International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.8May - June – 2024
DOI:10.46647/ijetms.2024.v08i03.065 ISSN: 2581-4621

Water's Second Chance: Exploring Natural Remediation for Wastewater

Harshitha Vishaalaakshi R M[1], Subarna P [2], Vaishnavi S [3], Eunice J [4]
[1,2,3]UG - Department of Civil Engineering, Thiagarajar College of Engineering, Madurai, Tamil Nadu, India
[4]Assistant Professor, Department of Civil Engineering, Thiagarajar college of Engineering, Madurai, Tamil Nadu, India

Abstract
Wastewater treatment is a critical aspect of environmental management, aiming to remove contaminants from water before it is discharged back into natural water bodies. With growing concerns about water scarcity and pollution, the need for effective and environmentally friendly solutions has never been more pressing. The need for treating wastewater naturally is driven by a desire to protect the environment, conserve resources, promote community health and well-being and build resilient and sustainable water infrastructure for future generations. In recent years, there has been growing interest in utilizing natural processes for wastewater treatment, offering a sustainable and cost-effective alternative. Natural treatment approaches, such as Phytoremediation, Constructed Wetlands, Aquaponics, Natural Chemical Processes, Algal Treatment, Waste stabilisation pond, Lagooning and Bioremediation, showcase the potential of harnessing biological processes and plant-microbe interactions to remediate wastewater sustainably. Natural treatment systems can often be integrated with other land uses, such as agriculture or landscaping, providing additional environmental benefits. These natural treatment methods demonstrate the diverse range of approaches available for sustainable and eco-friendly wastewater remediation. It offers sustainable and environmentally friendly alternatives to conventional wastewater treatment processes. They can be particularly beneficial in rural areas or developing countries where access to centralized treatment infrastructure may be limited. By harnessing the power of nature's processes and organisms, we can achieve effective water purification while minimizing environmental impact.
Keywords: Phytoremediation, Constructed Wetlands, Aquaponics, Natural Chemical Processes, Algal Treatment, Waste stabilisation pond, Lagooning and Bioremediation

1. Introduction

Wastewater treatment is a critical aspect of environmental management, aiming to remove contaminants from water before it is discharged back into natural water bodies. With growing concerns about water scarcity and pollution, the need for effective and environmentally friendly solutions has never been more pressing. The use of natural processes for wastewater treatment offers a sustainable and cost-effective alternative to conventional treatment methods. Natural treatment approaches, such as Phytoremediation, Constructed Wetlands, Aquaponics, Natural Chemical Processes, Algal Treatment, Waste stabilisation pond, Lagooning and Bioremediation, showcase the potential of harnessing biological processes and plant-microbe interactions to remediate wastewater sustainably[1][2].

Phytoremediation is a natural treatment approach that uses plants to remove contaminants from wastewater. This can be achieved through various mechanisms such as constructed wetlands, rhizofiltration, rhizodegradation, phytodegradation, phytoaccumulation, phytotransformation, and hyperaccumulators[2]. Constructed wetlands are artificial systems designed to replicate the natural processes of wetland ecosystems for wastewater treatment. They are particularly effective in removing nutrients, metals, and organic pollutants from wastewater[1][2].

Aquaponics is a sustainable method that combines fish farming and hydroponics to create a closed-loop system for wastewater treatment. The fish waste serves as a nutrient source for the plants, which in turn purify the water for the fish[1]. Natural chemical processes such as chemical precipitation, ion exchange, neutralization, adsorption, and disinfection can also be used for wastewater treatment[1][2]. Algal treatment is a promising natural method that uses algae to remove nutrients and organic pollutants from wastewater[1].

Waste stabilisation ponds and lagooning are natural treatment methods that use the natural processes of sedimentation, aerobic and anaerobic digestion, and plant uptake to treat wastewater[1]. Bioremediation is a natural treatment approach that uses microorganisms to break down contaminants in wastewater. This can be achieved through various methods such as aerobic treatment, anaerobic treatment, bioreactors, and percolating or trickling filters [2].

