metals and their sources

Any metallic chemical element with a comparatively large density and low toxicity or poisonous concentration is referred to as a heavy metal. Mercury (Hg), lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), iron (Fe) and thallium (Tl) are a few examples of heavy metals. Heavy metals are present in the planet's crust by nature. They are not wiped out or made insignificant. Because they have a tendency to bioaccumulate, heavy metals are risky. Bioaccumulation is the process by which the amount of a compound in a biological organism increases over time in comparison to that chemical's concentration in the environment. When substances are ingested and kept in living organisms more quickly than they are decomposed (metabolised) or eliminated, compounds accumulate. Because acidic rain breaks down soil and releases heavy metals into rivers, lakes, streams and groundwater, it is possible for heavy metals to infiltrate a water supply through industrial and consumer waste [5,6] (Figure 1).

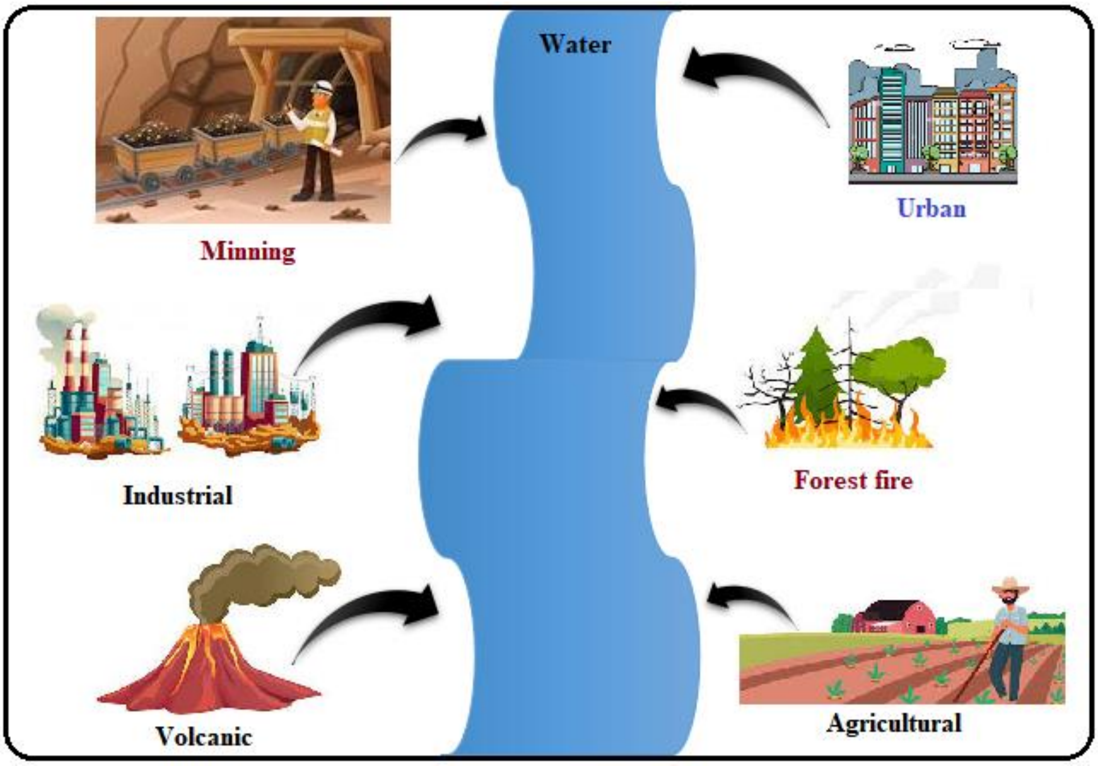


Figure 1: Schematic representation of sources of heavy metal pollution in aquatic environment

Toxic heavy metals and their effects

When heavy metals build up in soft tissues without being metabolised by the organism, they become poisonous. When heavy metals come into contact with people in settings such as agriculture, industrial, pharmaceutical, manufacturing or residential ones, they may do so through water, air, food or skin absorption. One typical way that adults become contaminated is through industrial exposure. Children are most frequently exposed through ingestion [1, 7]. Children who often put their hands in their mouths while playing in polluted soil or who ingest non-food items like dirt or paint chips may develop hazardous levels [8]. Less frequent exposure sources include using radiological equipment, administering incorrect doses or monitoring during intravenous (parenteral) nourishment, using a faulty thermometer, or attempting suicide or homicide. Commonly encountered toxic heavy metals are:

- Arsenic (As)
- Lead (Pb)
- Mercury (Hg)

- Aluminum (Al)
- Cadmium (Cd)
- Iron (Fe)

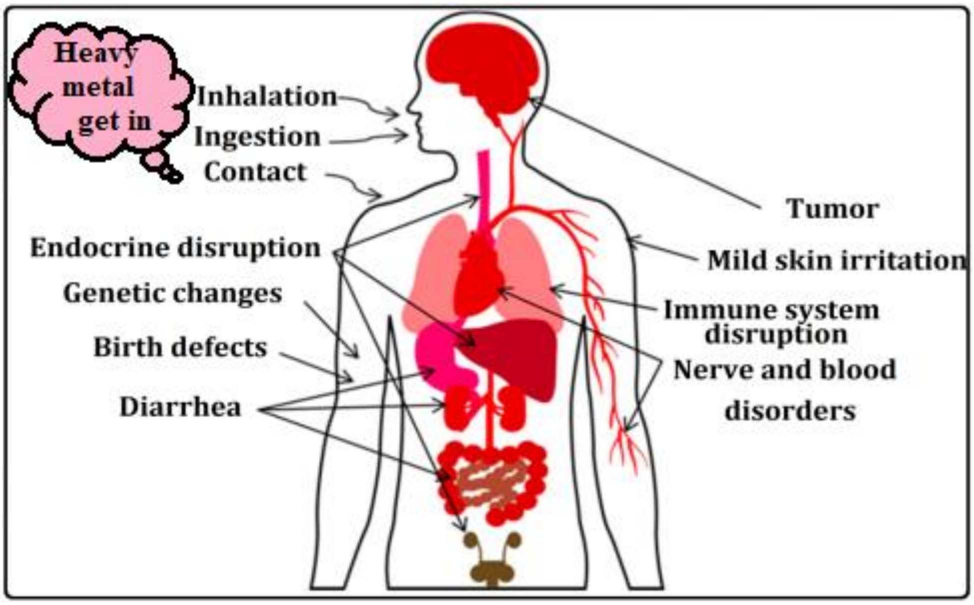


Figure 2: Toxic effect of heavy metal upon human health

Arsenic

According to the Agency for Toxic Substances and Disease Registry (ATSDR), arsenic is the most frequent acute heavy metal poisoning cause in humans and ranks first on their "Top 20 List." When copper, zinc, and lead are melted, as well as when chemicals and glass are made, arsenic is released into the atmosphere. A typical byproduct of the production of insecticides containing arsenic is arsine gas. Additionally, arsenic may be present in water supplies all around the world, exposing shellfish, cod, and haddock to it. Paints, fungicides, rat poisons and wood preservatives are further possibilities. The blood, skin systems, kidneys, central nervous and digestive systems are the target organs [3, 5]. Figure 2 shows some common health effect of heavy metal pollution.

Lead

The "Top 20 List" of the ATSDR ranks lead at second place. Lead is responsible for the majority of paediatric heavy metal poisoning cases (Roberts, 1999). It is a highly soft metal that has long been utilised in pipes, drains, and soldering materials. Millions of homes built before 1940 still contain lead (for example, in painted surfaces), exposing people to it over time through weathering, flaking, chalking, and dust. Every year, businesses around the world create approximately 2.5 million tonnes of lead [3]. The majority of this lead is used in batteries. The rest is utilised to make cable covers, plumbing, and gasoline additives. Other applications include paint pigments and PVC plastics, insecticides, crystal glass manufacturing and X-ray shielding.

Mercury

Mercury is ranked third on the "Top 20 List" by ATSDR. According to Castro and Mendez (2008) [9], mercury is one of the most dangerous heavy metals in the environment. Marine foods frequently contain higher quantities. Most organic mercury compounds can be absorbed from food up to 90% of the time. In prehistoric cave paintings, the mercury compound cinnabar (HgS) was employed to create red hues. Metallic mercury was also used in ancient Greece, along with white lead, as a cosmetic to brighten skin. In addition to the treatment of syphilis stated earlier, mercury compounds have also been employed in medicine as diuretics [calomel (Hg_2Cl_2)], and mercury amalgam is still used for tooth fillings in several nations. Most people are exposed to mercury through their diet, with fish being a significant source of methyl mercury exposure, as well as dental amalgam. Mercury vapour is emitted from amalgam fillings, and chewing may speed up the release rate, according to a number of experimental studies. While blood mercury can be used to determine exposure to methyl mercury, mercury in urine mostly relates to (very recent) exposure to inorganic compounds. A well-known powerful neurotoxic that has detrimental effects on the developing human brain is methyl mercury [3]. Any exposure during pregnancy is very concerning because it easily crosses the blood-brain barrier and the placental barrier. According to the International Agency for Research on Cancer (IARC, 1993), methyl mercury is classified as category 2B and is thought to be probably carcinogenic [10]. Congenital cases children born to exposed parents exhibited more symptoms than the parents did. Severe nervous system dysfunction and severely delayed developing skills were among the symptoms. The condition frequently manifests as sensory problems in the hands and feet, ataxia, a narrowing of the field of vision, hearing loss, balance problems, speech problems, trembling in the hands and feet, and problems with ocular movement.

Aluminum

Despite not being a heavy metal (specific gravity of 2.55-2.80), aluminium is the third most common element on earth and accounts for around 8% of its surface (ATSDR ToxFAQs for Aluminium). According to the ATSDR ToxFAQs for Aluminium, aluminium is easily ingested by humans through the use of food additives, antacids, buffered aspirin, astringents, nasal sprays, and antiperspirants, as well as through drinking water, tobacco smoke, car exhaust, aluminium foil, cookware, cans, ceramics, and fireworks. When scientists discovered what they deemed to be a considerable amount of aluminium in the brain tissue of Alzheimer's patients, studies started to emerge about 20 years ago showing that aluminium may have a probable connection with developing Alzheimer's disease. Despite the fact that aluminium was also discovered in the brain tissue of individuals without Alzheimer's disease, extensive public attention was given to the advice to stay away from sources of aluminium. Because of this, many businesses and individuals had a level of anxiety that led them to get rid of all of their aluminium cookware and storage containers and to be cautious around other potential sources of aluminium [5, 11].

Cadmium

Cadmium is the seventh substance on the ATSDR's "Top 20 list" and is a result of the mining and smelting of lead and zinc. It is utilised in paint pigments, PVC plastics, and nickel-cadmium batteries. Insecticides, fungicides, sludge, and commercial fertilisers used in agriculture that contain cadmium can all be detected in soil. Reservoirs where shellfish are present may contain cadmium. Cadmium is also present in cigarettes. Electroplating, motor oil, dental alloys, and exhaust are lesser-known sources of exposure. 2-7% of ingested cadmium is absorbed in the gastrointestinal system, while inhalation contributes for 15–50% of absorption in the respiratory system. The liver, kidneys, lungs, brain, bones and placenta are among the target organs [11].

Iron

This protocol only discusses iron toxicity when it comes to ingestion or environmental exposure. Iron is a heavy metal of concern despite not being on the ATSDR's "Top 20 List," in part because it can acutely harm young children who consume dietary iron supplements (for example, as few as five to nine 30-mg iron tablets for a 30-lb child). The majority of iron's harmful effects result from consumption because it is quickly absorbed in the digestive system. Iron's tendency to corrode appears to further increase absorption [1]. Children mistaken red-coated ferrous sulphate tablets or adult multivitamin preparations for sweets seem to be the main cause of overdosing. Recently, the accidental intake and overdose of iron pills by kids have been decreased thanks to blister packaging and the necessity that containers with 250 mg or more of iron have child-proof bottle lids [5]. Cookware, iron pipes and drinking water are other sources of iron.

Causes of heavy metal pollution

Although heavy metal pollution can come from a variety of sources, it is most frequently caused by the smelting of copper and the manufacture of nuclear fuels. Chromium and cadmium are mostly obtained by electroplating. Heavy metal pollutants have the ability to localise and remain latent through precipitation of their compounds or by ion exchange into soils and muds. Heavy metals do not degrade like organic contaminants do, which makes remediation more difficult. Currently, some heavy metals like mercury are being tentatively removed using plants or microorganisms [3]. Heavy metals can be removed from soils by concentrating them in the bio matter of plants that show hyper accumulation. In some cases, mining tailings are treated by burning the vegetation in order to recover the heavy metals. Water sources include heavy metals as lead, mercury, iron, cadmium, aluminium, and magnesium. If certain metals are found in sediment, they can enter the food chain via plants and aquatic animals. In the event that the level in the water is very high, this results in heavy metal poisoning.

Table 1 shows the different sources of heavy metal pollution and their effect on human health.

Table 1: List of some heavy metal pollutants, sources and their effect on human health

Sr. No.	Name of heavy metal	Symbol	Sources	Health effects
1.	Mercury	Hg	Pesticides, batteries, paper and pulp industry	Damage badly to nervous system
2.	Lead	Pb	Paint, pesticides, automobile emission, burning and mining of coal	Liver and kidney damage, mental illness in Children, intestinal problems
3.	Arsenic	As	Metal smelters, pesticides and fungicides	Dermatitis, bronchitis
4.	Cadmium	Cd	Fertilizer, nuclear plants, electroplanting, pesticides, batteries	Cancer of bone, kidney damage, bronchitis, intestinal disorder
5.	Zinc	Zn	Metal planting, brass manufacture, refineries	Damage to nervous membrane, skin problem
6.	Manganese	Mn	Fuel addition, welding, ferromanganese production	Inhalation or contact causes damage to central nervous system

Remediation for heavy metals

In recent years, microbial biotechnology has become a vital and environmentally benign alternative to heavy metal bioremediation. For heavy metal bioremediation, microorganisms that are resistant to heavy metals can be utilised [5]. Numerous possible heavy metal tolerance mechanisms have been reported by various scientists. These mechanisms include redox reactions, pumped, compound formation with other elements, and extracellular and intracellular sequestration. For the purpose of heavy metal bioremediation, Pseudomonas sp., Streptococcus sp., and Staphylococcus sp. bacteria were isolated from pulp and paper industry wastewater. Pseudomonas sp. successfully removes cadmium, manganese, and mercury, according to tests done on the bacteria's capacity to remove heavy metals. According to Hakeem and Smita (2010), Streptococcus sp. and Staphylococcus sp. may be more adept at extracting copper [12]. For the water bioremediation of heavy metals, Kang *et al.* (2016) [13] suggested utilising a bacterial consortium rather than a single bacterial organism since it would be more effective. With the help of the bacterial consortium, they also got rid of other metal toxins, recording reductions of 98.3% lead, 85.40% cadmium, and 5.6% copper. Streptomyces sp, Bacillus firmus, Oscillatoria anguistissima, Chlorella fusca, Sargassum natans, Ascophyllum nodosum, Rhizopus nigricans, Penicillium chrysogenum, and Aspergillus niger biomass had the maximum potential for metal adsorption from 5 to 641 mgg1 for Cr, Cd, Ni, Cu, Zn, and Pb metals. Fungi were previously investigated as water pollution bioremediation agents [13].

According to Saha *et al.*, polymer supported metal nanocomposites (i.e., resin immobilized gold nanocomposites) can we employed for the adsorption and removal of heavy metal ions from water samples [14, 15, 16]. Chitin and chitosan, which are well-known to be excellent heavy metal ion biosorbents, are present on the fungal cell surface. Penicillium piscarium has the potential to remediate locations that are contaminated with metal. The dead biomass of P. piscarium in metal biosorption was investigated by Coelho *et al.* [17]. The results were astounding and demonstrated that the dead biomass of P. piscarium may hold the key to traditional heavy metal-polluted water treatment technologies. The promotion of this reliable, affordable, and environmentally friendly wastewater management technology can come from business operations. Algae are autotrophic, which means they use fewer nutrients and produce more biomass than other microbial biosorbents. According to Cardoso *et al.* (2017), these biosorbents were frequently employed for the removal of heavy metals with high sorption potential [18].

