Edited Book

Green Frontiers

Emerging Technologies for a Sustainable Future

Editors

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Preface

In an age marked by rapid scientific progress and increasing global challenges, the integration of knowledge across disciplines has become essential for meaningful innovation and sustainable development. *Green Frontiers: Emerging Technologies for a Sustainable Future* is conceived as a comprehensive academic work that brings together diverse fields of study to present a unified perspective on contemporary scientific and technological advancements. The book seeks to highlight how evolving knowledge systems can address pressing environmental concerns, enhance technological capabilities, and contribute to the betterment of society.

The primary purpose of this volume is to provide a balanced understanding of both foundational concepts and emerging trends across multiple domains. It explores critical issues such as environmental degradation, renewable energy development, advanced materials, and intelligent systems, emphasizing their interconnected nature.

The scope of the book is intentionally broad, encompassing insights from environmental science, physics, engineering, biotechnology, and applied sciences. It reflects the growing need to move beyond isolated disciplinary frameworks and adopt integrated perspectives that foster innovation.

This volume is designed to serve as a valuable resource for students, researchers, and professionals alike. Students will find it particularly useful in building conceptual clarity and gaining exposure to emerging areas of study.

The relevance of *Green Frontiers: Emerging Technologies for a Sustainable Future* lies in its focus on the dynamic relationship between scientific advancement and societal needs. As the world faces challenges such as climate change, resource scarcity, and technological disruption, there is an increasing demand for knowledge that is both comprehensive and applicable. It is hoped that this work will encourage critical thinking, inspire innovation, and enable readers to contribute effectively to a sustainable and technologically advanced future.

— Editorial Board

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“Innovation and sustainability are not opposites—they are partners in shaping the future.”

— Paul Polman

Former CEO, Unilever; Sustainability Leader

CHAPTER 6

WATER POLLUTION: A REVIEW OF CAUSE AND SOLUTION

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Abstract:

Water pollution is a major environmental threat that contaminates public health, sacrifices the ecological balance and economic order. In this review may be the main elements responsible to water pollution: Discharges from industries, run off of agricultural area and urban areas combined with lack of treatment plants. This reflects the effects of pollutants to fall into two sites: heavy metals, nutrients and pathogens with water quality in organized steps I toxin entering aquatic ecosystems. Further, strong measures to reduce pollution in water have been covered that are necessary components like the technological interventions aimed at waste treatment technology; effective policies/ regulatory frameworks for agricultural practices and community led conservation acts. This review highlights the critical role of both regulatory and underlying non-regulatory mechanisms that are combined in holistically integrated approaches, incorporating case studies as well as current research — placing emphases on scientific advances to address water pollution for long term protection of our precious resources for future generation.

Keywords:

Water pollution, contamination, human health, pollution

Introduction:

The generalization still applies here, eutrophication constitutes one of the most pertinent and complex environmental challenges with far-reaching societal implications stretching from ecological to human health and welfare. When pollutants such as industrial effluents, agriculture runoff and pathogens degrade the water bodies

that nobody can drink from or enjoy for recreation (or aquatic life to live in). Water pollution arises from various sources such as industrial processes, agriculture natural spread urban runoff mis use in sewage treatments etc.

Addressing the increase in water pollution has no shortcuts. There are also other long-term solutions by refining the wastewater treatment processes, tightening regulation and enforcement over effluents discharges into water bodies to enforce sustainable agriculture practices alongside public communications towards building awareness and involving community in conserving its usage. Water is valuable and with it so brings sustainable agriculture that can help save this resource for the wildlife or humankind.

Review of literature:

Cause and effect of water pollution

Water is the most important natural resource on this planet despite knowing that Water pollution is a very big problem in the world nowadays and in last few years it has increased rapidly every country being small or big is facing this problem the government of that country and water council are trying to resolve it but they are unable or failed to do this the main reason for the cause of water pollution are human activities near about (80%). We human are the biggest cause of water pollution despite knowing that it will become threats for us because without water living on this earth for a single day is next to impossible more than 80 percent of water on this earth is contaminated there are many cause of water pollution but the biggest one is industrial waste industrial and radioactive waste is directly release in big ponds and rivers which contaminate the water and it is very difficult to treat it and make it clean because some harmful chemical get dissolve in it and it is very difficult to separate in the second most comes the sewage problem is sewage pipes are directly connected river other causes like animal waste food, climatic changes, sedimentation are some cause of Agriculture sites also contribute of water pollution farmer use pesticides and fertilizer to protect their crop from bacteria and insects these chemical are harmful for clean water when they go deep inside the soil they contaminate ground water global warming is also one cause of water pollution as in that case temperature increases in some of region felt drought and some