These natural treatment methods demonstrate the diverse range of approaches available for sustainable and eco-friendly wastewater remediation. They can be particularly beneficial in rural areas or developing countries where access to centralized treatment infrastructure may be limited. By harnessing the power of nature's processes and organisms, we can achieve effective water purification while minimizing environmental impact [1][2].

2. Importance of Wastewater Treatment

Wastewater treatment plays a crucial role in achieving sustainable development and environmental protection by removing contaminants from water before it is discharged back into natural water bodies. It also contributes to the circular economy by ensuring that products are recycled and reused effectively. The use of natural treatment approaches, such as phytoremediation, constructed wetlands, aquaponics, and other methods, showcases the potential of harnessing biological processes and plant-microbe interactions to remediate wastewater sustainably. These methods offer sustainable and environmentally friendly alternatives to conventional wastewater treatment processes, providing benefits such as protecting the environment, conserving resources, promoting community health and well-being, and building resilient and sustainable water infrastructure for future generations. The integration of natural treatment systems with other land uses, such as agriculture or landscaping, further enhances their environmental benefits. By utilizing the power of nature's processes and organisms, effective water purification can be achieved while minimizing environmental impact [3][4].

3. Environmental and Societal Benefits of Natural Treatment Methods

Natural treatment methods for wastewater have numerous environmental and societal benefits, including the reduction of pollution and the conservation of resources. These methods harness biological processes and plant-microbe interactions to remediate wastewater sustainably, offering advantages like protecting the environment, promoting community health and well-being, and building resilient and sustainable water infrastructure for future generations. The integration of natural treatment systems with other land uses, such as agriculture or landscaping, further enhances their environmental benefits. Studies have shown that natural treatment systems not only improve water quality but also contribute to public health, social well-being, and sustainable resource management. The use of natural treatment approaches aligns with the principles of sustainability and offers cost-effective solutions for wastewater treatment while minimizing environmental impact. [5][6][7].

4 Overview of Natural Treatment Approaches

Natural sewage treatment methods can be effective, environmentally friendly alternatives to conventional treatment processes. However, their efficiency depends on factors such as site characteristics, climate, and the composition of the wastewater. Additionally, proper design, operation, and maintenance are essential to ensure optimal performance and environmental

DOI:10.46647/ijetms.2024.v08i03.065 ISSN: 2581-4621

protection. Treating sewage naturally involves utilizing biological processes and natural systems to purify wastewater before it is released back into the environment. Here's an overview of some natural methods used for sewage treatment:

4.1 Phytoremediation

Plants can remove organic and inorganic contaminants from soil and water using different mechanisms depending upon plant species and environmental conditions. Interaction of plants with the environment (soil, water, and air) and microorganisms play a crucial role in removing the contaminants. The effectiveness of remediation depends on the contaminant, the plant species, and the soil. Plant biomass and metabolism play a critical role in the efficiency of remediation, which is affected by soil pH, electric conductivity, organic matter contents, microbial processes, and other soil amendments.

Phytoremediation potential of the plants are generally evaluated by determining Bioconcentration Factor (BCF), described as the ratio of pollutant concentration in the plant parts to that in the media, and Translocation Factor (TF), defined as the ratio of elemental accumulation in plant's shoot compared to plant's root. Based on the processes of phytoremediation involved in the remediation of toxic contaminants from soil and water, the overall mechanisms of phytoremediation depicted. [8]