Conclusion:

In this chapter we discussed the deleterious effects of some heavy metals, i.e. arsenic, mercury, lead, cadmium, iron, manganese and zinc etc. on the environment and living organisms, mainly aquatic life and human beings, respectively. It is essential to have strong laws, regulations, and ways to identify locations with greater levels of heavy metals. Heavy metals have harmful side effects, therefore failure to control exposure will lead to significant problems in the future. Employee exposure to heavy metals at work can be reduced by engineering solutions. By monitoring heavy metal exposure and perhaps taking action to lower further exposure in both people and the environment, a substantial step towards mitigation can be made. Cooperation on a national and worldwide level is crucial for the development of efficient heavy metal toxicity prevention measures.

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GROUNDWATER POLLUTION: SOURCES, IMPACTS AND HEALTH CONCERNS

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Abstract:

Groundwater pollution is a pressing environmental concern that threatens the vital natural resource of groundwater, which serves as the primary water source for various human activities and ecosystems. The escalating demand for water supply due to population growth and human activities has led to extensive groundwater exploitation. However, this widespread usage has also resulted in significant contamination issues, stemming from various sources. The sources of groundwater pollution are explored, encompassing industrial activities, agricultural practices, waste disposal, underground storage facilities, accidental spills, and leakage from pipelines. The pathways and transport of contaminants into waterways are discussed, including the role of hydrologic cycles and watersheds in trace metal chemistry and health risks associated with consuming contaminated groundwater are highlighted, with examples of diseases and conditions linked to exposure to specific pollutants. Public awareness and community involvement are deemed essential in promoting water conservation and protecting groundwater quality. Continuous research, monitoring, and innovative solutions are called for to address the complex challenges posed by groundwater pollution and ensure the sustainability of groundwater resources for future generations.

Introduction:

Water, air, and soil are the three fundamental resources that humanity depends on to survive on Earth. Water is the most significant of these since it serves as the primary channel for the emergence of life. Groundwater, as the essential foundation of the ecological system, stands as the most crucial natural resource. It serves as the primary water source for various activities, including drinking, domestic use, agriculture, industry, recreation, and environmental purposes. Consequently, the demand for water supply has escalated, primarily fulfilled through the exploitation of groundwater resources (Krishna kumar *et al.*, 2017). The utilization of water has risen in tandem with the growth of the human population and activities. One third of the water consumed by humans worldwide is groundwater. The ratio is higher in rural areas: more than half of all drinking water, groundwater is used to supply the entire world (Al-Sudani, 2019). Numerous elements, including precipitation, climate, soil type, vegetation, geology, flow conditions, groundwater, and human activities, have an impact on water quality.

Groundwater pollution occurs when pollutants from the ground infiltrate water bodies beneath the surface of earth. If fecal-contaminated water, which carries pathogens, seeps into the ground, it renders the groundwater unsuitable for consumption. Pathogens found in the polluted groundwater may include viruses, protozoa, bacteria, and occasionally, helminth eggs. (Chaudhry *et al.*, 2017)

Importance of ground water

It should be noted that water is a limited resource in some regions. Farmers rely on canals and wells to pump out groundwater for agricultural uses because there is a lack of surface water and irrigation infrastructure (Darwish *et al.,* 2011). Aquifers and groundwater are regarded as the most abundant water supplies for rural communities and enterprises that are dependent on surface water sources. Groundwater holds immense significance not only for society and industries but also plays a crucial role in sustaining water-dependent ecosystems. According to research by Kath and Dyer (2017) shallow groundwater is widespread, covering about one-third of land surfaces, and it forms vital connections with numerous high-valued rivers, ponds, and floodplains through aquifers. This interconnectedness further facilitates the extraction of groundwater. A decline in groundwater levels or contamination directly impacts the quality of surface water sources that rely on groundwater connections. Therefore, groundwater is not only essential for the socio-economic well-being of human beings but also plays a pivotal role in maintaining the proper functioning of flora and fauna within ecosystems.

Sources of groundwater pollution

In addition to natural processes, virtually every sort of man-made facility, as well as each and every one of his actions, might eventually cause issues with groundwater quality, making groundwater pollution a complex problem with many different origins. Waste disposal has the most common impact on groundwater quality (Mahar *et al.,* 2001). Pollutants generated can enter ground-water systems and slowly travel through the subsurface environment. Once pollutants are underground, they remain hidden until they resurface on the surface or in water wells, making it challenging to detect groundwater pollution at an early stage. Due to the slow turnover of groundwater, pollution effects may persist for years, decades, or even centuries, causing damage to aquifers beyond repair. There is a misconception that groundwater, being protected by layers of soil and rock, is safe from contaminants. However, the reality is that pollutants can pass through these layers and the unsaturated zones, ultimately penetrating the aquifer and leading to a deterioration in water quality. This phenomenon challenges the common belief that groundwater is naturally protected from pollutants (Ghahremanzadeh *et al.,* 2018)

1. Industrial activities

The main cause of water pollution, is attributed to various industries releasing untreated waste into aquatic ecosystems. Some of the industries mentioned include distillery, tannery, pulp and paper, textile, food, iron and steel, and nuclear industries. The pollutants released during industrial production consist of toxic chemicals, organic and inorganic substances, toxic solvents, and volatile organic chemicals. If these industrial wastes are not adequately treated before disposal, they can lead to water pollution. (Chowdhary *et al.,* 2020)

2. Agricultural practices

Because of the high rate of production, farmers are willing to use chemical fertilizers in order to increase agricultural productivity (Goudarzi *et al.,* 2017). Groundwater contamination from veterinary antimicrobials can come from intensive agricultural operations with high mortality rates. Groundwater quality can be impacted by high animal death rates and on-farm burial of carcasses.

3. Waste disposal and landfills

Extremely putrescent and occasionally dangerous garbage are frequently handled by landfills. Consequently, a range of contaminants are present in the leachates produced by the aerobic and anaerobic breakdown of these wastes, and they are bad for the environment. Due to fluctuations in their composition and flow rates, seasonal variations in the quantity of precipitation, the kind and age of the facility, and other factors, landfill leachates are actually one of the most challenging wastes to handle (Pandey *et al.*, 2019).

4. Underground storage facilities

Groundwater with naturally occurring high levels of dissolved substances is considered contaminated. However, regulatory efforts primarily focus on human activities that introduce contaminants artificially into groundwater. In essence, the distinction lies in naturally occurring contamination versus human-induced pollution. Underground storage tanks can affect groundwater through accidental spills and routine activities such as washing machinery and rinsing chemical storage tanks, which release contaminants into the soil and groundwater. The tank system includes the tank itself, underground-connected piping, underground ancillary equipment, and any containment system. A UST system is defined as a tank or a combination of tanks with connected piping that has at least 10 percent of its combined volume underground. Contaminants can migrate through the soil and contaminate the groundwater. Some contaminants may dissolve in the groundwater as it percolates through the soil, while others may dissolve in gases present in soil pores and spread before ultimately dissolving in the groundwater. Predicting the fate of contaminants released into the soil or groundwater is highly challenging due to various factors and complexities involved (Ahmad *et al.*, 2005).

5. Accidental spills and leakage

Onshore pipelines primarily serve to transport natural gas or various oil and oil-related products, including crude oil, gasoline, kerosene, diesel, and heavy fuels. Occasionally, they are also used for transporting other chemicals, albeit to a lesser extent. Pipeline transportation is widely regarded as the safest method for transferring fluids between two locations on land. This claim is supported by the relatively low frequency of accidents and the limited number of fatal incidents recorded, despite the extensive network of pipelines spanning millions of kilometers worldwide. However, it is essential to recognize that sections of pipelines can contain substantial amounts of hazardous materials, and in the event of leaks, the spill volumes can be significant. Moreover, since pipelines often extend for hundreds of kilometers, secondary containment measures are typically only implemented at critical points, such as river or road crossings. Spills might occur in unmanned locations, leading to potential delays in emergency response operations. While natural gas pipelines pose fire and explosion hazards to the population, oil pipelines pose a primary concern due to the environmental risks they present (Bonvicini *et al.*, 2015).

Pathways and transport of contaminants into waterways

The hydrologic cycle and watersheds influence trace metal chemistry in drinking water.

Water quality, discharge, and biological activity are key factors in trace metal transport. Storage and discharge affect dispersion and trace metal concentration. Unlike synthetic contaminants, trace metal contamination originates from natural sources through atmospheric and aqueous pathways. (Rasmussen, 1998). Moving water can dissolve and transport metals, including contaminants from the earth's surface and subsurface, to drinking water sources. In urban areas, stormwater collects pollutants from impervious surfaces and flows into water bodies used for drinking. Impervious surfaces worsen contamination as they prevent soil from filtering out pollutants (Marsalek and Schroeter, 1988). Storage of some waste material or tailings from mine operations in regions where high concentrations of sulfide and microorganisms may be present can result in formation of a highly acidic leachate, known as acid rock drainage. This type of mining effluent generates high concentrations of sulfuric acid that can solubilize metals and potentially compromise the quality of drinking water drawn from surface water or groundwater (Gray, 1998).

Facilitated transport is another mechanism that can move trace metals that might otherwise be relatively immobile in the aquatic environment. Trace metals can bind to colloids, natural complexing agents (humic and fulvic acids), and anthropogenic complexing agents such as nitrilotriacetic acid (NTA), which can "protect" the metal from some precipitation and adsorption reactions (Grout *et al.,* 1999 and Gadh *et al.,* 1991). The amount of trace metal contamination in water is often difficult to quantify because the pollution may be transient and may flow in variable patterns. For this reason, sediments are good long-term indicators of contamination (Smith and Hamilton, 1992 and Wilber and Hunter, 1979). Moving water has the ability to dissolve and mobilize metals, transporting surface and subsurface contaminants into sources of drinking water. In urban settings, stormwater is collected through sewers due to the prevalence of impervious surfaces, which accumulate significant metal pollution from streets. This polluted stormwater can then flow into bodies of water that serve as drinking water supplies, posing a risk to public health. The creation of impervious surfaces exacerbates the contamination problem, as it reduces the natural capacity of soil to filter out contaminants, further compromising water quality. (Young *et al.,* 1992 and Tessier *et al.,* 1979) Each of these phases holds contaminants with different affinities. Contaminants in the easily reducible phase may be available to the water column with only a small change in the environmental conditions, whereas, in order for the trace metals sequestered in the residual phase to become available for uptake by organisms, the water would have to become very acidic.

Transport of contaminants can be augmented as storms, high water flows, and turbulence from boating activities physically disrupt sediment layers. This is one mechanism by which pollution can be transported while still sediment associated. Sediments can release some of their contaminant load when environmental conditions change (Tessier *et al.,* 1994). These events can include aerobic sediments becoming anoxic by burial, changes in redox potential or pH, burrowing by benthic organisms, etc. As more sediments are deposited, layers accumulate and the conditions change, resulting in physical and chemical reactions occurring in the sediments. The water in sediments, often referred to as interstitial water or porewater, also plays an important role in determining contaminant fluxes between the water column and the sediment column and cycling of contaminants within the sediment column. Complex processes occur at the sediment–water interface that result in fluxes of contaminants between the sediment and water. Dredging or removal of contaminated sediments may also release large amounts of pollution. One remediation method is to cover the sediments with a layer of material that isolates the sediments, thereby protecting the sediment surface from physical disruption by natural or anthropogenic means (Carigan *et al.*, 1985).

Types of groundwater pollutants

1. Organic pollutants

Emerging Organic Contaminants include a wide range of different substances, including pharmaceuticals and personal care products (PPCPs), pesticides, veterinary products, industrial compounds and by-products, food additives, steroids, surfactants, plasticizers, metabolic regulators, and engineered nanomaterials. Numerous studies have chosen EOCs based on priority lists created after considering consumption, anticipated environmental concentrations, as well as ecotoxicological, pharmacological, and physicochemical data because there are so many potential compounds (Lapworth *et al.,* 2012)

2. Inorganic pollutants

High concentrations of inorganic contaminants are caused by both anthropogenic and natural activity in groundwater. Natural inorganic contaminants frequently render groundwater unsafe for human consumption. Groundwater that contains inorganic contaminants in excess of the World Health Organization's (WHO) recommended maximum contamination level (MCL) is common. Because inorganic contaminants are present in groundwater, one of the main sources of drinking water, it is bad for people's health. The primary inorganic pollutants include arsenic, and fluoride. Natural events such the weathering of rocks and sediments, the deposition of hydrothermal ores, volcanic eruption, geothermal activity, and forest fires all release arsenic. Fluoride concentrations in groundwater are accelerated by a number of natural processes, including the weathering of bedrocks, most frequently igneous and sedimentary rocks in various aquifers. (Kurwadkar *et al.*, 2020)

3. Nutrients and Fertilizers

Nutrients derived from fertilizers applied to the soil are carried into nearby streams and lakes through various pathways, including rainwater runoff, erosion, irrigation channels, and seepage. These nutrients also contaminate underground water supplies through leaching, leading to adverse effects on the physicochemical properties of water (Shamrukh *et al.,* 2001; Obire *et al.,* 2008 and Namdev *et al.,* 2011). The accumulation of nutrients in water bodies results in a phenomenon known as eutrophication. Eutrophic water bodies support the proliferation of unwanted aquatic plants and surface blooms of cyanobacteria, commonly known as blue-green algae. As these undesirable aquatic plants decompose, they deplete oxygen levels in the water body, leading to restricted use of the water for fisheries, recreation, industry, and drinking.

4. Heavy metals

The main threats to human health are associated with the exposure to heavy metals like lead, cadmium, zinc, manganese, copper, nickel, chromium, mercury and arsenic. Heavy metals typically enter the subsurface environment as a result of anthropogenic activity. High levels of heavy metals in groundwater can pose a serious health risk. For instance, significant mining operations may cause heavy metals to move around and contaminate groundwater supplies. Heavy metals are frequently found in groundwater supplies as a result of numerous abandoned and disused electronic devices, batteries that contain heavy metals, and general garbage. (Kurwadkar *et al.*, 2020).

5. Petroleum hydrocarbons

The significant contribution of petroleum resources to meet global energy demand and economic development, especially in oil-producing over the past fifty-five years. The petroleum industry holds substantial influence in the world today, and petroleum hydrocarbons are considered an essential commodity that serves as the backbone of the global economy (Ite *et al.*, 2018)

6. Microbial contaminants

Groundwater contamination by microbiological agents arises from wastewater originating from humans and animals. The sewage can contain various pathogens, such as pathogenic bacteria, viruses, and protozoa, posing a serious threat to public health if present in water supplies. Contaminants can enter the underground environment through leakages from sewage, septic tanks, mines used for waste disposal, landfills, or land-based drainage as fertilizer. The extent of groundwater pollution and its flow are heavily influenced by the volume of liquid waste and the exposure of groundwater to surface-derived pollution. Poor management of solid waste can lead to detrimental effects on aesthetics, environmental hazards, and pollution. Groundwater pollution may also occur due to potential contamination from leachate produced by waste (Al-Sudani, 2019)

Impact on water quality and human health

Human health is severely impacted by unsafe water. According to the UNESCO 2021 World Water Development Report, approximately 300,000 children under the age of five, or 5.3% of all deaths in this age group, die each year from diarrhea brought on by contaminated drinking water, improper sanitation, and poor hand hygiene (Lin *et al.*, 2022). The global issue of wastewater disposal, with approximately 80% of industrial and municipal wastewater being discharged into the environment without treatment. This practice has negative consequences for both human health and ecosystems. The situation is particularly concerning in least developed countries, where there is a severe lack of sanitation and wastewater treatment facilities.

1. Health risks from contaminated groundwater

Groundwater possesses longer residence times compared to other components of the hydrological cycle. As a consequence, the effects of aquifer degradation might go unnoticed for decades, potentially leading to a failure in recognizing the long-term implications of groundwater quality on human health. Groundwater bodies face numerous sources of potentially toxic elements (PTEs), posing a threat to human well-being if ingested (e.g., through cooking or showering) or in contact with the skin (e.g., during irrigation, recreational activities, or showering) (Pinto *et al.*, 2020). Waqas *et al.* (2017) reported that the consumption of groundwater contaminated with arsenic or direct skin contact with As-contaminated water results in a significant incidence of black foot disease, skin lesions, and various types of cancers, including those affecting the skin, kidneys, bladder, liver, and lungs, among the local population.