region felt flood urbanization and deforestation can be one of the reason water pollution as it lead to reduction in rain fall and then if there is a rainfall if might be in not a proper place from where we can use water and most of the people in their houses there is no rain water harvesting so water get wasted. People nowadays use detergent powder in household and daily life is very harmful when mix with the clean water because it is also very difficult to clean it at low levels. These are some chemical method of water pollution if we come to the physical method of water pollution the human beings throw unwanted things in beaches and in clean river which change the colors of water increases or decreased the potential of hydrogen of water and makes it unhealthy to use apart from this oil spill and leakages contaminate the large area of ocean water when ship runs on the water sometimes there is leakage in it and the engine oil or petroleum get split over large surface of water and in this way they contaminated the water. If water pollution continues in this and if we don't have good techniques to resolve it very soon we all will faces water crisis.

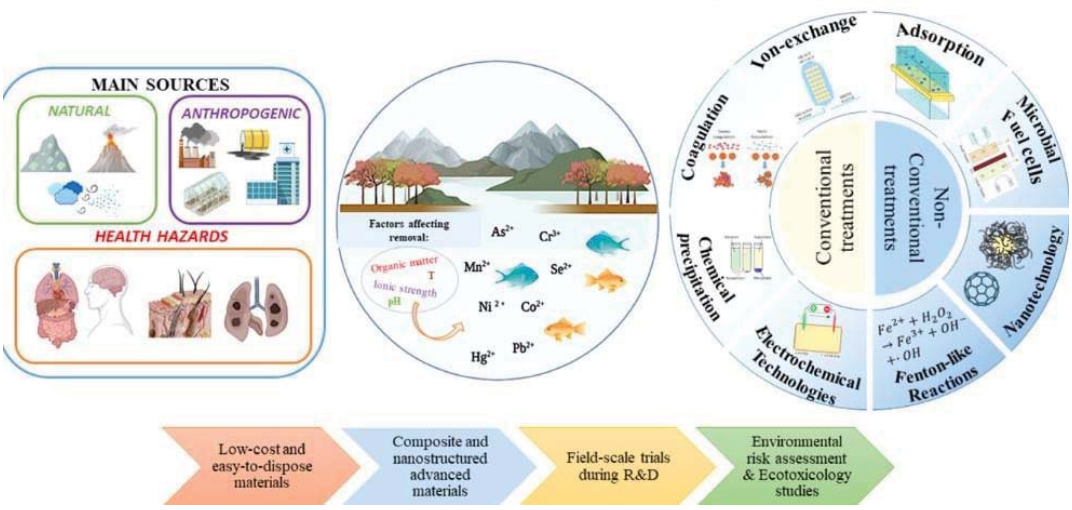

Figure 1: Heavy water pollution and remediation [1]

Water pollution is a great threat to human health because it pollutes drinking water sources and allows harmful substances into the body. These pollutants, like industrial waste, agricultural runoff and chemicals to heavy metals or other different contaminants including pathogens etc., affect the quality of water causing various health related issues. The effects on human health, in turn depend upon the contaminants and what concentration of it is present in water.