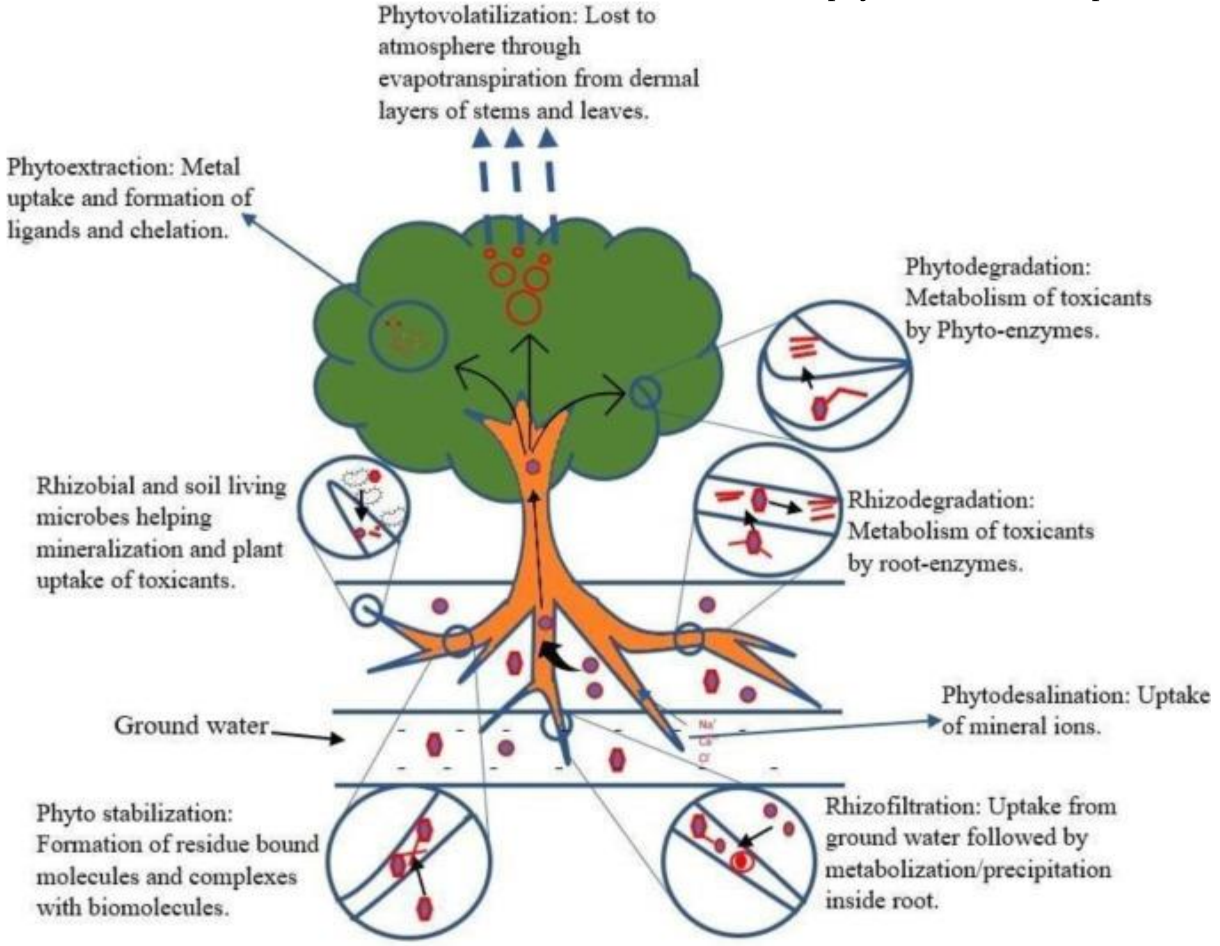

FIGURE 1 Phytoremediation [8]

4.2 Constructed Wetlands

Constructed wetland sewage treatment systems are derived from the simulation of natural wetlands; they use the triple synergistic effects of natural ecosystems in physical, chemical and biological states to achieve sewage purification. Depending on the length-to-width ratio and ground slope, particles fillers of a certain size (such as gravel, soil, peat, etc.) and aquatic plants, are used together to constitute the constructed wetland treatment system . The aquatic plants generally used are beautiful and have good processing qualities , a high survival rate, strong water resistance,

International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.8May - June – 2024
DOI:10.46647/ijetms.2024.v08i03.065 ISSN: 2581-4621

long growing seasons and high economic value (such as reeds, caltrops, iris, etc.). Together with animals and microorganisms that live in the water and filler, they form a unique flora and fauna environment. When the sewage flows through the patch surface and the gaps between patch fillers, an efficient purification can be achieved through filtration, adsorption, sedimentation, ion exchange, absorption by plants, microbial decomposition, etc.

Constructed wetland systems have been used for treating numerous forms of wastewaters, mainly including industrial, rural household, urban household and nonpoint-source pollution, especially urban household sewage and nonpoint-source pollution. At present, constructed wetlands have been developed into a sewage treatment technology that has high economic efficiency and environmental effectiveness that is particularly suited to sewage treatment in rural areas.