Cadmium is naturally present in rocks, coal, and petroleum, but in low concentrations. However, it can enter both groundwater and surface water through industrial discharge and metal painting processes. When cadmium enters the body, it replaces zinc biochemically, leading to severe health issues such as high blood pressure, liver and kidney damage, and anaemia. The emission of cadmium is increasing significantly because it is not recycled and often disposed of improperly with household waste. Mercury exposure is a concern for the general population, primarily through food consumption. Fish is a major source of methyl mercury exposure, and dental amalgam can also contribute to this exposure. Lead is introduced into the environment through industrial activities, mining, and its use as a water additive. Exposure to lead affects the chemistry of red blood cells and can cause delays in the normal physical and mental development of babies and young children. Additionally, some adults may experience an increase in blood pressure due to lead exposure (Vaishaly *et al.*, 2015). The release of substantial amounts of toxic materials into streams, lakes, and coastal waters can lead to changes in biomass and community diversity. Aquatic pollution, often involving sewage with organic waste, can boost secondary productivity but also alters the characteristics of the aquatic community. Many fish species, particularly those sought after as food, are highly sensitive to even minor pollution levels and may decline or disappear in response to pollution intensity (Owa, 2013).

Conclusion:

Groundwater plays a critical role as the core of the ecological system and serves as a vital natural resource. With the ever-increasing human population and activities, the demand for water supply has escalated, leading to the extensive exploitation of groundwater resources. However, the widespread use of groundwater also brings forth significant challenges, particularly concerning its pollution. The preservation and sustainable management of groundwater resources are of atmost importance to ensure the well-being of both human populations and the environment. Proper waste management, responsible agricultural practices, and stringent regulations are essential in preventing pollution and protecting groundwater sources. Public awareness and community involvement are crucial in safeguarding groundwater quality and promoting water conservation. Continuous research, monitoring, and innovative solutions are fundamental to address the complex challenges posed by groundwater pollution and secure this invaluable natural resource for future generations.

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UTILIZATION OF COAL MINE PRODUCED WATER USING DIFFERENT WATER TREATMENT PROCESS: AN APPROACH

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Abstract:

India is the third largest coal producing country in the world. Jharkhand with coal production of 113. 04 million tones retained as second position in coal producing state in India. Bokaro, Rajmahal, Karanpura, Jharia and Ramgarh coalfields are the main coal producing areas in the Jharkhand. During the coal mining process, a massive amount of mine water drained out, which has caused not only the wastage of ground water assets, but also creates several distresses on water pollution. Coal mining produced water discharges into rivers, streams and nallahas, which contain mainly several soluble minerals present in coal or associated rocks. The coal mine water needs to be necessarily treatment and purificationbefore used for drinking, domestic and agriculture purposes. In this chapter different methods and technological process like coagulation, sedimentation, filtration and disinfection etc. are discussed for coal mine produced water treatment and purification. By use of these different mechanical and chemical processes of water treatment, the TDS of treated water reduce below 500 ppm for use of drinking purpose and less than 1000 ppm is use for agriculture purpose. Which may overcome the water scarcity in coal mine areas as well as reduce the impact of mine produced water on environment.

Keywords: Coal Mine produced Water, Water treatment, TDS, Hardness, Turbidity.

Introduction:

Nature has provided a wonderful gift in the form of coal- a plentiful resource to meet energy demand of the country. Coal is a fossil fuel and has been formed as a result of alteration of vegetationunder action of combined effects of pressure and heat over millions of years to form coal seams. It's chiefly composition of C, H, N, S and O, beside other non-combustible inorganic matter.

India is the third largest coal producing country in the world. Coal is vital for sustainable development of our country. Coal production influences economic, industrial as well as social development ofour country. The GDP contribution of the mining industry varies from 2. 2% to 2. 5% only, but going by the GDP of the total industrial sector it contributes around 10% to 11%[1]. It is the most widely used energy source for electricity generation and an essential input for steel production. However, due to the mining activitybalance of naturehas been disturbed severely. There are several direct or indirectdistress imposed on ecology, agriculture, forest lands, ground water and hence ultimately to the human being.

Coal mining in the country is carried out by both opencast and underground methods. Opencast mining contributed about 93% of the total production. In case of open cast mining, land surface is completely disturbed, whereas underground mining has limited losses on surface except ground subsidence. However, both the miningmethod affects the quality and quantity of surface and ground water resources in coal mining region of India [2-9]. By and large, groundwater gets contaminated mainly due to leaching and percolation [10]. Mining's impacts on the natural water ecosystem may be observed throughout the life cycle of a mine and even after long time of mine closure [11]. The large volumes of water can be released from aquifers during opencast and underground coal mining operation. Water pollution in mining areas is mainly due tooverburden (OB) dumps, surface impoundments, mine water, industrial effluents, acid mine drainage, and tailing ponds [2]. With increase in human population there is tremendous pressure of good quality water for drinking, domestic and agriculture uses. So it is very important to treat waste mine water for its optimal use and to save our mother nature.

Physical and chemical characteristics of waste mine water

The quality of goodwater plays an important role in agricultural production and on human health. Quality of water is depending on the use of water, hence different uses require different criteria of water quality. The quality of water is known by some features like total dissolved solid (TDS), total hardness (TH) due to presence of cations (Ca^{2+}, Mg^{2+}) and anions (HCO_3^-, F^-, Cl^-, NO_3^-, SO^{2-}). The chemistry of anions and cations indicates that ionic presence as: HCO3- > SO4->Cl-> NO3->F- and Mg2+>Ca2+> Na+> K+ in the coal mine water. The coal mine water also contains suspended solid & high level of TDS ranging from 430 to 1090 mg per litre. The coal mine water needs to be necessarily treated and purified before used. Since more than 70% of pollutants from the mining industry are discharge into water, the removal of these contaminants prior to discharge is very necessary. It is critical to avoid a discharge of toxic components into the environment and subsequently back to the food-chain.

Fortreatment of waste mine water in effective manner to utilise it for domestic and agriculture purpose, it should be imperative that to knowthe physical and chemical properties of water. It is equally important that to assess the impurities mainly present in the mine waste water.

The quality of water contains mainly following characteristics for its utilisation of domestic as well as agricultural purposes:

a) Acidic and basic strength of water, which is measureon pH scale.
b) Colour of water, which represents the different dissolved matterpresent in water.
c) Total dissolve organic and inorganic solid i. e. Total Dissolved Solid (TDS) present in water.
d) Total hardness (TH) of the water due to presence of cations (Ca^{2+}, Mg^{2+}) and anions (HCO_2^-, F^-, Cl^-, NO_3^-, SO^{2-}).
e) The bio-degradable amount of organic content of water is measure by BOD (biological oxygen in demand).
f) Total organic and inorganic pollutant of waste water, which can oxidizedand measure by COD (chemical oxygen in demand).

Methods used for treatment of mine waste water

Before planning for waste water treatment, it is significant to identify the contaminants, which generally are present in the mine waste water. The most probable pollutantsneeds to remove from waste coal mine water are as follows

a) Physical impurities, like Suspended solid, colloidal particals.
b) Organic impurities, like Coal, Oil, grease and phenolic compounds etc.
c) Inorganic impurities like Heavy metals (Cr, Hg, Cu, Cd, Pb, Zn, Ni etc.)
d) Dissolved salt.
e) Biological impurities like Bacteria, Viruses, Protozoa, Algae, etc.

For removal of above impurities from waste mine water different stages of treatment should be performed.

Preliminary treatment: In the first step of water treatment, theremoval of physical and organic impurities has been carried out from waste mine water.

(a) Screening-The mine waste water is passed through screens, having large no of tiny size holes, then floating matters are retained by them.

(b) Skimming- Impurities which are lighter than water like oil, grease are removed by mechanical skimming. For this waste mine water is passed through skimming tank, which is so design to remove oil and grease from waste water flow.

Primary treatment: In the primary treatment of waste mine water, the following are main water process has been used.

(a) Sedimentation-This is a process of allowing water to stand for 2-6 hours undisturbed in big tank about 5m deep, when most of the suspended particle settle down at the bottom due to the force of gravity. The clear supernatant water is then drawn from tank with the help of pumps. Sedimentation is generally carried out in continuous flow type tank.

(b) Flocculation-The mine waste water is passed through a tank were it retain for 30 min. This tank is fitted with paddles rotating at a speed of 0. 5m/s. Due to this steering the finely divided suspended solids comes together and form large particles which settle down with this process.

(c) Coagulation- This is the process of removing fine suspended and colloidal impurities by the addition of requisite amount of chemical (coagulants). Coagulants when added to water form an insoluble gelatinous, flocculants precipitate. These precipitate descents through water absorbed and entangle very fine suspended impurities forming bigger flocs, which settle down easily. Coagulants mostly used for waste mine water treatment areAl_2(SO4) (Alum), Ferrous sulphate, Sodium Aluminate. Reaction of these coagulants in water is given as

$Al_2(SO_4) + Ca(HCO_3) \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2$

Alum flocculants ppt.

$NaAl_2O + 2H_2O \rightarrow Al(OH)_3 + NaOH$

Sod. aluminate gelatinous floc

Copper or ferrous sulphate ($FeSO_4$. $7H_2O$) act when pH < 8. 5

$FeSO_4 + Mg(HCO)_3 \rightarrow Fe(OH)_3 + MgCO_3 + CO_2 + H_2O$

In water

(d) Neutralization- Acidic or alkaline mine waste water is neutralized before its discharge. Acidic water is neutralizing by adding lime stone or caustic soda and alkaline water by adding sulphuric acid.

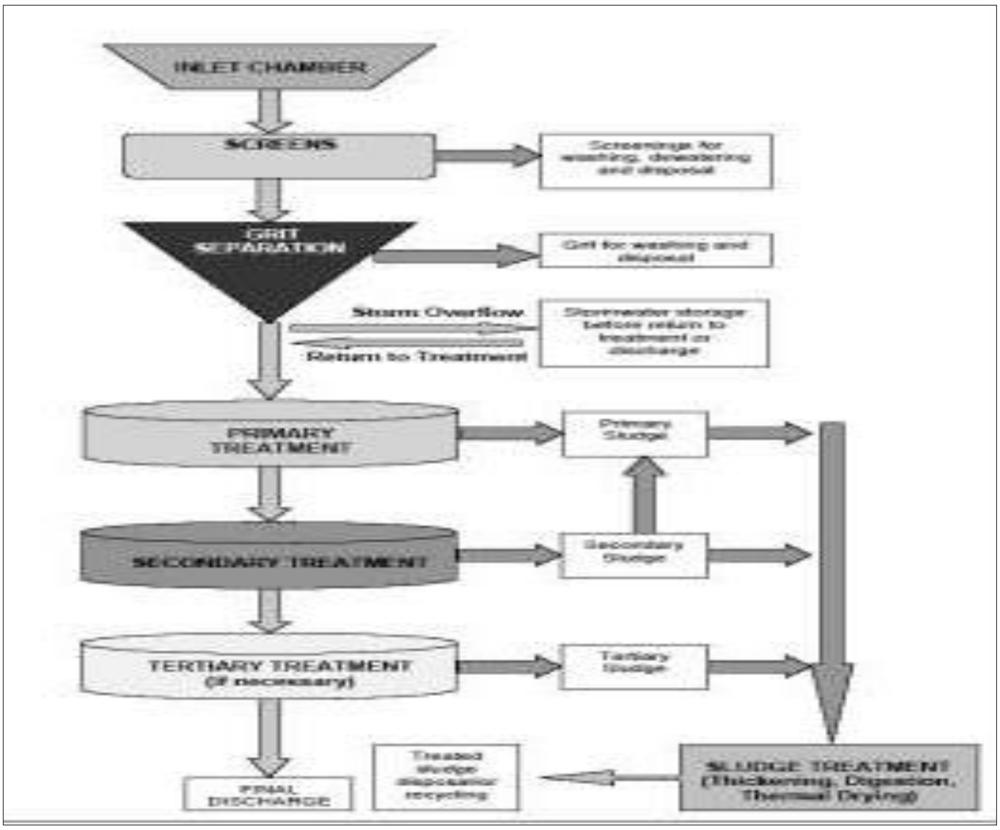

Figure 1: Flow chart of coal mine water treatmentmethodology

Secondary treatment: In this method, the process includes for waste mine water treatment are**:**

(a) Oxidation pond - Oxidation Pond is also called lagoons or stabilisation pond. Ponds are generally constructed of brickwork with relatively small depth. Waste water treatment occurs naturally by interaction of sunlight, bacteria and algae. It efficiently removes bacteria, biodegradable organic and inorganic impurities from waste water. 98-99% of BOD reduction is often possible.

(b) Trickling filter - It is also known as sprinkling filter. It has a well like structure made up of brick of a circular rectangular bed, 3-5cm at the top and 10-15cm at the base with a depth of 1-3m. This aerobic process is used to remove organic matter from waste mine water by use of microorganism attached to surface of well.

Tertiary treatment: This method of waste mine water treatment includes

(a) Chlorination- Chlorine (as gas or concentrated solution), bleaching powder or chloramine is added tothe waste mine water. These chemical produce hypochlorousacid, which is germicide and bactericidal.

$Cl_2 + H_2O \rightarrow HOCl + HCl$

HOCl + Bacteria →Bacteria are killed

(b)Coagulation Sedimentation-After primary and secondary treatment of water, wastemine water is again coagulated using chemicals, so that remaining colloidal particle settle down by means of gravity.

(c) Adsorbtion-This is a physical process used to remove low concentration of impurities from water that is difficult to remove by other means. In this process porous activated carbon is used, which have very large surface area available for adsorption of impurities (7. 3 millionsq. ft/lb).

(d)Reverse Osmosis-Thisis a waterpurification method, using semi permeable membraneto remove ion, unwanted particles and molecule against pressure gradient. In this process impure water is placed across semi permeable membrane and pressure is increases by use of high pressure pump on impure side. The pure water flows through the semi permeable membrane and salt molecules in water is retained by the membrane.

(e) Electro Dialysis- In this processelectro dialysis cell is used to purify water containing concentration of ionic impurities. When current is passed cations get deposited in cathode & anions on anode and central compartment carries water which is free from ionic impurities.

Result and Discussion:

An enormous amount of mine water drained out from the coal mining, which has the wastage of ground water assets. Coal mining produced water discharges into rivers, streams and ponds creates several adverse impacts on surface water pollution because it contains several soluble minerals present in coal or associated rockswith other associated impurities. To utilize the coal mine waterfor drinking, domestic and agriculture purposes, it necessarily needs treatment and purification.

In primary treatment water, oils, greases, colloidal particles, suspended particles are removed from mine waste water. The pH level of water is balanced by use of acid and base. The water quality after primary treatment has TDS approximately1000ppm, which can be used for agriculture purpose. Whereas, after secondary treatment this treated water, it became almost free from biological and biodegradable organic and inorganic chemicals. This water can be used for domestic purpose. Moreover, the tertiary treatment removes all inorganic impurities at molecular level from impure water. Hence, the TDS level ofwater has becomeless than 500ppm, which can be used for drinking purpose.

Conclusions:

The crisis of drinking water is the facing by all most all part of the world, due to increase in population. India also has tremendous pressure of good quality water for drinking, domestic and agriculture purposes. Henceforth, each and every drop of water is precious. An enormous amount of mine water drained out from the coal mining, which has the wastage of ground water assets. So, it is very important to treat waste mine water for its optimal use and to save our mother nature. These waste mine produce water can be fulfilling our daily water requirements for vary purposes using above water treatment methodologies. The treatment of coal mine produce waste water will resolve the water crisis problem in respective coal mine areas of Jharkhandand balance our ecosystem as well.

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ROLE OF ENZYME IN TEXTILE DYES DEGRADATION

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Microorganisms degrade the dyes with the help of enzymes such as azoreductase, laccase, lignin peroxidase and manganese peroxidase etc. Both anaerobic and aerobic conditions are required for complete degradation of reactive dyes.