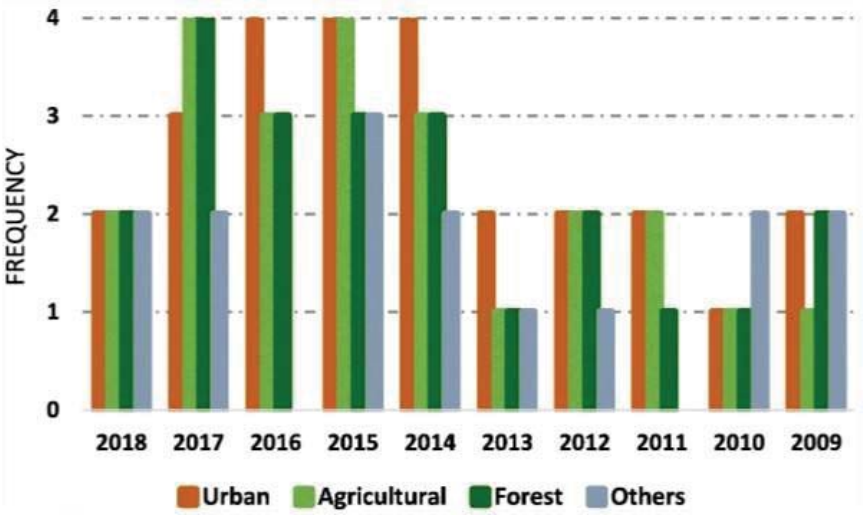

Figure 2: Frequency of land use attributes used in different studies in Malaysia [2]

Diseases Caused by Pathogens:

Pathogens like bacteria, viruses and parasites (pathogenic) in polluted water cause various kind of waterborne diseases such as cholera, dysentery, tuberculosis, typhoid fever, gastroenteritis. The diseases spread through fecal-oral routes, which take place from water contaminated with the faces that cause severe dehydration and acute watery diarrheas up to death within days in children or immunocompromised individuals. The other is parasitic infections like schistosomiasis and giardia that affect more than a billion people globally, when the Sartor Laboratory for Comparative Gastrointestinal Inflammation at UNC School of Medicine study was carried out.

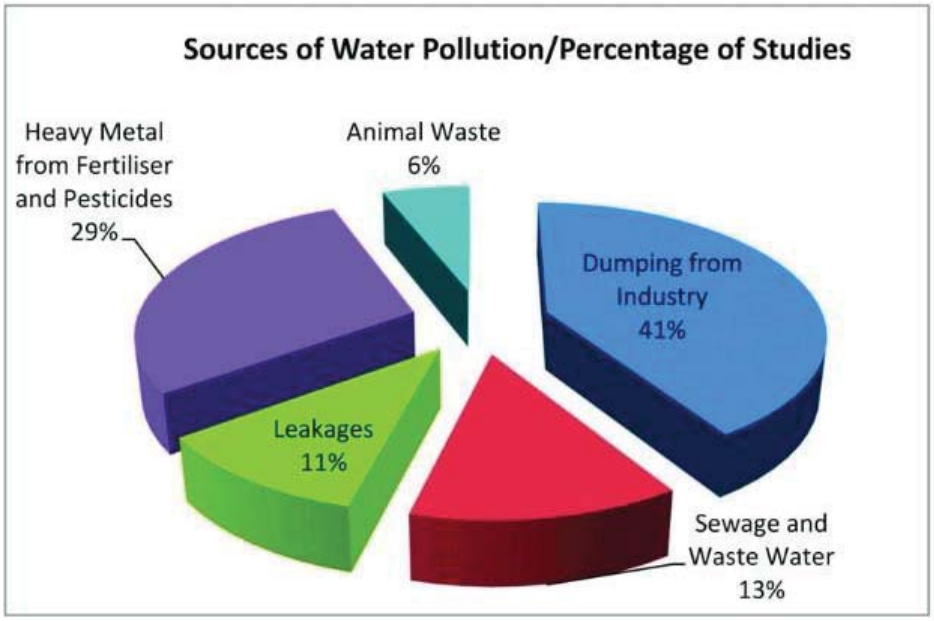

Figure 3: Source of water pollution [3]

It is known that industrial pollutants with long-term health effects in humans include heavy metals (lead, mercury, cadmium and arsenic), pesticides such as DDTs misplaced more than three decades ago (they are the same organic compounds mentioned previously) or VOCs -Volatile Organic Compounds-. Long-term exposure to these toxin chemicals can lead to serious health issues that may include:

- Lead and mercury are particularly dangerous for children, resulting in lower IQs, developmental delays (mercury), cognitive impairment and neurological disorders such as Alzheimer's disease.
- Cancer: Some chemicals, such as arsenic, nitrates and certain industrial-process by-products are associated with elevated risks of cancer - especially the bladder, liver, and kidneys.