The key elements of the applications of constructed wetlands in sewage treatment are plants and media. Medium means filler can be used to intercept significant pollutants in sewage through sedimentation, filtration and adsorption. It is also the substance wherein the other active elements (plants and microorganisms) of constructed wetlands survive. Therefore, the selection of filler plays a key role in constructed wetlands to provide effective water purification. At present, typical constructed wetland fillers are zeolite, vermiculite, gravel, limestone, coal ash, slag, grit and soil, clay minerals and some industrial by-products.

The filler medium plays an important role in wetland processes for sewage treatment. At present, the wetlands treatment process makes wide use of grit sands, soil, gravels and other substrate fillers. The investment is more efficient, but the nitrogen and phosphorus removal efficiencies of these fillers are not ideal; therefore, experts have constantly developed new wetland fillers and carried out different levels of tests. [9]

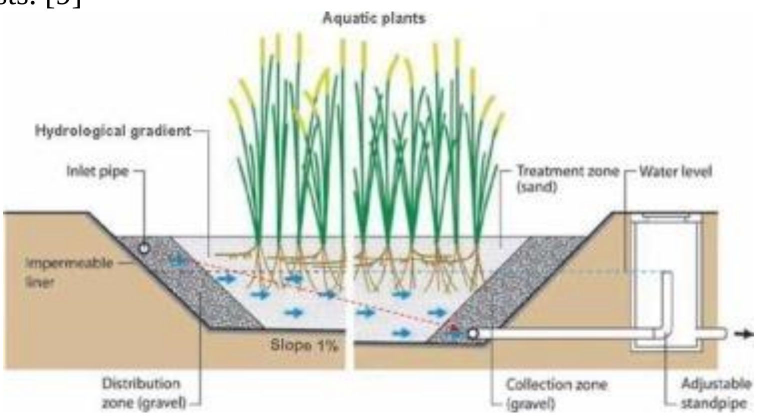

FIGURE 2. Constructed wetlands[9]

4.3 Aquaponics

The major challenges to the development of sustainable aquaculture are the issues associated with environmental protection, food safety and water depletion. The aquaculture wastewater contains suspended solids, nitrogen compounds and compounds of phosphorus. Wastewater treatment is essential in aquaculture systems to keep a healthy fish culture and also to avoid detrimental effects on the environment. There are numerous limitations to use conventional wastewater treatments in aquaculture systems due to the economic and energy burden created by them. In addition to that, the traditional treatment methods like aerobic and anaerobic treatment methods for aquaculture wastewater is releasing greenhouse gases like CO2 and CH4, and also the nutrient resources in wastewater could not be efficiently reused. The improvement of the traditional treatment methods is essential for maintaining sustainability in the aquaculture industry. In the present study latest innovations in aquaculture wastewater treatment has been studied concerning their sustainability in promoting a safe environment to the biotic as well as abiotic systems.

Conventional systems and Recirculation systems in aquaculture units are compared to assess the pros and cons. Constructed wetland systems has been studied to analyse the improvement in aquaculture waste water units. The study of Aquaponics Systems for waste water treatment has also been carried out to find the sustainability in terms of energy efficiency. The use of local and low

DOI:10.46647/ijetms.2024.v08i03.065 ISSN: 2581-4621

trophic level biomass like microalgae as feedstock in aquaculture for effective reduction of environmental impacts has been analysed. The study of integrated multi-trophic aquaculture operation combining fed aquaculture with organic extractive aquaculture has been carried out. The development of more efficient reactor systems and a holistic, integrated approach to wastewater treatment can ensure sustainable aquaculture systems which helps to maintain sustainability in the water -food -energy system. [10]

Aquaculture treatment technologies - sustainability aspect:
The sustainability concept is evolved to strengthen "the ability of future generations to meet their own needs". Availability of pure water resources and protection of available water and provision for hygienic safety is a precondition of sustainable development in rural and municipal areas. The major challenges to sustainable water treatment systems in developing countries are
(1) economic backwardness
(2) existing technological deficiencies
(3) Energy paucity to operate affordable solutions. [10]

4.4 Natural Chemical Processes

Chemical treatment of wastes will help us to transform high hazardous waste to lesser hazardous nature. Chemical treatment also helps us to recover valuable by-products from hazardous wastes, thus reducing overall costs of the disposal of wastes. Thus, chemical treatment options shall be adopted before the consideration of landfill options. Different chemical treatment processes adopted in hazardous waste management industries are solubility, neutralization, precipitation, coagulation and flocculation, oxidation and reduction, and ion-exchange method.