Azoreductase

Azobenzene reductase, also known as azoreductase, is an enzyme that catalyzes the reductive cleavage of azo groups (-N=N-) under mild conditions. As its name suggests, it catalyses the cleavage of benzidiene based dyes and other compounds containing azo bond to produce aromatic amines.

The systematic name of this enzyme class is N,N-dimethyl-1,4-phenylenediamine,aniline:NADP+oxidoreductase. Other names in common use include, azo reductase, azo dye reductase, dibromopropylaminophenylazobenzoic azoreductase, dimethylaminobenzene reductase, methyl red azoreductase, N,N-dimethyl-4-phenylazoaniline azoreductase, NAD(P)H:1-(4'-sulfophenylazo)-2-naphthol oxidoreductase, NADPH2-dependent azoreductase, NADPH2:4-(dimethylamino)azobenzene oxidoreductase, NC-reductase, new coccine (NC)-reductase, nicotinamide adenine dinucleotide (phosphate) azoreductase, orange I azoreductase, orange II azoreductase, p-aminoazobenzene reductase and p-dimethylaminoazobenzene azoreductase (Ooi *et al*., 2007). Plate 1 represents structure of azoreductase enzyme isolated from *Escherichia coli*.

Plate 1: The crystal structure of AzoR (azoreductase) purified from *Escherichia coli*.

Chemical reaction

Azo reductases catalyze the reaction only in presence of reducing equivalents like FADH and NADH. The reaction catalyzed by this enzyme proceeds via a Bi-Bi ping-pong mechanism by using 2 equivalents of NAD(P)H to reduce one equivalent of the azo compound substrate. Catalytic reaction of azoreductase is as follows:

4-(dimethylamino)azobenzene + NADPH + H+ $\rightleftharpoons$ N,N-dimethyl-1,4-phenylenediamine + aniline + NADP+

The 3 substrates of this enzyme are 4-(dimethylamino) azobenzene, nicotinamide adenine dinucleotide phosphate and hydrogen ion, whereas its 3 products are N,N-dimethyl-1,4-phenylenediamine, aniline and nicotinamide adenine dinucleotide phosphate ion.

This enzyme belongs to the family of oxidoreductases, specifically those acting on other nitrogenous compounds as donors with NAD+ or NADP+ as acceptor (Mullar *et al*., 1949).

The bacterial azoreductases are classified into two families based on their cofactor requirement and molecular weight.

1. NADPH dependent azoreductase have been found in *Bacillus* spp. Such as *Bacillus* spp. OY1-2 and *Bacillus subtilis*, as well as in other Bacteria like *Geobacillus stearothermophilus*, *Rhodobacter sphaeroides* and *Staphylococcus aureus*. This azoreductase prefers NADPH as an electron donor and has subunits of about 18 kDa.
2. NADH dependent azoreductase requires FMN as a prosthetic group for activity. It is found in several *Bacillus* spp. Some of this type of azoreductase were thought to play an important role in electron transport during redox reaction into the cells (Ooi *et al*., 2009).

Many bacterial strains possess unspecific flavin dependent cytoplasmic enzymes, which act as Azorductases and under anaerobic conditions transfer electrons via soluble flavins to azo dyes (Puveneshwari *et al*., 2006). Most of the azo dyes have sulphonate substituent groups and a high molecular weight. Thus, they are unlikely to pass through cell membranes. Therefore, the enzyme reducing activity of the dye is not dependant on the intracellular uptake of the dye (Robinson *et al*., 2001).

Russ *et al*. (2000), also suggested that, bacterial membranes are almost impermeable to flavin containing cofactors and therefore, restrict the transfer of reduction equivalents by flavins from the cytoplasm to the sulphonated azo dyes. Thus, there may be a different mechanism responsible for sulphonated azo dye reduction in bacterial cells with intact cell membranes other than reduction by reduced flavins formed by cytoplasmic flavin-dependent azo reductases.

There are many models that are proposed for the reductive cleavage of azo dyes by Macwana (2001). The first model proposed by Stolz describes azo dye reduction as being dependent on reduced flavins, as previously mentioned. Under aerobic conditions, oxygen and the azo dye compete for the reduced electron carriers and hence the successful reduction of azo dyes is due to its more optimal redox potential state.

The second model is based on studies with facultative anaerobes by Roxon *et al*. (1967) and Walker (1971), which suggested that unspecific reduction of azo dyes was carried out by reduced flavins generated by cytosolic flavin reductases. But the inability of the reduced flavins to cross the cell membrane and the highly polar sulfonated azo dyes was found to be limiting factor of second model. It suggests that this process does not generally occur.

The third model involves the electron transport-linked reduction of sulphonated azo dyes in the extra-cellular environment. It is possible whenever there is a link in between intracellular electron transport systems and the high molecular weight, azo dyes. For such a link to be established, the electron transport components must be localized in the outer membrane of the bacterial cells (in the case of Gram-negative bacteria), where they can make direct contact with either the azo dye substrate or a redox mediator at the cell surface (Myers and Myers, 1992). In addition, Walker (1971) have stated that low molecular weight redox mediator compounds can act as electron shuttles between the azo dye and an NADH (Nicotinamide adenine dinucleotide) dependent azo reductase that is situated in the outer membrane.

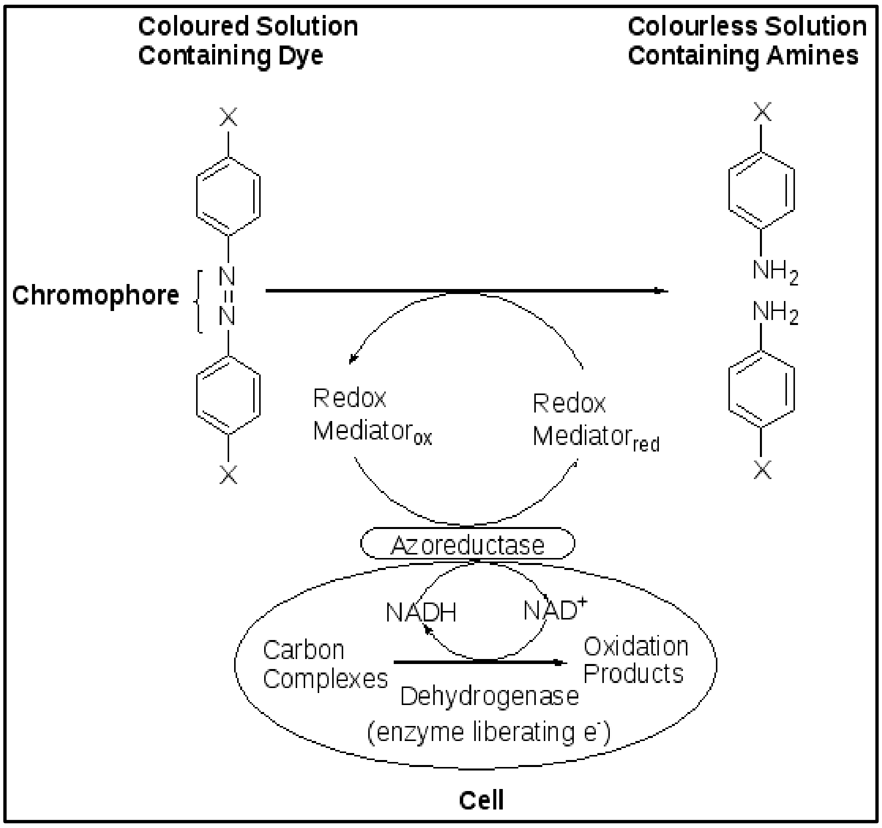

Figure 1: Proposed mechanism for reduction of azo dyes by azoreductase by Keck *et al*., 1997

These mediator compounds are either formed during the metabolism of certain substrates by the bacteria or they may be added externally (Russ *et al*., 2000). In case of aerobic extracellular environment, oxygen will inhibit this reduction mechanism due to the preferential oxidation of the reduced redox mediator by oxygen rather than by the azo dye.

Kudlich *et al*. (1997), support the thought that the membrane-bound azo reductase activity, mediated by redox compounds is responsible for the reduction of sulphonated dyes is different from the soluble cytoplasmic azo reductase which is responsible for reduction of non-sulphonated azo dyes. Therefore, the membrane-bound and the cytoplasmic azo reductases are two different enzyme systems. Fig. 1 shows a proposed mechanism for the redox-mediator-dependent reduction of azo dyes using whole bacterial cells, under anaerobic conditions.

Although the final reduction of the azo dyes is a dominantly chemical redox reaction, the same redox mediators depend on cytoplasmic reducing enzymes to supply electrons (Yoo *et al*., 2001). It is also possible that this chemical redox reaction works in conjunction with a direct enzymatic reaction involving an azo reductase, which may be a dehydrogenase enzyme that is synthesized throughout the cytoplasm and secreted without accumulation inside the cell (Bragger *et al*., 1997).

A model was proposed for *Sphingomonas xenophaga* BN6 by Kudlich *et al*. (1997) and Keck *et al*. (1997). In this model it was suggested that in addition to reduced flavins, quinoid redox mediators were required for the reduction of the azo dye. In this system, the quinones acted as redox mediators which were enzymatically reduced by the cells to form hydoquinones, which in turn reduced the azo dye. And hence the transport of the hydroquinone /quinine redox mediator and the highly polar sulfonated azo dye across the cell membrane was not required, as the quinine reductase activity was observed in the cell membrane.

Other electron carriers suggested by van der Zee (2002), can stimulate the reduction of azo compounds as shown in Table 1.

Table 1: Electron carriers for reduction of azo compounds

Sr. No.	Redox mediators used for azo dye reduction	Redox mediator Redox potential (E0)
1.	Methyl viologen	440
2.	Benzyl viologen	360
3.	Riboflavin	208
4.	FAD	219
5.	FMN	219
6.	Menadione	203
7.	Neutral Red	325
8.	Anthraquinone-2-sulphonate	218
9.	2-hydroxy-1, 4-naphthoquinone	139

The fourth model proposed by Rafii and co-workers, suggested that the dye was not required to be transported across the cell membrane. According to this model experiments associated with *Eubacterium*, *Clostridium*, *Butyrivibrio* and *Bacteroides* reduce the dye using extracellular enzyme activity. They observed that some of the azoreductase activity was extracellular or supernatant associated (Rafii *et al*., 1990; Rafii *et al*., 1995).

Azorductases have been detected in no. of species including *E. coli*, *Pseudomonas aeruginosa, Enterococcus faecalis*, *Sinorhizobium melioli*, *Saccharomyces cerevisiae* and several anaerobic bacteria. Azoreductase is also present in liver cells and in intestinal bacteria of most animals, humans. Some of them are sharing only minimal sequence identity. They have common three dimensional fold. An important function associated with intestinal bacteria is their ability to metabolize xenobiotics, such as azo dyes. Several intestinal bacteria are known to have azoreductase activity and hence thereby the isolation and characterization of azoreductase genes from these intestinal bacteria will provide information to their biochemical function within the cells. The azoreductase gene has been cloned, expressed and characterized from various intestinal organisms which include *Enterococcus faecalis*, *Escherichia coli*, *Shigella* and S*taphylococcus aureus.* Interestingly, the properties of these azoreductases vary. For example, the azoreductase obtained from *E. coli* is a homodimer , requires FMN as a cofactor and uses NADH as an electron donor; while the *Staphylococcus aureus* azoreductase is a tetramer and utilizes NADPH for azo dye reduction. In addition, the deduced protein sequences do not share significant sequence homology (Macwana *et al*., 2009).

The first flavin dependent azoreductases from an intestinal bacterium were isolated from *Shigella dysenteriae* type I by Punj *et al*. (2008). These enzymes could utilize NADH as well as NADH for activity. Azoreductase I was dimer with 28 kDa M.W. while Azoreductase II was a monomer with 11 kDa M.W. Misal *et al*. (2013), also purified and characterized the azoreductase from human intestinal flora *E. coli*. The presence of an azoreductase in this intestinal microorganism is playing an important role in azo dye metabolism in the intestine and possibly impact human health (Macwana *et al*., 2009).

Liu *et al*. (2009), studied the physiological role of *Escherichia coli* azoreductase AzoR. They concluded that AzoR was capable of reducing several benzo-, naphtho-, and anthraquinone compounds, which were better substrates for AzoR than the model azo substrate Methyl red.

Leelakriangsak *et al*. (2012), extracted azoreductase enzyme from *Bacillus subtilis*. They stated that Enzyme production could be induced by Methyl Red. The decolorizing activity of azoreductase is firstly associated with the cytosolic fraction and NADH as a cofactor. Ooi *et al*. (2009), studied the enzymatic properties of azoreductase present in *Bacillus* spp. B29.

Laccases

Laccases are polyphenol oxidases that catalyze the oxidation of various aromatic compounds, particularly those with electron-donating groups such as phenols (−OH) and anilines ($-NH_2$), by using molecular oxygen as an electron acceptor. Laccase enzymes are widely presents among plants, fungi and bacteria. These enzymes have various biological functions, such as degradation of complex polymers, lignification, detoxification, pathogenicity, morphogenesis, sporulation, polymerization of melanin and spore coat resistance. The fungal laccases can catalyze the oxidation of pharmaceuticals and various halogenated pesticides, alone or with the help of mediators (Margot *et al*., 2013).

Bacterial laccase is intracellular and present as periplasmic protoplast. The first bacterial laccase was found in the symbiotic bacterium, *Azospirillum lipoferum.* A number of bacteria including *Bacillus subtilis, Bordetella compestris, Caulobacter crescentus, Escherichia coli, Mycobacterium tuberculosum, Pseudomonas syringae, Pseudomonas aeruginosa,* and *Yersinia pestis has* ability to produce laccase, which can be used to degrade synthetic dyes. Laccase containing six putative copper binding sites were discovered in marine bacterium *Marinomonas mediterranea* also, but no functional role was assigned to this enzyme.

Laccases occur in various fungi over a wide range of taxa including soft- white rot fungi and geophilous saprophytic fungi. Fungi from the *Deuteromycetes, Ascomycetes* as well as

Basidiomycetes are the wellknown producers of laccase. Among them, *Basidiomycetes* are considered as an efficient laccase producers. Other laccase producers of wood-rotting fungi include *T. hirsuta* (*C. hirsutus*), *T. villosa*, *T. gallica*, *Cerrena maxima*, *Lentinus tigrinus*, *T. ochracea*, *Pleurotus eryngii*, *Trametes* (*Coriolus*) *versicolor*, *Coriolopsis polyzona*, etc. Laccase has also been produced by many edible mushrooms including the oyster mushroom *Pleurotus ostreatus*, the rice mushroom *Lentinula edodes* and champignon *Agaricus bisporus*.

Laccases are well known as benzenediol:oxygen oxidoreductase. Laccases are the most abundant members of the multicopper protein family. Their typical molecular mass ranges from 60 to 85kDa. Phylogenetically, these enzymes have developed from small sized prokaryotic azurins to eukaryotic plasma proteins, such as ceruloplasmin. Laccases contain four histidine-rich copper binding domains, which coordinate copper atoms types 1- 3 that differ in their environment and spectroscopic properties. Laccases are categorized as blue laccase (containing four copper sites) and laccase lacking type-1 copper site.

Laccases are the model enzymes for multi-copper oxidases and participate in the crosslinking of monomers, degradation of polymers and ring cleavage of aromatic compounds. It catalyzes the oxidation of various aromatic compounds (particularly phenols) with the concomitant reduction of oxygen to water. It has wide reaction capabilities and broad substrate specificities. And thus, laccases appear to be a promising biocatalyst to enhance the biodegradation of micropollutants in wastewater in a complementary treatment step (Tavares *et al*. 2008). The enzyme preparations can efficiently degrade the different types of dyes, such as azo dyes, anthraquinonic dyes, triarylmethane dyes, basic dyes, reactive dyes and indigoid textile dyes which are commercially used in textile industries (Abdulla *et al*., 2000; Zille, 2005).

Commercial azo, triarylmethane, anthraquinin and indigoid textile dyes are efficiently decolorized with laccase enzyme preparations from *Pleurotus ostreatus*, *Schizophyllum commune*, *Neurospora crassa*, *Polyporus* spp., *Sclerotium rolfsii*, *Trametes villosa* and *Myceliophtora thermophila*. The nature of substituent on the dyes benzene rings influences enzyme activity while hydroxyl and amino group enhances the decolorization. The presence of lignin peroxidase and/or manganese peroxidase in addition to laccase, increases decolorization up to 25% (Abdulla *et al*., 2000).