Endocrine Disruption: Pollution including certain chemicals like BPA and phthalates can disrupt hormonal function in animals, impairing reproductive health processes if not causing developmental deficits as well.

Heavy metals such as Mercury, lead and cadmium pollute the environment over time to cause poisoning of these toxins which accumulate in body. In organelle formation, especially in the kidney and liver as well as nerves. Ingesting arsenic in drinking

water, for instance, can lead to skin lesions over the long term and has even been linked with heart disease or cancer.

Impact on Workers and Vulnerable Populations

Waterborne diseases and chemical exposure especially affects children, pregnant women and the elderly. When pregnant women are exposed to water contaminated with lead, it can result in severe consequences for the developing fetus such as birth defects, low body weight at birth and developmental issues later on. In addition, the immune system in children is less strong and therefore contrasts to our older age groups here of course there are most pathogens found in polluted water than allow higher morbidity rates enjo motivation for areas with better sanitation by all levels.

Water Pollution: Disease Heterogeneity

Background Disease heterogeneity in cancer is distribution and ability of disease to grow across populations/regions. Water pollution helps to product this heterogeneity in different way.

Type of Pollutant: Industrialized regions, Factory-produced chemical waste (chemical pollution), It leads to a higher number people with cancer and neurological disorders being found. On the opposite end of the spectrum, underprivileged countries experience much greater incidences when it comes to infectious waterborne diseases since proper sanitation is not provided prolonged exposure will contain microbial impurities.

Socioeconomic disparities: Low-income communities have less access to clean water and therefore are more likely to be exposed to contaminated sources. The poor bear a greater load of attested diseases (waterborne and chronic long-term conditions) in their communities, reinforcing health inequalities.

Water Treatment Technologies for the Removal of Contaminants in Water:

Inorganic and organic pollution has been detected worldwide causing a negative impact on the environment as well in human health. There are numerous technologies that provide safe and efficient drinking water treatment. Being dependent on the nature of pollutants, these processes for removal inorganic / organic contaminants depend and mechanisms employed are different for chemical nature of pollutants-

themselves,, also Different techniques (at least some) serve similar rotes.

Inorganic Contaminants:

Ironically charged metals, Heavy metal pollutants (eg - lead, mercury and arsenic), minerals including fluoride or nitrate anions; inorganic constituents like sulfates of chlorides. Sources of debris can include industrial effluent in rivers, agricultural runoff (particularly wearing high levels of chemical fertilizer and/or pesticides into those water bodies), as well as activities such tectonic mineral mines producing mercury or other toxins. Unity Engine, the rest is partaking rock weathering. Common water treatment technologies for inorganic contaminants-

- **Chemical Precipitation:** Despite being still used for removal of heavy metals and other dissolved inorganic pollutants, it is a very old technology. This consists of the dosing of chemicals (lime, sodium hydroxide or aluminium sulfate) that react with contaminants to form insoluble materials which will be removed by sedimentation and/ filtration. Lime softening is typically used to remove hardness (having calcium and magnesium ions).

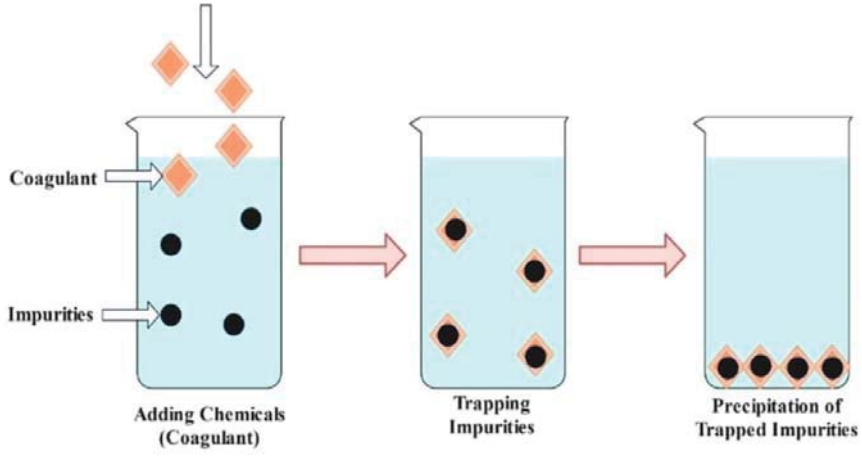

Figure 4: Chemical precipitation technique [3]

- **Ion Exchange:** Ideal for nitrates, fluoride and many heavy metals based dissolved ions removal Which are actually nontoxic ions such as sodium or chloride, which work to displace contaminants in the form of cations and anions with either ion-exchange resins or other appropriate macromolecular substances i membranes. It is widely required for smaller scales thus mainly used in treatment of water softeners and demineralization systems.