Solubility: Hazardous waste may be organic and inorganic containing various chemical elements and with various structural configurations. Water, known as the universal solvent, will dissolve many of these substances, while others have only limited water solubility. Solubility of various salts inorganic and organic is utilized as a means of treatment of hazardous waste when wastewater treatment facilities are available and landfill options are limited.

Neutralization: Neutralization of acids and alkaline waste streams is an example of the use of chemical treatment to mitigate waste characterized as corrosive. Neutralization of an acid or base is easily determined by measuring its pH. Acid-based reactions are most common chemical process used in hazardous waste treatment. Neutralization prior to landfill will be necessary so that interactions are avoided in landfill. As neutralization process is exothermic in nature, if pre-neutralization did not take place, the temperature of landfill layers increases, thus damaging liners.

Precipitation: Often, undesirable heavy metals are present in liquid and solid wastes, which are in slurry form. The usual method of the removal of inorganic heavy metals is chemical precipitation. Metals precipitate at varying pH levels depending on the metal ion, resulting in the formation of an insoluble salt. Hence, neutralization of an acidic waste stream can cause precipitation of heavy metals. The hydroxides of heavy metals are usually insoluble so lime or caustic is commonly used to precipitate them.

Coagulation and flocculation: Precipitation is greatly improved by adding coagulants. Most commonly used coagulant is alum. Many polyelectrolytes are used as coagulants. These coagulants neutralize the charge of colloids in suspended condition, thus allowing them to settle rapidly.

Oxidation and reduction: The chemical processes of oxidation and reduction can be used to convert toxic pollutants to harmless or less toxic substances. Heavy metal wastes are subjected to reduction process to precipitate to safer compounds of heavy metals. Example is hexavalent

DOI:10.46647/ijetms.2024.v08i03.065 ISSN: 2581-4621

chromium precipitated into trivalent chromic hydroxide. Similarly, alkaline chlorination of cyanide neutralizes highly toxic cyanide wastes.

Ion-exchange methods: Ion exchange is reversible exchange of ions between liquid and solid phases. Ions held by electrostatic forces to charged functional groups on the surface of insoluble solids are replaced by ions of similar charge in a solution. Ion exchange is stoichiometric, reversible, and selective removal of dissolved ionic species. [11]