Decolorization of 4 Reactive dyes present in textile effluents such as Reactive blue, Reactive orange, Ramazol black and Congo red was studied by enzyme treatment extracted from *Polyporus rubidus* by Dayaram *et al*. (2008). The decolorization was observed in a laboratory scale bioreactor constructed with laccase immobilized Na-alginate beads. More than 80% of dyes were degraded within 5 days under stationary incubation conditions.

A new laccase was purified from *Trametes hirsuta* IMA2002 by Almansa *et al*. (2004). The isolated laccase had a molecular mass of 62 kDa and an isoelectric point of pH 7. It had an optimum pH of 3.0 and an optimum temperature of 55°C. The laccase was quite stable at 30°C and pH 4.0 with a half-life of more than 100h. A purified laccase from *Trametes hirsuta* organism were able to degrade triarylmethane, indigoid, azo and anthraquinonic dyes. Initial decolorization velocities depended on the substituent on the phenol rings of the dyes (Abdulla *et al*., 2000).

Kuddus *et al*. (2013), stated that the purified laccase enzyme extracted from *Pseudomonas putida* MTCC 7525 gave maximum activity and stability at 40ºC and pH 8. It showed decolorization of synthetic dyes and textile industrial effluents up to 58%–93% when treated with culture. This was the first report on bacteria *P. putida* producing laccase.

Margot *et al*. (2013), studied four strains of the bacterial genus *Streptomyces* (*S. cyaneus, S. ipomoea, S. griseus and S. psammoticus*) and the white-rot fungus *Trametes versicolor* for their ability to produce active extracellular laccase to treat wastewater with different carbon sources. Among the *Streptomyces* strains evaluated, only *S. cyaneus* produced extracellular laccase having sufficient activity to its potential use in textile effluent treatment plant. Laccase activity produced by *T. versicolor* was 20 times more than laccase activity shown by other isolates.

Peroxidases

Peroxidases are oxidoreductases that catalyze a variety of reactions such as reduction of peroxides such as hydrogen peroxide and oxidation of a variety of organic and inorganic compounds. These are heme proteins and contain iron (III) protoporphyrin IX as the prosthetic group. They have a molecular weight ranging from 30 to 150kDa.

Peroxidase enzyme is a globular protein with an active site which binds to substrate molecules and helps to catalyze a reaction by holding molecules in the correct spatial conformation for the reaction to take place. The activities of the peroxidase are determined by their 3-dimensional structure. Most enzymes are much larger than the substrates they act on and only a small portion of the enzyme around 3-4 amino acids is directly involved in catalysis (Rao *et al*., 2014)

These enzymes catalyses the polymerization of toxic compounds by cross reaction, with other phenolics or with toxic co substrates and generates polymeric products (dimmers, trimmers, hybrid oligomers), which will very likely accumulate in soil or in water systems. Peroxidases have potential for bioremediation of waste water contaminated with phenols, cresols and other industrial effluents. Thus it can be use for decolorization of textile dyes, removal of endocrine disruptive chemicals, degradation of pesticides, polychlorinated biphenyls, chlorinated alkanes and alkenes of soil, phenoxy alkanoic herbicides, triazine herbicides, chlorinated dioxins and chlorinated insecticides. Peroxidases are also used as biosensors (Bansal *et al*., 2013).

These enzymes are isolated from various sources like plants, animals and microbes and they have been reported as excellent oxidant agents to degrade dyes (Rao *et al*., 2014). Peroxidases were detected in different microorganisms responsible for the biodegradation of industrial dye. *Bacillus* spp. VUS isolated from textile effluent contaminated soil showed capability for degrading a variety of dyes because of presence of peroxidase enzyme (Chacko *et al*., 2011). Ng *et al*. (2010), studied Acid Orange 7 dye decolorization ability of peroxidase enzyme isolated from *Brevibacterium casei*. An edible macroscopic fungi *Pleurotus ostreatus* produced an extracellular peroxidase has ability to decolorized remazol brilliant blue, Bromophenol blue and Methylene blue dyes upto 10% to 98% (Shin *et al*., 1997).

Bholey *et al*. (2012), observed that the liginin peroxidase extracted from *Pseudomonas aeruginosa* and *Serratia marcescens* were able to textile dye effluent up to 50% to 58%, while the heterogeneous combination of lignin peroxidases from mixed consortia gave 70% to 75% decolorization of textile dye containing effluent which is significantly high.

Rajkumar *et al*. (2013), suggested that the different medium components like pH, temperature; carbon sources, nitrogen sources and amino acids affected the production of peroxidase from *Bacillus* spp.

Finally, the author concludes that the biological enzymes could be particularly useful in textile effluent decolorization process of small-scale textile or dyeing units because most of the microbial strains producing these enzymes can be grown on locally available and low-cost growth substrates (Saranraj, 2013). Thus, there is a need to develop novel biological decolorization processes leading to more effective cleanup of dyes using a single/consortium and adaptable microorganisms that can efficiently degrade various dyes.

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GROUNDWATER QUALITY STATUS OF THE PARAMBIKULAM - ALIYAR – PALAR BASIN, TAMIL NADU USING RS AND GIS TECHNIQUES

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Abstract:

The dependency of ground water is raising day by day. The ground water gets recharged mainly through rainfall. Thirty five water samples were collected from Parambikulam Aliyar Palar basin from open wells, bore wells and dug cum bore wells and analysed for chemical properties for two years duration (2010 and 2011) at three months interval (summer, winter, southwest monsoon, northeast monsoon) and analysed for the quality parameters. The samples were classified under USSL classification. Most of the samples come under medium salinity class (C_2) (48.57%) followed by low salinity class (C_1), high salinity class (C_4) and very high salinity class (C_3) with 28.57, 14.29 and 8.57 per cent respectively in all the seasons. Majority of the samples exhibit there is no permeability hazard. Salinity persists in the basin and possibility of salt accumulation in irrigation pipes observed from LSI values. Using remote sensing and GIS technique, the mapping was done for the groundwater quality of PAP basin. The variations in the ground water quality of the basin are directly correlated with rainfall pattern and geology of the basin. For effective utilization of saline water in the basin, management strategies were formulated and field experiments were conducted in the farmer's holdings in the sampling area of the basin.

Keywords: Groundwater – Quality – PAP basin – RS and GIS.

Introduction:

Groundwater is generally less susceptible to contamination and pollution when compared to surface water bodies. Pollution of groundwater due to industrial effluents and municipal waste in water bodies is major concern in many cities and industrial clusters in India. It leads to deterioration of groundwater quality (Neale *et al.,* 2002). Irrigation of poor quality water through the extraction of groundwater from deep aquifers leads to salinisation of the agricultural soils. An estimate on extent of poor quality water irrigation and sources of the poor quality water will give a real picture for adopting management strategies for remediation. Hence this study was taken to assess the groundwater quality of PAP basin in Tamil Nadu (Janardhana, 2007).

Study area

Parambikulam-Aliyar basin is located in the south western part of the Peninsular India, and covers the areas in Kerala and Tamil Nadu States. Aliyar river rises in the eastern slopes of Anamalai hills of the Western Ghats is Coimbatore district is at an elevation of 2250 m above MSL and flows in the north-westerly direction on its 45 km runs from its origin, it is joined by a tributary namely the Palar River on its right bank traversing by another 15 km westwards, it enters the Palaghat district of Kerala State through Palaghat gap. Parambikulam river and

Sholayar river are the tributaries of the Chalakudi river (flowing in Kerala State). It has its origin from the western slope of Anamalai hills of Western Ghats and flows in west – south westerly direction. Parambikulam-Aliyar River basin has an undulating topography with maximum contour elevation in the plain is 300 m and the maximum spot height in the plain is 385 m above MSL. One third of the basin area (822.73 km^2) is covered with hills and dense forest cover. The total area of PAP basin is 2388.72 km^2. This basin is bounded in north and east by Cauvery basin, south and west by Kerala State.

The PAP basin area lies (except the ayacut area) within the coordinates between 10° 10' 00" to 10°57'20" N and 76°43'00" to 77° 12'30" E. The basin area lies within the Coimbatore district only and the ayacut area is extent beyond Coimbatore district up to Tiruppur and Erode districts share the basin area. The total command area worked out to 1,74,553 ha.

Sub basins: Sub basins are Sholayar, Aliyar and Palar.

Sholaiyar sub basin: Sholaiyar sub basin has no direct Ayacut.

Aliyar Sub basin: Aliyar sub basin has an old ayacut to an extent of 2,591 ha and new ayacut to an extent of 1,796 ha. Five canals from old ayacut and four canals from new ayacut irrigate about 20,558 ha.

Palar sub basin: Palar sub basin has old Ayacut to an extent of 1,302 ha. It has two components one being system tanks and other being direct Ayacut. New Ayacut is 15,263 ha. In total the irrigation area under Palar sub basin is 1,74,553 ha.

Irrigation system in the PAP basin

The Aliyar sub Basin area of 20536 ha including old command is irrigated through four canals. The entire command area has been divided into two zones viz. A & B and each zone gets irrigation for a period of 135 days (4 ½ months) once in two years.

Irrigation pattern

Aliyar sub basin: Old Ayacut includes double crop/ wet and irrigation season being 15th May to 31st March. New Ayacut includes double crop/ dry and irrigation season being 1st September to 15th January in two zones A and B.

Palar sub Basin: Old Ayacut includes double crop/ wet. Irrigation season I begins on 1st August and upto 31st December. Irrigation season II begins on 1st and upto 31st May. New Ayacut includes irrigated dry (I.D) crops. Irrigation schedule in the range once in two years. *i.e.,* each zone will get supply in alternate years.

PAP command area

Parambikulam Aliyar Project command comes under Aliyar and Palar sub-basins. Pollachi main canal (New ayacut) of Aliyar sub-basin which extends upto a length of 48 kms with 30 distributaries. The 4(L) distributaries of Pollachi main canal located at 5.22 kms has been selected for in depth water management study where the entire command has been divided into A zone and B zone. Each zone gets canal supply once in alternate years. The area under A zone and B zone are 226.96 ha and 265.01 ha respectively. Apart from canal supply, there are 103 bore wells and 95 open wells in the command area.

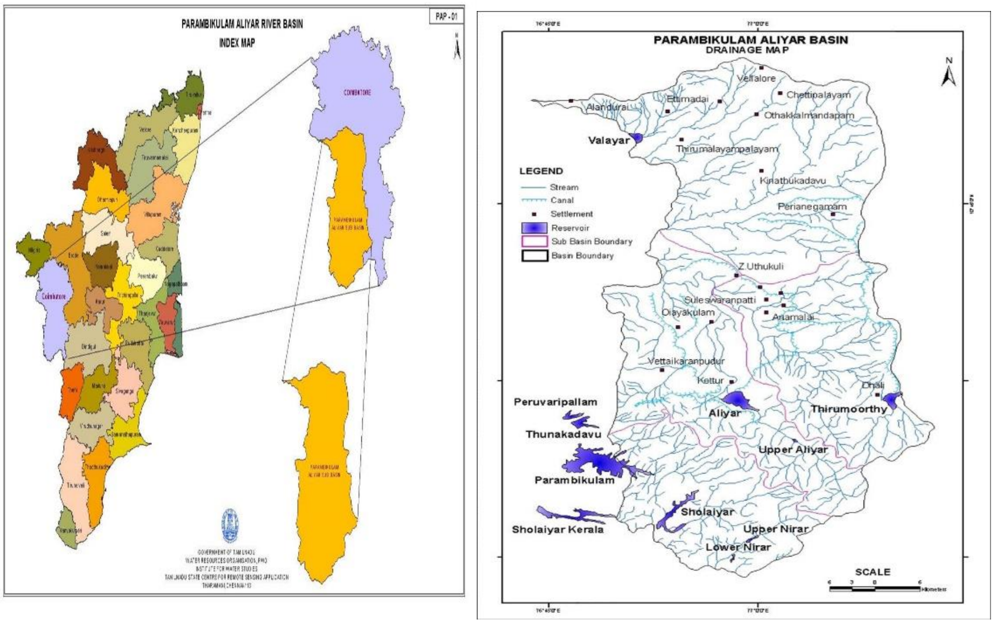

Figure 1: Location and drainage map of the PAP basin (Source: PWD)

Details of crop grown in PAP Basin

The crops such as Coconut, Silk Cotton, Mango, Tomato, Chillies, Bhendi, Sorghum, Grass Moringa, Banana, Arecanut, Cowpea, Teak, Jack, Horse gram, Sugarcane, Maize, Amla, Sapota and Guava were grown in the basin and irrigation practices followed are Micro Irrigation and Flood Irrigation

Soil type in the PAP basin

In this sub basin, due to different stages of weathering and parent materials, the soil types are met with combination of Inceptisol, Alfisol and Entisol. More prominent type is Inceptisol.

Inceptisol: Red or brown or grey soil with surface horizon more developed than sub surface. They are developing soils, moderately deep, coarse loamy to loam moderately drained to well drained and suited for commonly grown crops with exceptions.

Alfisol & Entisol: The red or brown soils having accumulation of illuviated clay in sub surface horizon it well drained, poor water and nutrient holding capacity and annual crops with shallow roots systems comes up well. In Aliyar sub-basin mostly, the soil is red loam, sandy loam, reddish gravel, black clayey soils and black soils with PH - ranging from 7 to 8.9.

Geology of the study area

Geologically, the area is comprised of crystalline rocks of Archaean age. Charnockites form the major rock type of the basin followed by granites, granitic gneisses, dunites, limestones, quartzite basic and ultra basic intrusives of pegmatites and quaternary veins. Charnockites and associated migmatites occupy a major part of the area. The Anamalai hill ranges are composed of charnockites and their magmatised equivalents. Granites intruded into the older gneisses and charnockites and have undergone metamorphism and metasomatism. They occupy mostly small mounds or linear domes in the area. Hornblende, biotite, gneisses occupy the central and northern portion of the basin area (Fig 3). The thickness of laterites seldom exceeds 15m. The thickness of weathered zone is 9.3 to 10 m. The lineaments traversing to a length of 10-15 kms in

NW –SE direction are predominant. Several patterns of sheared and fractured zones are noticed along contact zones and also between varied geological formations. Geomorphologic maps help to identify the various geomorphic units and ground water occurrence and quality.

Materials and Methods:

Collection of ground water samples

Thirty five water samples covering the entire PAP basin were collected from open wells, bore wells and dug cum bore wells during south west, north east, winter and summer seasons of 2010 and 2011 and analyzed for irrigation water quality parameters. Observation wells are spread over the entire basin area (Fig. 2). The irrigation wells in the study area are broadly grouped as dug wells, dug-cum-bore wells and shallow bore wells. The groundwater extraction is worked out based on the cropping pattern and the existing number of wells and their categories.

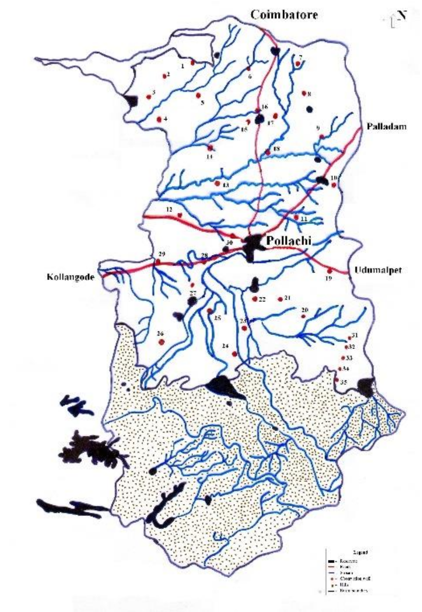

Figure 2: Location of the sampling wells

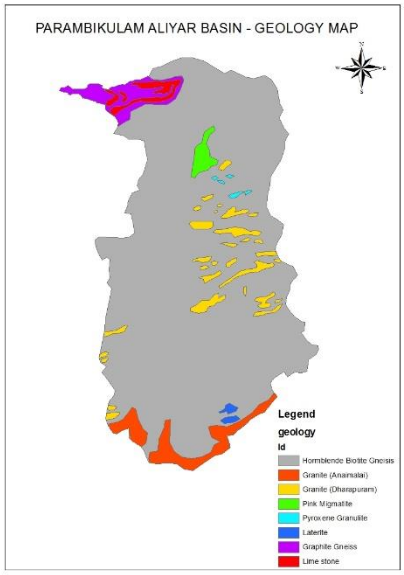

Figure 3: Geology map of PAP basin

Results on ground water quality of Parambikulam Aliyar basin

Thirty five water samples were collected from Parambikulam Aliyar basin from open wells, bore wells and dug cum bore wells during south west, north east, winter and summer seasons of 2010 and 2011 (Four seasons) and analyzed for chemical properties like EC, pH, cations and anions (Fig. 4).