- **Adsorption:** Adsorbent materials consumers for inorganic ions up and down by physical (or) chemical interactions like activated carbon, zeolite etc. Their brand is not removed for lead, arsenic and fluoride contaminants as this way of removing. Granular activated carbon (GAC) filters are usually used to remove chlorine and certain heavy metals in drinking water.

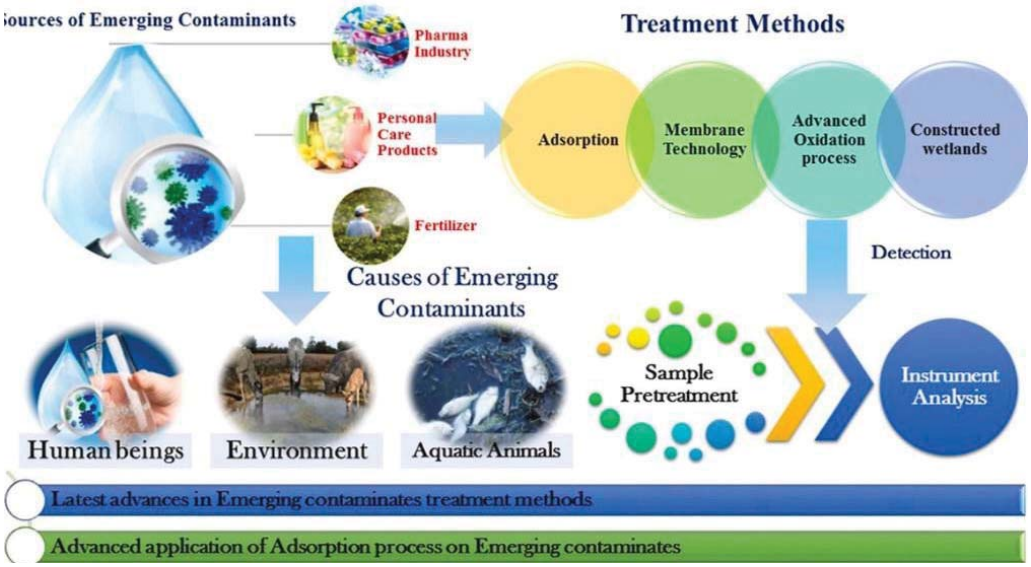

Figure 5: Application of adsorption process [1]

- **Reverse Osmosis (RO):** Reverse osmosis is a membrane technology in which the water under pressure passes through the impermeable to it solutes, and most other chemical agents. One of the most common operations is desalinization and cleansing inorganic contaminants-laden water.

- **Electrodialysis (ED):** In the Electrodeionization (E-D) process, an electric potential

is used to drive ions through a membrane between cationic and anionic species This divides in which into positive hydronium ion [acid (H+)] And Hydroxide ion [. The main use of this method is to extract a few inorganic impurities, for example nitrate or fluoride.