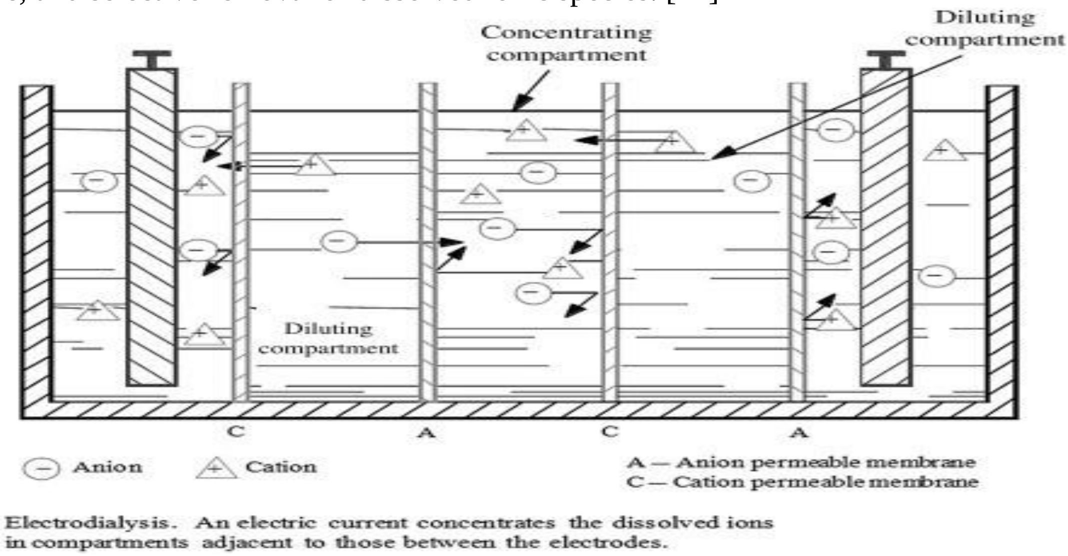

FIGURE 3. Natural Chemical Process [11]

4.5 Algal Treatment

Algae are primarily aquatic and autotrophic organisms that lack true roots, stems, leaves, and distinct multicellular productivities. They are autotrophic and commonly classified as either microalgae or macroalgae. Like other autotrophs, carbon (C), nitrogen (N), phosphorus (P), and various micronutrients play a vital role in metabolic processes. Algae are photosynthetic organisms that are widely distributed on earth. They are naturally cultivated into the natural environment and produce biomass. Algae are composed of unicellular organisms (microalgae) such as Chlorella, diatoms, and Prototheca, or multicellular organisms (macroalgae) such as green and brown seaweeds.

The advantage of using algae as bio refinery feedstock are manifold, such as fast growth rate, handling, higher biomass yield, and cultivation in non-arable land. The algae-based industries are expanding due to the multiple high-value products such as proteins, carbohydrates, lipids, pharmaceutical compounds, and unique biomass bio refinery products. Algae are used for the production of biodiesel, bioethanol, bio methane, fine organic chemicals, and food supplements due to the presence of a high amount of lipids, proteins, carbohydrates, enzymes, vitamins, pigments such as Chlorophyll

Natural algae biomass is an important food source for marine organisms like fish, shrimps, and mollusks . The high value-added products can be extracted from the algae biomass after downstream purification methods. This harvesting of the value-added products from pre-treated biomass is called bio refinery. The application of the biorefinery is useful for the extraction of metabolites from a single type of algal biomass, making it the most successful approach in the industrial algae biotechnology sector. Algal biomass has been employed for the production of bioenergy, bioactive compounds, antimicrobial and antiviral compounds, biofuels, bio fertilizers, and food additives.

Cellular composition of algae and application:
The cellular composition of the algae plays an important role in the interaction and removal of pollutants from wastewater. The algae cells contain lipid, carbohydrates, and protein algae are reported in the range of 5–23%, 7–23%, and 6–52%, respectively.The algal cell wall comprises microfibrillar exo-polysaccharides, containing functional groups such as -COOH-, -OH-, -PO43-, –RSH, SO42-, and others. These functional groups impart an anionic nature to the cell wall.

Wastewater treatment mechanism using algae and biorefinery:
The primary mechanism for removing the toxic chemicals is bio-adsorption, bioaccumulation, and extracellular and intracellular bioremediation. These mechanisms play a substantial part in removing pollutants from wastewater. The algae were found effective in the elimination of antibiotics, heavy metals, and pesticides via their cell membrane, extracellular and intracellular mechanisms. The algae-mediated mechanism of removal of toxic

Algae in resource recovery and sustainable development:
Advancements in urbanization and industrialization have created immense pressure on natural reservoirs and the environment. The improper and extensive utilization of the water in industries, agriculture, and, household activities produces 380 trillion L/year of wastewater worldwide. The ample amount of nutrients in wastewater makes it the better choice for the growth of algae. [11]

4.6 Waste Stabilisation Ponds
Waste stabilization ponds (WSPs) are a very appropriate method of wastewater treatment in developing countries, where the climate is most favorable for this application. Their lower implementation costs and operational simplicity are commonly regarded as their main advantages. However, the processes that occur in wastewater treatment ponds still are not completely understood. [12]

Algal-bacterial symbiosis:
Treatment in WSP is a biological process and reduces the level of contaminants in wastewater including organics, nutrient, heavy metals, and other contaminants by the mechanism of algal-bacterial symbiosis. Various types of pollutants are present in domestic as well as industrial wastewater such as farmland effluent may contain high concentration of pesticides, herbicides; coke plant effluent may contain PAHs.