Salinity (EC)

Electrical conductivity values were ranged from 0.3 to 5.19 dsm^{-1}, 0.29 to 6.80 dsm^{-1} 0.3 to 6.84 dsm^{-1} and 0.64 to 4.17 dsm^{-1} during south west, north east, winter and summer seasons of 2010, respectively. The salt content was slightly increased during winter and summers seasons as compared to south west and north east. This may be due to the decreased water table / level in the open and bore wells (Table 1). During 2011, the similar results were obtained.

pH

Natural waters will be having the pH values from 6 to 8.5. The water with pH values >8.5 may contain appreciable amount of sodium carbonates and bicarbonates. pH values range from

6.63 to 7.98 during SW, 6.6 to 8.4 during NE, 7.10 to 8.20 during winter and 7.0 to 8.6 during summer, 2011. In most of the samples, pH values were decreased during SW and NE when compared to winter and summer.

Cations

The samples were analyzed for cations like calcium, magnesium, sodium and potassium. Calcium content ranged from 0.60 to 2.90 m.e L^{-1}, 0.80 to 3.10 m.e L^{-1}, 0.90 to 3.20 m.e L^{-1} and 1.20 to 3.50 m.e L^{-1} during south west, north east, winter and summer seasons of 2010-2011, respectively. Magnesium content varied from 1.00 to19.1 m.e L^{-1}, 1.2 to 26.0 m.e L^{-1}, 0.0 to 26 m.e L^{-1} and 1.00 to 26.5 m.e L^{-1} during south west, north east, winter and summer seasons of 2010-2011, respectively. Most of the samples were found to be with magnesium dominating water. Magnesium exceeds the calcium content in most of the water samples both during south west, north east, winter and summer seasons of 2010-2011, respectively. Magnesium toxicity will be exhibited in continuous use of water to crops. Magnesium and Sodium were the most dominant cations than calcium and potassium. The cations content of the water samples increased during summer season. During 2011, the similar results were obtained. The cations were more during the summer and winter than southwest and north east monsoon seasons.

Anions

Anions like carbonate, bicarbonate, chloride and sulphate were analysed in the water samples. Carbonates varied from 0.30 to 3.5 m.e L^{-1}, 0.0 to 4.0 m.e L^{-1}, 0.0 to 4.2 m.e L^{-1} and 0.2 to 4.5 m.e L^{-1} during south west, north east, winter and summer seasons of 2010-2011, respectively. Bicarbonates found to dominate and it ranged from 0.80 to 12.80 m.e L^{-1}, 1.6 to12.8 m.e L^{-1}, 2 to 10 m.e L^{-1} and 2 to 11.6 m.e L^{-1} during south west, north east, winter and summer seasons of 2010-2011, respectively. Chloride concentration in irrigation water is classified as excellent (<5 m.e L^{-1}) Good (5-10 m.e L^{-1}) and injurious (>10 m.e L^{-1}). Most of the samples (54 % during SW, 43 % during NE, 49 % during winter and 34 % during summer (2011) come under excellent category. Chloride was the most dominant anion during all the four seasons. Most of the samples recorded slightly increase in the anions content during summer and winter when compared to monsoon seasons. This is directly correlated with the water table depth in the bore well and rainfall pattern and distribution. During 2011, the similar results were obtained. The anions were more during the summer and winter than southwest and north east monsoon seasons.

Total hardness

Hardness is an indication of the amount of calcium and magnesium in the water and is expressed as m. eq of $CaCO_3$ L^{-1}, or parts per million $CaCO_3$. The amounts of these two elements in irrigation water are variable. Water with hardness in the range of 100 to 150 mg $CaCO_3$ L^{-1} is considered desirable for plant growth. Plants tolerate high levels of these elements, so toxicity is not normally a problem. However, excessive hardness may cause foliar deposits of calcium or magnesium carbonate under overhead irrigation. Soft water (<50 mg $CaCO_3$ L^{-1}) may need additional calcium and or magnesium over and above that supplied by typical fertilizers to achieve good plant growth. Total hardness in the study area varied from 9.6 to 83.8 m.e L^{-1}

during SW, 10.9 to 112.6 m.e L^{-1}during NE, 6.3 to 112.9 m.e L^{-1} during winter. Micro nutrients and heavy metals contents in all the 35 water samples collected during the 2010 were with in the critical limit. Among the heavy metals, lead was not found in the water samples.

Residual sodium carbonate (RSC) and Residual sodium bi carbonate (RSBC)

RSC values are classified as safe (<1.25), moderate (1.25-2.5) and unsafe (>2.5) based on total hardness. Most of the samples are coming under safe category (86 % during SW, 82.0 % during NE, 72 % during winter and 72 % during summer). Similarly, RSBC ranged from -1.40 to 10.2 meL^{-1} during SW, -1.00 to 10.0 meL^{-1} during NE, -0.5 to 8.10 meL^{-1} during winter and -1.00to 9.40 meL^{-1} during summer. RSBC values are classified as safe (<5.0), moderate (5.0 – 10.0) and unsafe (>10.0) based on total hardness. Most of the samples are coming under safe category (86 % during SW, 82 % during NE, 72 % during winter and 72 % during summer). Compared to 2010-2011 periods, the water quality parameter such as EC, pH, anions and cation contents were decreased during 2011-2012 due the decrease in the rainfall during the period (Fig 4).

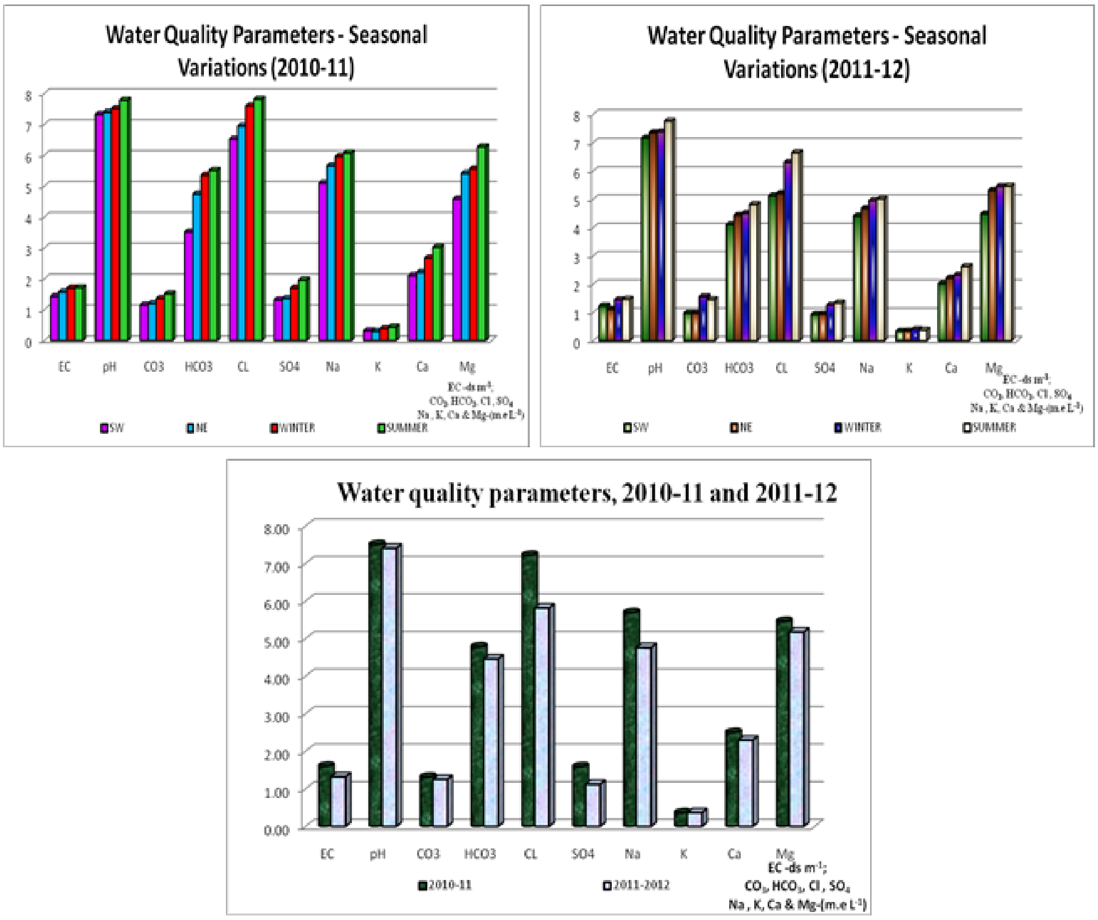

Figure 4: Water quality parameters during different seasons of 2010 and 2011 (Mean of 35 samples)

Table 1: Water table depth (Open well (m), Bore well (Feet), Bore well water level (feet)) in PAP basin (average value)

S.No.	SW			NE			Winter			Summer		
	Open well	Bore well	BW water level	Open well	Bore well	BW water level	Open well	Bore well	BW water level	Open well	Bore well	BW water level
1	12.6	410	110	13.4	410	115	11.9	410	104	11.3	410	98
2	12.0	402	102	17.0	402	107	15.5	402	96	14.9	402	90
3	12.0	415	115	12.3	415	120	10.8	415	109	10.2	415	103
4	7.5	450	150	8.0	450	155	6.5	450	144	5.9	450	138
5	9.0	465	165	8.5	465	170	7.0	465	159	6.4	465	153
6	10.5	410	110	9.9	410	115	8.4	410	104	7.8	410	98
7	9.6	450	150	9.7	450	155	8.2	450	144	7.6	450	138
8	10.8	460	160	15.3	460	165	13.8	460	154	13.2	460	148
9	8.1	475	175	8.6	475	180	7.1	475	169	6.5	475	163
10	9.0	485	185	9.6	485	190	8.1	485	179	7.5	485	173
11	9.6	420	120	9.9	420	125	8.4	420	114	7.8	420	108
12	4.8	435	135	6.3	435	140	4.8	435	129	4.2	435	123
13	3.0	415	115	8.1	415	120	6.6	415	109	6	415	103
14	5.1	465	165	4.5	465	170	3.0	465	159	2.4	465	153
15	12.9	470	170	18.3	470	175	16.8	470	164	16.2	470	158
16	11.4	490	190	11.7	490	195	10.2	490	184	9.6	490	178
17	10.5	415	115	11.2	415	120	9.7	415	109	9.1	415	103
18	8.7	425	125	7.7	425	130	6.2	425	119	5.6	425	113
19	10.2	405	105	9.4	405	110	7.9	405	99	7.3	405	93
20	11.1	415	115	11.4	415	120	9.9	415	109	9.3	415	103
21	9.0	430	130	12.8	430	135	11.3	430	124	10.7	430	118
22	10.2	440	140	10.8	440	145	9.3	440	134	8.7	440	128
23	8.7	455	155	7.7	455	160	6.2	455	149	5.6	455	143
24	8.1	460	150	7.4	460	155	5.9	460	144	5.3	460	138
25	9.9	415	110	10.2	415	115	8.7	415	104	8.1	415	98
26	10.2	465	150	14.5	465	155	13	465	144	12.4	465	138
27	4.8	490	140	5.1	490	145	3.6	490	134	3	490	128
28	5.7	485	150	5.8	485	155	4.3	485	144	3.7	485	138
29	7.2	480	135	7.4	480	140	5.9	480	129	5.3	480	123
30	10.5	465	140	9.7	465	145	8.2	465	134	7.6	465	128
31	8.7	470	130	7.7	470	135	6.2	470	124	5.6	470	118
32	7.8	475	155	8.3	475	160	6.8	475	149	6.2	475	143
33	9.6	490	150	9.9	490	155	8.4	490	144	7.8	490	138
34	11.1	480	165	11.4	480	170	9.9	480	159	9.3	480	153
35	8.7	450	145	8.0	450	150	6.5	450	139	5.9	450	133

Analysis and interpretation of groundwater quality status in PAP basin

The two years data for the 35 samples were analysed using data analysis software and results were obtained and given in the tables 1 and 2. The means value of EC during 2010-2011 was 1.43, 1.57, 1.70 and 1.71 dS m^{-1}, respectively at SW, NE, winter and summer seasons. The maximum EC value of 1.71 dS m^{-1} was recorded at summer season. Among the four seasons the lowest EC was recorded at SW monsoon. The results of the water samples showed that, the gradual increase in the pH was observed during the four seasons. It was ranged from 7.32 to 7.78. The highest pH was recorded at summer season (7.78) and lowest pH was recorded at SW monsoon (7.32). Anions like CO_3, HCO_3, Cl and SO_4 content was analysed in water samples during 2010. Of the four seasons tested for CO_3, the lowest value was recorded at the samples collected from SW monsoon period (1.15 m.e L^{-1}). The highest value of 1.51 m.e L^{-1} was observed at summer seasons. The CO_3 content of the water samples of four seasons ranged from 1.15 to 1.51 m.e L^{-1}. The mean HCO_3 content of water samples during 2010-2011 ranged from 3.51 to 5.51 m.e L^{-1}. The gradual increase in HCO_3 content was noticed up to summer season. The maximum and minimum HCO_3 content of 3.51 and 5.51 m.e L^{-1}, respectively was recorded at 2010-2011. The data on chloride content revealed that, it was higher at summer seasons. During 2010-2011 periods, the maximum sulphate content was observed at summer season (1.96 m.e L^{-1}) and the minimum was observed during the monsoon seasons.

All the major cations like Na, K, Ca and Mg were present in the water samples. the maximum Na, K, Ca and Mg content of 6.07, 0.44, 3.02 and 6.28 m.e L^{-1}, respectively was observed at SW, NE, winter and summer seasons. Regarding K content the lowest and highest content of 0.32 and 0.44 m.e L^{-1} was observed at SW and summer, respectively. The least Ca and Mg content of 2.10 m.e L^{-1} was recorded at SW monsoon (Table 1)

Similar to 2010, in 2011 also among the four seasons of water sample analysis, the highest EC of 1.47 dS m^{-1} was recorded at summer season, the slight reduction in EC value was observed at NE monsoon. Compared to all the four seasons, NE monsoon recorded the lowest EC. The pH of the water samples was analysed and the results shows that, the pH value of four seasons were 7.16, 7.35, 7.38 and 7.76, respectively during SW, NE, winter and summer. The highest and lowest pH of 7.76 and 7.16, respectively during summer and SW monsoon (Singh *et al.*, 2008).

The various anions like, CO_3, HCO_3, Cl and SO_4 content of the water samples were analyses during 2011-2012. The CO_3 content of four seasons were 0.98, 0.98, 1.56 and 1.46 m.e L^{-1}, respectively during SW, NE, winter and summer. The maximum HCO3 content was observed at summer season (4.81 m.e L^{-1}). In case of chloride content of the water samples ranged from 5.12 m.e L^{-1} to 6.64 m.e L^{-1}. The maximum (6.64 m.e L^{-1}) and minimum (5.12 m.e L^{-1}) chloride content was recorded at summer and SW monsoon season, respectively. The maximum sulphate content of 1.34 m.e L^{-1} was observed at summer season. The cations (Na, K, Ca and Mg) content in the water samples were analyses and the results shows that, the maximum cations content of 5.02, 0.38, 2.62 and 5.47 m.e L^{-1} of Na, K, Ca and Mg was recorded respectively at SW, NE, winter and summer. The minimum concentration (4.41, 0.34, 2.02 and 4.48 m.e L^{-1}) observed at SW, NE, winter and summer season. The gradual increase in cation content were observes from SW monsoon season to summer season (Table 2, 3). Compared to 2010-2011 periods, the water quality parameter such as EC, pH, anions and cation contents were decreased during 2011-2012. All the interpretations were directly related to water table depth, water level and rainfall pattern in the basin (CGWB, 1984).