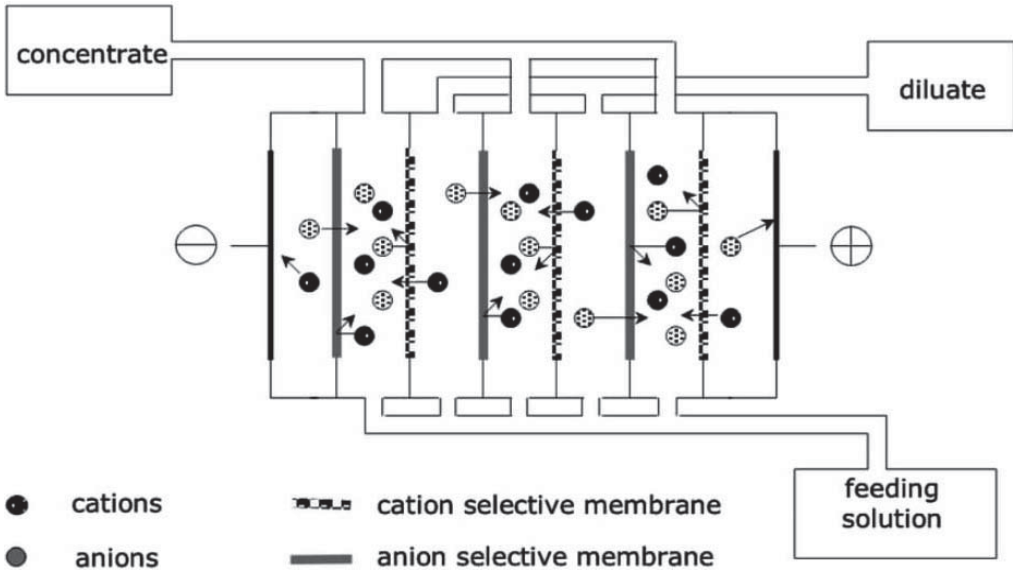

Figure 6: Principle of the electrodialysis technique [4]

- **Coagulation and Flocculation:** For a coagulant, they neutralize the charge of suspended particles (some inorganics). These Impurities are then made to flocculate into flocs, and using sedimentation or filtration can be easily separated from water.

Organic Contaminants:

Natural contaminants are organic in nature, including pesticides, pharmaceuticals, industrial chemicals and also volatile compounds (VOC), etc., Natural occurring minerals can be present e.g. - humic acids as well. Industrial runoff, agricultural waste and improper disposal of chemical products all release these contaminants into our water supply. Organic contaminants are more complex chemicals, and generally require more sophisticated treatment processes for removal. Treatments Include:

- **Biological Treatment:** Both aerobic and anaerobic digestion processes are based on biological metabolism of microorganisms to remove organic pollutants. One of the

more familiar processes for those who know about wastewater treatment plants is when organic compounds are broken down to simpler less harmful structures by microorganisms. Biological treatments are suitable for biodegradable organic pollutants, e.g., sewage, agricultural run-off and certain industrial wastes.

- **Centralized oxidation processes (COVs):** They use heavily reactive AOPs, mainly hydroxyl radicals (·OH) to degrade complex organic molecules into simpler and less toxic compounds – this involves processes such as ozonation, UV radiation or hydrogen peroxide treatment (result set). They tend to excel at removing persistent organic pollutants (POPs) - things like pesticides and pharmaceuticals.
- **Activated Carbon Adsorption:** The large molecular structure ensures that activated carbon effectively adsorbs organic contaminants such as VOCs, pesticides and industrial solvents. Activated carbon dust or ions, namely activated granular forms emitted by electronic adsorption organic matter and taste odor clean-up in a little water treatment operation.
- **Membrane Filtration:** Sedimentation processes TREATEES Intermediate Ultrafiltration, and less often nanofiltration membranes are used to separate organic compounds based upon molecular size. They are designed to target the removal of large organic molecules, and also employed as performance improvement before other water treatment processing paths. Nanofiltration is mainly used for the removal of selected organic contaminants (such as pesticides, natural organic matter) which are difficult to be removed by reverse osmosis.
- **Photocatalysis:** This phenomenon in which light-activated by a catalyst such as titanium dioxide (TiO2) is used to decompose organic pollutants generating reactive species that degrade them into carbon, water and some other non-toxic elements. This approach is specially fascinating with regard to in the cleanup water of pharmaceutical residues and VOCs.
- **Chlorination and Ozonation:** The strong oxidizing agents such as chlorine or

ozone make the water germ-free also it has to keep away from organic contaminants. Many of the largest municipal water treatment systems around the world use chlorination, which is effective in eliminating a wide variety of bacterial species and even breaking down some organic compounds; more complex molecules might be removed through ozonation but it can come at higher installation costs.