Table 2: Water quality parameters during different seasons of 2010 (mean of 35 samples)

Parameter	**Mean**				**Range**				**SD**			
Seasons	**SW**	**NE**	**Winter**	**Summer**	**SW**	**NE**	**Winter**	**Summer**	**SW**	**NE**	**Winter**	**Summer**
EC	1.43	1.57	1.70	1.71	4.89	6.51	6.54	3.53	1.09	1.23	1.23	0.86
pH	7.32	7.39	7.51	7.78	1.60	1.80	1.10	1.35	0.34	0.41	0.26	0.33
CO_3	1.15	1.2	1.36	1.51	3.20	3.20	4.00	4.00	0.81	0.81	0.86	1.10
HCO_3	3.51	4.74	5.35	5.51	12.0	11.2	8.00	9.60	2.37	2.15	2.02	2.13
Cl	6.52	6.94	7.59	7.81	35.2	44.0	44.0	44.4	6.78	7.70	8.17	7.76
SO_4	1.32	1.36	1.70	1.96	7.29	7.95	7.21	6.88	2.20	2.29	2.19	2.08
Na	5.09	5.66	5.96	6.07	14.4	19.4	21.6	16.1	3.39	4.64	5.66	4.15
K	0.32	0.30	0.39	0.44	2.42	1.04	1.00	1.50	0.45	0.29	0.29	0.40
Ca	2.10	2.21	2.67	3.02	4.48	4.56	4.56	9.28	1.24	1.41	1.39	1.93
Mg	4.58	5.41	5.56	6.28	18.1	24.8	26.0	25.6	3.40	4.42	4.45	4.38
SW: South West Monsoon; NE- North East Monsoon; Units-EC- ds m^{-1}, CO_3, HCO_3, Cl, SO_4, Na, K, Ca & Mg - m.e L^{-1}												

Table 3: Water quality parameters during different seasons of 2011 (mean of 35 samples)

Parameter	**Mean**				**Range**				**SD**			
Seasons	**SW**	**NE**	**Winter**	**Summer**	**SW**	**NE**	**Winter**	**Summer**	**SW**	**NE**	**Winter**	**Summer**
EC	1.23	1.11	1.45	1.47	4.61	5.31	3.5	3.13	0.90	1.05	0.92	0.78
pH	7.16	7.35	7.38	7.76	1.62	1.22	1.71	1.29	0.32	0.26	0.41	0.25
CO_3	0.98	0.98	1.56	1.46	3.2	4.0	4.2	4.30	0.63	0.79	1.00	0.98
HCO_3	4.11	4.43	4.50	4.81	14.2	15.3	6.4	8.20	2.77	3.21	1.72	1.99
Cl	5.12	5.20	6.31	6.64	18.8	20.4	14.8	15.2	3.65	4.17	4.39	4.57
SO_4	0.93	0.94	1.26	1.34	6.68	6.83	6.88	7.05	1.53	1.55	1.96	2.04
Na	4.41	4.67	4.95	5.02	11.6	11.6	13.8	14.6	2.86	2.88	3.62	3.73
K	0.34	0.35	0.40	0.38	1.28	1.35	1.09	2.00	0.35	0.36	0.27	0.38
Ca	2.02	2.22	2.32	2.62	2.30	2.30	2.30	2.30	0.62	0.62	0.62	0.62
Mg	4.48	5.31	5.46	5.46	18.1	24.8	26.0	12.6	3.40	4.42	4.45	2.72

SW: South West Monsoon; NE- North East Monsoon ;
Units-EC- ds m^{-1}, CO_3, HCO_3, Cl, SO_4, Na, K, Ca & Mg - m.e L^{-1}

Rainfall pattern, groundwater fluctuation and water quality status

The rate and level of recharge depends upon the geological, geomorphological and soil conditions in the particular area. So comparison is also made between rainfall and ground water level. The rise in groundwater level is a direct consequence of precipitation, particularly in the monsoon season. The rise of water level at a particular place is characteristic feature of unsaturated zone. There exists a definite relationship between the amount of rise in water level and precipitation for a particular region. To study this relationship in PAP basin, the water level and rainfall data were collected and used. The rainfall distribution in the study area is not uniform due to the presence of hills in the study area and the changes in the topography and ground surface elevation. It depends upon spatial and temporal variations. The study area experiences four seasons namely, Winter season (January & February), Summer season (March, April and May), South west monsoon (June, July, August and September and North East Monsoon (October, November and December). More rainfall occurred in the last two seasons of each year. The rainfall occurs due to north east as well as south west monsoons. But the percentage of rainfall occurring due to north east monsoon is more than south west monsoon (Todd, 1980).

The study area is supplied with irrigation water through Pollachi main canal, whose length is 48 kms with 30 distributories, divided into two zones receiving water once in alternate years. So the farmers have to inevitably depend on groundwater during non supply period and also during supply period in deficit years of monsoon. There are large number of bore wells and open wells in the area. Hence it is necessary to study the groundwater utilization and its impact in long run. An accurate estimation of the spatial and temporal fluctuation of a water table is of prime importance in the management of groundwater resources. Groundwater recharge in hard rock areas is by monsoon rains only. The water table will be lowest in the beginning of the monsoon (May), attains highest level at the end of monsoon (Nov-Dec) and recedes thereafter during the non-monsoon period. The response of groundwater depends on many factors such as initial groundwater level, intensity and distribution of rainfall, drainage pattern of the watershed, vegetation, and water withdrawal pattern for irrigation purpose etc (Vande Aa, 2003).

The rainfall distribution in the study area is not uniform due to the presence of hills and the changes in the topography. The entire PAP basin is influenced by 4 rain gauge stations in plain area and 11raingauge stations in hilly areas. There is a significant rise in water levels due to rainfall in the months of July, October and November. Total amount of rainfall received in the study area during 2010 was 628.7 mm. Rainfall amounts recorded in the study area revealed that there is no rainfall in January, February and March. During April, June, July and August rainfall amounts of less than 50 mm was recorded. About 64.5mm rainfall was recorded during the summer (May). The maximum rainfall of 150.5mm was recorded during the month November. Minimum rainfall occurs during April was 30.5mm. During 2010, there was no rainfall during winter, 15% rainfall occurs during summer, 35% of rainfall occurred during South West monsoon and maximum amount of rainfall 50% occurs during Northeast monsoon.

Total amount of rainfall received in the study area during 2011 was 783 mm. There is no rainfall in January, and July. During February, March, May, June, August and September rainfall amounts of less than 50 mm was recorded. About 33mm rainfall was recorded during the summer (May). The maximum rainfall of 256mm was recorded during the month October. Minimum rainfall occurs during February was 7mm. During 2011, there was rainfall during winter 1%, 18% rainfall occurs during summer, 9% of rainfall occurred during South West monsoon and maximum amount of rainfall 72% occurs during Northeast monsoon. In the study area, the data of water quality and water table of 35 observation wells between 2010 and 2012 was taken for consideration.

Mapping using RS and GIS

The latitude/longitude details of observation wells in PAP basin are taken using GPS and with the latitude/longitude details of observation wells, the quality map for the ground water status of PAP basin was prepared using ARC GIS software. The Electrical Conductivity (EC) values at different seasons of 2010 and 2011 were taken and quality map for the salinity was prepared (Fig 5 and 6).

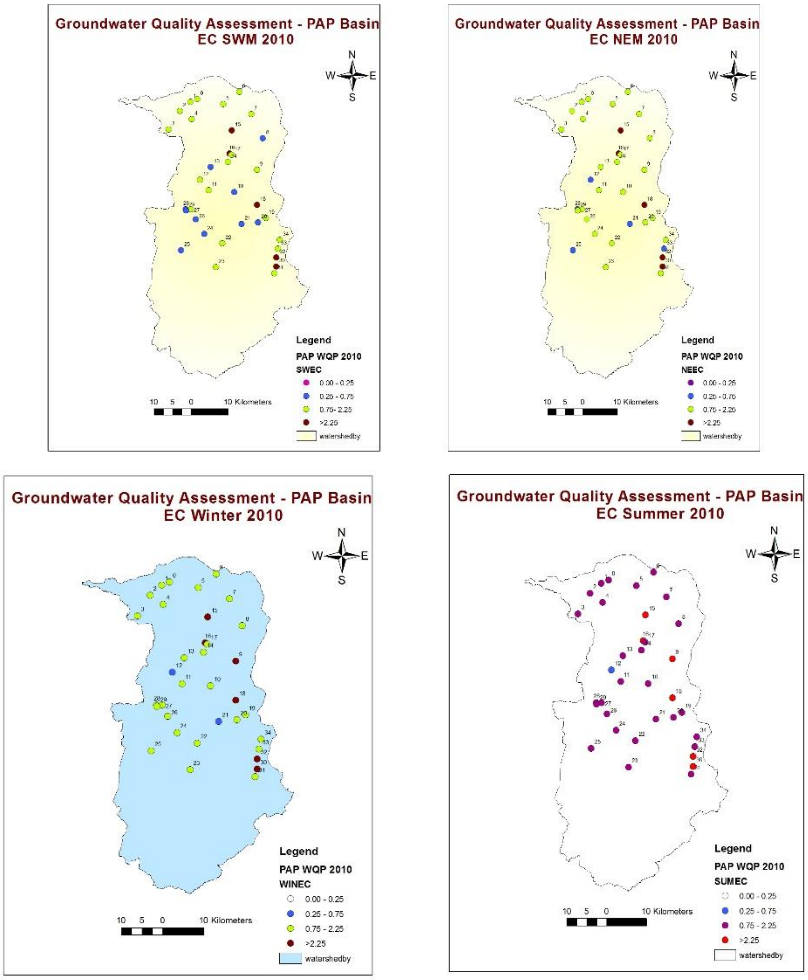

Fig 5: EC value in the groundwater samples of pap basin in various seasons of 2010

Electrical conductivity values were ranged from 0.3 to 5.19 dsm^{-1}, 0.29 to 6.80 dsm^{-1} 0.3 to 6.84 dsm^{-1} and 0.64 to 4.17 dsm^{-1} during south west, north east, winter and summer seasons of 2010-2011, respectively. The samples were classified under USSL classification. Most of the samples come under high salinity class (C_3) (57, 74, 77 & 80 %), followed by very high salinity class (C_4) (14, 11, 17 & 17 %) medium salinity class (C_2) (29, 15, 6 & 3 %) during the four seasons of 2010-2011, respectively. The salt content was slightly increased during winter and summers seasons as compared to south west and north east (Abiker *et al.,* 2007).

Electrical conductivity values ranged from 0.09 to 4.7 dSm^{-1}, 0.02 to 5.33 dSm^{-1}, 0.34 to 3.84 dSm^{-1} and 0.48 to 3.61 dSm^{-1} during south west, north east, winter and summer respectively. The samples were classified according to USSL classification. Most of the samples come under high salinity class (C_3) (57, 37, 63 & 69 %), followed by very high salinity class (C_4) (11, 14, 17 & 17 %) medium salinity class (C_2) (23, 37, 20 & 14 %) during the four seasons of 2010-2011, respectively. Most of the samples come under high salinity class (C_3) followed by medium salinity class (C_2), very high salinity class (C_4), low salinity class (C_1) during south west, north east, winter and summer.

The geology of the PAP basin was correlated and super imposed with quality of the ground water using GIS technique (Fig 7).

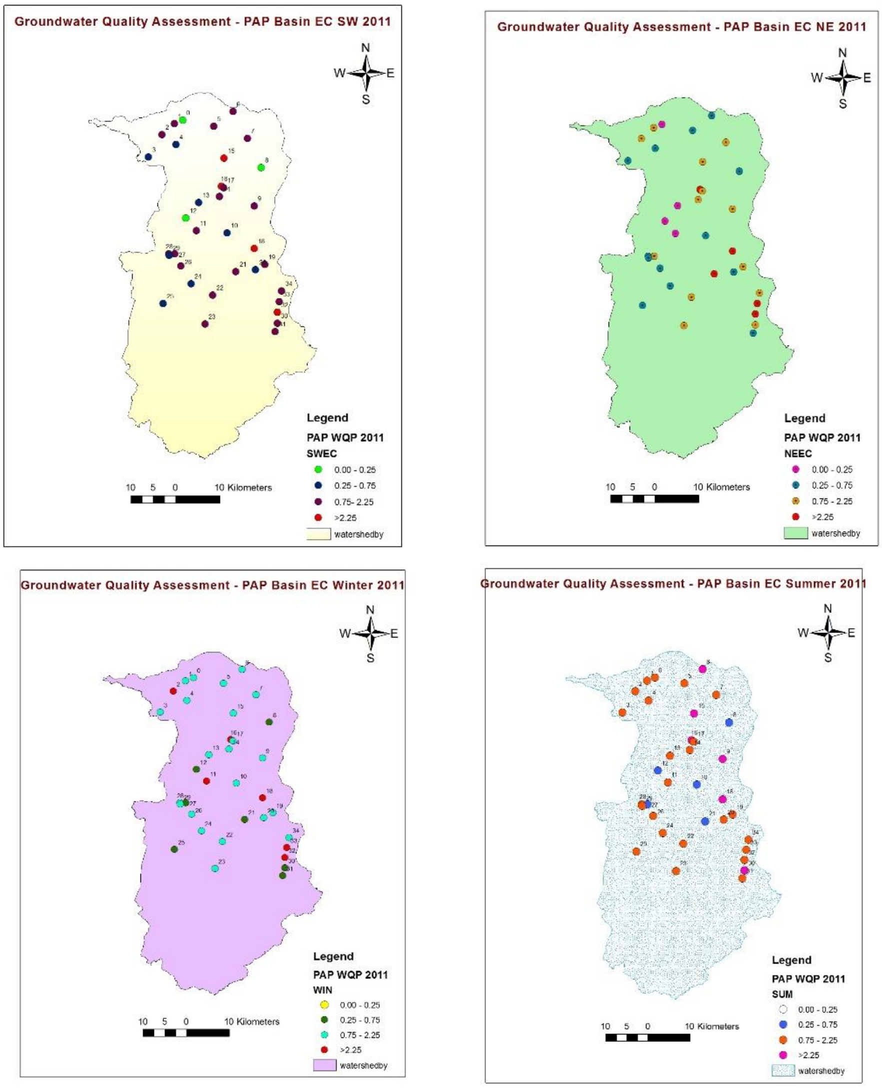

Figure 6: EC value in the groundwater samples of pap basin in various seasons of 2011

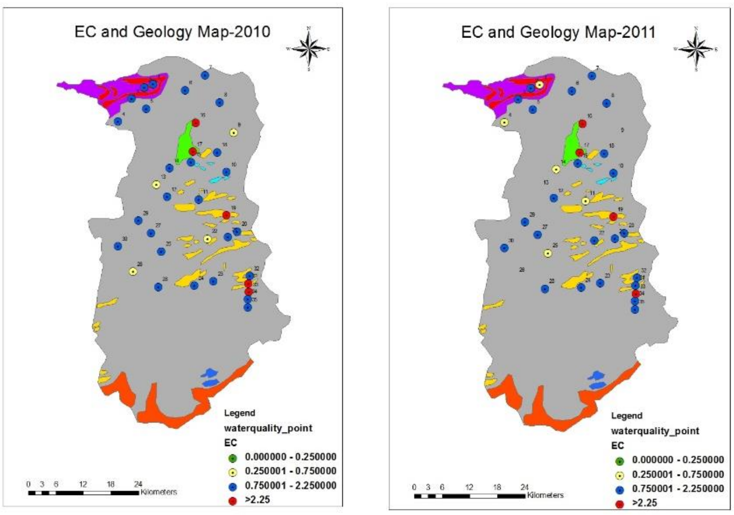

Figure 7: EC in the ground water samples with geology (2010 and 2011)

Conclusion:

Present study is to assess the groundwater quality in this basin. The increase in ground water levels and water quality mainly depends on the rainfall and recharge of ground water. Decrease in the ground water level in some of the observation wells are mainly due to over exploitation of ground water, and reduction in rainfall. When compared to summer, the post monsoon water sampling indicates that most of the samples cations like sodium, potassium, calcium and magnesium were reduced and the anions like carbonate, bicarbonate, chloride and sulphate were also reduced. The increase or decrease in the salt content of the water samples are positively correlated with the water table / level of the open or bore wells. Micro nutrients and heavy metals contents in all the 35 water samples collected during the 2010 and 2011 were within the critical limit. Some of the branch canals and distributaries remain dry for a long period except during supply through them (Richard and Peter, 2002). Hence the ground water recharge in these areas is not possible. Moreover, the ground water is also extracted for agriculture purpose during non irrigation period by the farmers. Hence the groundwater depletion is more in these areas. The management strategies such as growing of salt tolerant crops and varieties, conjunctive use of saline and good quality water, drip irrigation, gypsum treatment, judicious use of organic manures, ridge and furrow method of sowing etc maybe followed for the amelioration of groundwater quality in the basin.

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DISASTER DUE TO WATER LOGGING ON CROP AND SOIL ENVIRONMENT

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Abstract:

Fluctuations in the climate, often characterized by unpredictable instances of intense rainfall, lead to the issue of water accumulation in crops that are extensively irrigated. This problem becomes more severe when combined with higher temperatures and occurs prominently in areas where the soil's ability to drain internally is insufficient. The suppression of oxygen-dependent respiration that occurs when plants experience waterlogging hampers their energy metabolism, constrains their growth, and impacts various stages of development, spanning from the initiation of seed germination to the expansion of vegetative structures and subsequent reproductive phases. The primary factors responsible for disturbing the equilibrium between water influx and efflux, resulting in stagnant water, are improper handling of soil, water, and crops in irrigated areas, along with the interference of natural drainage systems due to various developmental actions. Comprehending the extensive range of potential impacts on the environment, soil system, and crops arising from waterlogging is a significant area of concern.

Keywords: water logging, environment, soil, crop, drainage etc.

Introduction:

The negative effects of climate change are expected to raise the likelihood of more frequent occurrences of both flooding and waterlogging. Soil is deemed waterlogged when the layer of standing water on its surface exceeds the soil's field capacity by a minimum of 20% (Mohanty *et al.*, 2020). Plants are the living organisms most vulnerable to waterlogging due to their close interaction with both soil and water. Waterlogging significantly impacts crops such as maize, mulberry, rice, sugarcane, tomatoes, wheat, beans, and a variety of vegetables. In situations where plants experienced waterlogging, there was a lack of oxygen around their roots, leading to insufficient aerobic respiration. This scarcity resulted in an increase in anaerobic respiration (Shu *et al.*, 2019). Soil compaction additionally raises resistance against root expansion and has the potential to impact the germination, emergence, and growth of crops (Kaur *et al.*, 2019). According to work done by Abhay Sankar Sahu (2014) waterlogging occurs due to the complex interplay of factors such as geological formations, soil composition, land height, incline, the density of drainage systems, unorganized barriers, groundwater levels, human interventions, and other relevant aspects, all viewed from both spatial and environmental standpoints. Both internationally and within India, waterlogging has been recognized as a concern for agriculture in rural regions due to the presence of sunken basin-like formations, blocked drainage systems, and the occurrence of floods following substantial rainfall. Based on the research conducted by Joshi *et al.* (2021) the primary issue of waterlogging arises from elevated tides and inadequate drainage systems during peak periods in the monsoon season. To address this, potential solutions and measures need to be devised to minimize waterlogging and tackle associated salinity problems. Based on the findings of previous works it was observed that waterlogging diminishes the accessibility of nutrients, diffusion of oxygen, and cellular respiration, all of which impact plant water interactions and hinder the growth of biomass. The decrease in yield is further intensified by the developmental consequences of waterlogging, which encompass the shedding of flowers induced by ethylene.

As documented in the studies conducted by Shunsaku Nishiuchi *et al.* (2012) regarding waterlogging, the processes involve the creation of aerenchyma tissue and a restriction in the occurrence of root oxygen loss (ROL). These adaptive characteristics grant rice plants the ability to endure submersion or waterlogging significantly better than other crops that thrive in arid conditions. Based on the findings of Jiawei Pan *et al.* (2021) in situations of waterlogging, leaf stomata shut down, while the breakdown of chlorophyll, leaf aging, and yellowing collectively diminish the capacity of leaves to harness light, resulting in a drop in the rate of photosynthesis. Waterlogging removes air from the pores in the soil, causing a hindrance in the exchange of gases between the soil and the atmosphere. Simultaneously, the rate at which oxygen diffuses in water is merely a fraction of what it is in air – approximately 1/10,000. As a consequence, the accessibility of oxygen in waterlogged soil becomes severely limited, leading to a decrease in root respiration, reduced root vitality, and a shortage of energy. According to study revealed by Maryam *et al.* (2012) the most undesirable outcome of waterlogging is the occurrence of hypoxia, which refers to an insufficient supply of oxygen, or anoxia, signifying a complete absence of oxygen within the soil environment. These conditions result in stunted growth, hindered metabolic functions, and ultimately lead to a decrease in wheat yield. According to the research conducted by Sahu *et al.* (2014), the occurrence of waterlogged conditions in a specific position is influenced by two topographical elements. These factors dictate the likelihood of waterlogging: it rises with a larger contributing drainage area and diminishes as the local slope angle increases. As per research documented by Jayan *et al*, (2010), the Kuttanad region in Kerala, India, experiences prolonged submersion throughout most of the year, and it is drained after the conclusion of the monsoon season. Specialized large sluice gates are in place, which can be managed to allow excess floodwater to drain into the sea and to block the intrusion of seawater into the lake. As indicated by research findings from Yanling *et al.* (2016) instances of waterlogging can arise due to extended periods of rain, flooding resulting from snowmelt, or inadequate soil drainage. The reduction in crop yield due to waterlogging can span from 15% to 80%, fluctuating based on the duration of the stress, types of soil, and the varying tolerance levels among different plant species. Hence, it is essential to give precedence to carrying out a comprehensive examination and crafting efficient approaches designed to combat the risks posed by waterlogging to both crops and the soil ecosystem.

Impact of water logging on crops

Of the numerous perils posed by waterlogging on the environment, the significant focus worldwide revolves around its impact on crop cultivation. As per research findings disclosed by Mohanty *et al.* (2020), tomatoes exhibited the development of adventitious roots when subjected to waterlogging conditions. This phenomenon assists the root system in directly accessing oxygen from the atmosphere and facilitates the absorption of nutrients from the soil by the plant. Since plant roots are in close contact with the soil and the water present within it, extended exposure to water leads to detrimental impacts on the physiological processes of plants. Excessive moisture in the soil has been demonstrated to induce stress in soybean plants. Indicators of stress caused by waterlogged conditions encompass suboptimal seed sprouting, yellowing of leaves, root deterioration, reduced nodulation, diminished yield, decreased plant mass, fluctuations in internal nutrient levels, and even plant demise. The stress experienced by soybeans due to waterlogging is intricate, involving intricate interplays among soybean plants, the chemical composition of the soil, the microorganisms residing in the soil, and prevailing weather conditions. Recognized mechanisms of stress resulting from waterlogged conditions encompass diminished soil oxygen levels, heightened soil carbon dioxide levels, alterations in nutrient accessibility, and heightened vulnerability to soil-borne pathogens. According to Baizhao *et al.* (2013) the impact of waterlogging on the buildup of dry plant material exhibited comparable outcomes for both cultivars. The detrimental consequences of waterlogging differed depending on the developmental phase and the duration of the waterlogging period.

Substantial declines in both the accumulation of dry matter and the pace of accumulation were observed subsequent to subjecting plants to waterlogging at different stages of growth. Plant roots typically reside in an environment where they are in touch with oxygen at a partial pressure akin to the surrounding gaseous atmosphere. Hypoxia denotes a drop in oxygen levels below the optimal threshold. This situation arises when plants experience brief flooding, causing partial submersion where the roots are underwater while the shoots remain in the air. This form of stress is prevalent and frequently encountered. An additional type of water-induced stress is Anoxia, wherein the plant becomes fully submerged in water. Consequently, the complete absence of oxygen triggers harm to the plant during extended periods of flooding (Moumita *et al.,* 2017). Based on experimental findings presented by Moumita *et al.* (2017), when examining Mulberry crops, the relative water content of leaves exhibited a progressive rise as the duration of flooding extended. Elevated leakage of electrolytes and amino acids into the surrounding medium indicated compromised membrane integrity due to excessive water stress. Among the various photosynthetic pigments, chlorophylls were the most susceptible to the effects of flooding. There was an inverse relationship established between the length of the flooding period and the levels of specific primary metabolites (such as total soluble sugars, total soluble proteins, and RNA). The concentration of ethylene displayed a gradual increase up until the tenth day of flooding, after which it sharply declined. Sugarcane yield is also affected due to water logging as per the study revealed by Palachai *et al.* (2019) under both brief and prolonged instances of waterlogging, there were marked variation s among cultivars in terms of yield characteristics like the amount of cane suitable for milling, the weight of individual stalks, the length and diameter of stalks.

Specifically, cultivars KK3, K88-92, TBy28-0941, and LK92-11 consistently demonstrated elevated millable cane yields in both conditions, while K93-219 exhibited notable single stalk weight in both scenarios. Furthermore, a correlation between single stalk weight and cane yield was identified during short-term waterlogging. Notably heavy cane weight during short-term waterlogging contributed to the attainment of high cane yields. In line with research documented by Mashetty *et al.* (2022), a deficiency of oxygen in the vicinity of the plant's roots leads to a notable reduction in the selectivity of potassium (K+) over sodium (Na+) uptake. Existing literature also indicates that under hypoxic conditions, the permeability of root membranes to Na+ diminishes. Boem *et al.* observed a significant decrease in the absorption of nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca) in canola plants when subjected to brief waterlogging stress. Similarly, decreased intrinsic levels of nitrogen, phosphorus, and potassium have been reported in maize plants. According to the perspective shared by (D. Steffens *et al.*, 2005), the hindrance of plant growth due to waterlogging is mainly attributed to a shortage of nutrients rather than an excess, as evidenced by the analysis of nutrient levels in barley and wheat shoots. The concentrations of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), copper (Cu), zinc (Zn), and manganese (Mn) exhibited significant decreases under the conditions of waterlogging treatment. The rice crops faces a serious water logging impact due to extended period of heavy rainwater accumulation in the rice fields as shown in fig.1.

Figure 1: Water logged rice field

If waterlogging occurs during the period of seed sowing or at the seedling stage, it leads to the death of the young plant and prevents any subsequent growth. This is due to the fact that seeds or the initial roots of seedlings are not immediately equipped to handle waterlogging and are especially susceptible to specific diseases triggered by excessive water inundation. In this fashion, waterlogging significantly impacts crops, leading to diminished yields and, in certain instances, even the demise of crop plants.

Impact of Water logging on Soil:

Another highly impacted aspect of the environment due to waterlogging is the soil. Because water gets absorbed into the soil, various physicochemical properties of the soil are altered, leading to soil erosion. The ideal soil makeup for supporting plant growth should consist of approximately equal parts solids and pore space, each accounting for around 50%. Within these pores, the combination of air and water should closely approach a 50:50 ratio, meaning that about 25% of the soil's volume should be filled with air. The efficiency of gas diffusion is influenced by the physical attributes of the soil, with soil porosity playing a significant role, particularly the portion containing air (Michelle Morales-Olmedo *et al.*, 2015). Gas flow within the soil is a constantly changing process, primarily driven by diffusion. The key factor to take into account is the gas diffusion coefficient within the soil. This coefficient is influenced by factors such as soil texture, structure, distribution, pore size, connectivity, and the complexity of pathways. The sluggish movement of gases within water speeds up the buildup of potentially harmful byproducts stemming from anaerobic processes, which include substances like ethanol, lactic acid, carbon dioxide (CO_2), nitrogen (N_2), hydrogen ions (H^+), and methane. Continuous extension of roots is essential for efficient resource acquisition during the vegetative phase of growth, even in crops that receive ample irrigation and fertilization. Consequently, environmental elements that impact root development, such as waterlogging, play a pivotal role in ensuring the highest possible final yield (Ullah Najeeb *et al.*, 2015). Waterlogging refers to a situation where the soil within a land area becomes fully soaked with water, either temporarily or permanently. In such areas, the water table rises significantly, saturating the soil pores within the region where crop roots grow. This saturation hampers the usual movement of air, leading to reduced oxygen levels and elevated carbon dioxide levels (Joshi *et al.*, 2021). Water saturation in the area where plants root is impacted by a variety of elements, which encompass climatic conditions, factors governing water infiltration into the soil, water flow across the soil surface, and the utilization of soil water by plants and various life forms. An important contributor to the rise in instances of flooding or waterlogging is the escalation in the occurrence of intense precipitation events and numerous days of wet weather. As per findings presented by Subrahmanyan (1927), the saturation of soils with excess water is a prevalent occurrence, particularly in tropical regions characterized by intense rainfall and recurrent instances of riverbank overflow and lake breaches. Extensive stretches of land frequently experience prolonged periods of submersion. Notably, the rice fields, spanning approximately eighty million acres in India alone, necessitate being sustained in marshy conditions for several months.

Controlling measures of water logging to avoid destruction of soil and crops

For soils that undergo temporary waterlogging due to inadequate practices or excessive rainfall, the choice of resilient rootstocks should account for strategies of immediate adjustment. This involves root mechanisms that react to soil variations, encompassing traits like antioxidant capability and the kinetics of nutrient assimilation. Additionally, the reshaping and dispersal of root system structure in soils prone to waterlogging should also be considered. In line with the findings of Justin and Armstrong (1987), species possessing naturally shallow-rooted systems exhibit significant resilience to extended periods of waterlogging. Among the trio of mechanisms responsible for regenerating root systems, one involves promoting the growth of pre-existing root primordia located within the base of the shoot, as observed in maize. The presence of excessive water saturation is beneficial for successfully cultivating rice in soils rich in iron (high-Fe soils). Our proposal stems from the idea that the subpar growth of rice in high-Fe soils, especially within waterlogged conditions or paddy-field setups, can be attributed to the heightened solubility of certain metals like iron (Fe), aluminum (Al), manganese (Mn), and other harmful metal ions. Earlier research has documented that waterlogging in acidic soils similarly led to a decrease in the dry weight of oat plants (*Avena sativa* L. cv. Selma). Embracing biodrainage technology could potentially transition a conventional agricultural farming approach into an agroforestry system. The decision to adopt this technology hinges on an individual's viewpoints. To evaluate the project's strengths and weaknesses, a SWOT analysis can serve as a valuable tool for identifying both the favorable and unfavorable aspects (Dubey, 2012). Data related to soil classification play a valuable role in the strategic development of aquaculture ventures, aiding in the preliminary evaluation of soil characteristics at a specific pond location. The physical attributes of soils wield a significant impact on various aspects such as plant growth, hydrology, environmental management, and engineering applications. The inherent characteristics and qualities of soil particles, including their size distribution and arrangement, directly influence the overall non-solid pore space volume as well as pore size. This, in turn, affects the interplay between water and air within the soil. In summary, numerous precautionary measures can be taken to prevent losses caused by waterlogging.

Conclusion:

Recent research has compiled the relevant effects of waterlogging on crops and soil ecosystems, encompassing disruptions in terms of chemistry, biology, and physical attributes within the environment. These investigations were carried out following a concise examination of waterlogging and its effects on different environmental elements, particularly soil and crops. At the same time, various preventive strategies are also deliberated upon, aimed at mitigating the harm caused by soil degradation and the adverse consequences of waterlogging on crop productivity. However, it is essential to recognize that waterlogging inadvertently contributes to the spread of aquatic devastation to soil fertility and crop production. This is because fields suffering from waterlogging require a considerable amount of time to recover and enhance the quality of the soil. The recommendation is to implement modern and appropriate field drainage systems, alongside conducting both physical and chemical soil analyses. This approach aims to prevent losses caused by waterlogging.

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