- **Electrochemical Treatment:** This technique uses electrical currents to break down organic pollutants. These are electrochemical oxidation reduction reactions and they degrade pollutants like phenols, dyes, pharmaceuticals etc. Electrocoagulation can remove suspended organic matter, along with emulsions and colloids (emulsion consisting of two immiscible fluids)

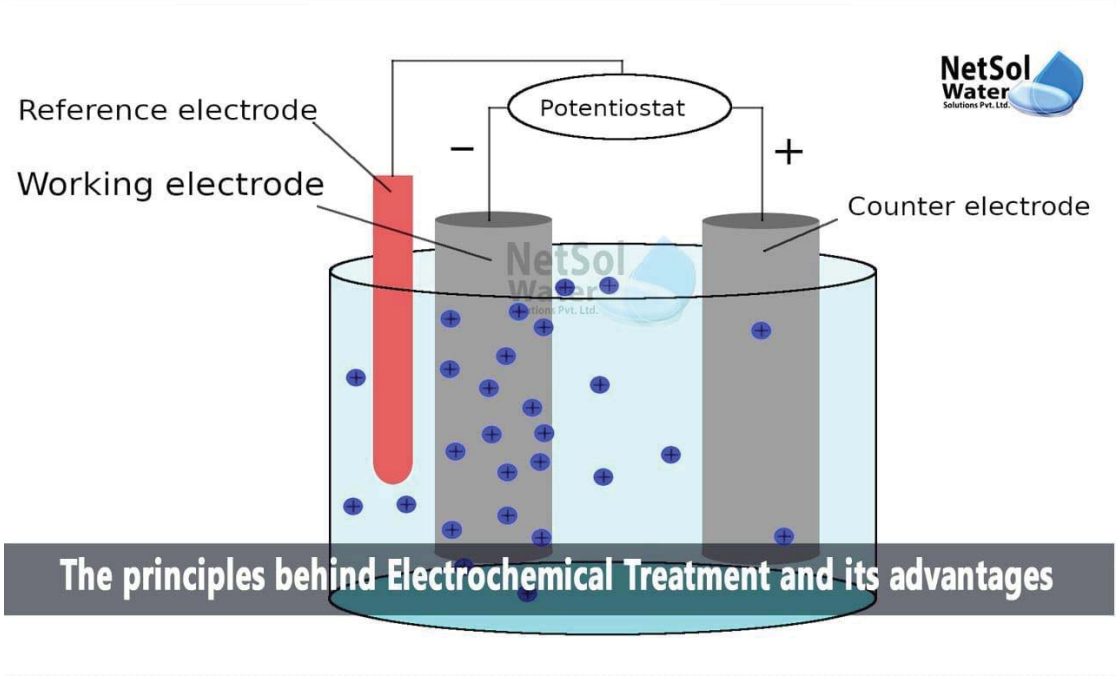

Figure 7: Electrochemical Treatment [5]

Conclusion:

Multiple sources, substance and methods must be used to prevent water pollution from occurring. The industrial, agricultural and urban interplay indicates that regulatory frameworks diversification of system boundaries is necessary for reducing the discharge of pollutants from sources (e.g. construction sites or agriculture) to sinks (e.g., rivers). New technologies have been developed with water quality in mind, leading to more modern ways on how waste management can be done outside wastewater treatment plants. A substantial part of this is about community engagement in education on responsible water use and conservation practices. With the ongoing issue of water pollution affecting our ecosystems and human health, it is vital to work in concert with governments, industries but also stakeholder's communities. Through promoting sustainable approaches, advancing research and technology we have the ability to reduce water pollution impacts while preserving our essential bodies of water for this generation and generations thereafter. Lastly, by making time to care for our environment and commit towards being eco-vibrated we not only clean up the water but honor ourselves with cleaner air and a more sustaining earth.

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Emerging Technologies for a Sustainable Future

Dr. Tanay Pramanik

Dr. Tanay Pramanik is a Professor of Organic Chemistry with over 13 years of academic, research, and administrative experience at institutions such as the National University of Singapore, Lovely Professional University, and the University of Engineering and Management, Kolkata. A university silver medalist, he qualified CSIR-NET with SPM Fellowship nomination and secured top ranks in GATE and JAM. He earned his PhD from NUS and specializes in organic electronics, conjugated polymers, green synthesis, and sustainable water purification. He has over 55 SCI/Scopus publications, 20 patents, and several books and chapters. His work has received international recognition, including awards at the Geneva Inventions Exhibition. He has also held key leadership roles and contributed significantly to teaching, research mentoring, and academic development.

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