Sunlight and temperature:
The algal photosynthesis or the process of algae creating its own energy mainly requires CO2, sunlight, and water. The optimum growth of these algae in pond occurs when intermittently exposed to optimum sunlight intensities. Sunlight not only facilitates the algal growth, but also damages pathogens (photobiological damage) by its UV portion directly. The intensity, quality and duration of sunlight received by the algae affects its growth and duration of sunlight (light/dark cycle) received has impact. [12]

Types of oxidation/waste stabilization ponds:
WSPs are also known as oxidation ponds or lagoons are basically large or shallow depth ponds utilized for the biological treatment of wastewater by the interaction of sunlight, bacteria, and algae. [12]

Modelling of WSP:
Mathematical models are in general used to optimize the plant design, predict the operational performance and to evaluate the experimental results. Kinetic analysis is an accepted pathway for describing the performance of biological treatment systems and for predicting their performance.

Various mathematical models are available in literature, which have been used to bridge a relationship between different process parameters and to scrutinize the experimental data. [12]

Cost and land availability assessment of waste stabilization ponds:

Treatment by WSP is preferred over other conventional treatment methods because of higher pollutants removal efficiency at lower cost. In any WSP, the expenses for treating the sewage or wastewater mainly include capital cost, operation and maintenance costs and the procurement of land. Thus, by estimating these costs it can be decided whether the project will be feasible or not. The International Water and Sanitation Centre (IRC) consider WSP as the most cost-effective wastewater treatment. [12]

Initial operation tasks:

The operation and maintenance of WSP plays an important role in creating an effective and efficient treatment system. WSP should be always free from unwanted vegetation. In a series pond system, when anaerobic pond discharges water into an empty facultative pond, an unpleasant odor is released. Therefore, facultative ponds should be filled prior to anaerobic ponds to avoid any kind of odor release. The facultative and maturation ponds should first fill with freshwater from river, lake or well.

Waste stabilization ponds (WSPs) are a very appropriate method of wastewater treatment in developing countries, where the climate is most favourable for this application. Their lower implementation costs and operational simplicity are commonly regarded as their main advantages. However, the processes that occur in wastewater treatment ponds still are not completely understood. [12]

4.7 Lagooning

Aerated lagoons have generally been viewed as an effective and low-cost method for removing pathogens, organic and inorganic matters. Their low operation and maintenance costs have made them a popular choice for wastewater treatment, particularly in developing countries since there is a little need for specialised skills to run the system. Wide variations in the standard performance of lagoon systems have been reviewed in the literature. Maehlum used on-site anaerobic–aerobic lagoons and constructed wetlands for biological treatment of landfill leachate. Overall N, P and Fe removals obtained in this system were above 70% for diluted leachate. Abatement of 55–64% of COD and 80–88% of phenol was achieved. However, as stricter requirements are imposed, lagooning may not be a completely satisfactory treatment option for leachate in spite of its lower costs. In particular, authors claimed that the temperature dependence of lagooning is a significant limitation because it mainly affects microbial activity. [13]

4.8 Bioremediation

Mechanism of action of microbial bioremediation:

Microbes are widespread in the natural environment and thrive in an environment polluted by heavy metals. So, toxic heavy metals are converted by these microorganisms into non-toxic forms. Microbes mineralize organic contaminants into end products such as H_2O, CO_2 and metabolites, which are used as the principal substrates for cell development throughout the bioremediation process. Microbes maintain a defence mechanism in ways for targeted pollutants develop degrading enzymes. [13]

Role of microbes in bio remediating heavy metals:

Many bacteria can degrade metals on an insufficient large scale without any chemical intervention. Sanitary efficiency is a factor in resistance to heavy metals to microbiological stress. GM microorganisms can thereafter be a possible answer to this problem. Genetic engineering is an essential stage in the change of these bacteria metabolic routes. The regulated activity of heavy metals will also limit detrimental actions. By utilizing processes like oxidation-reduction. [13]

Potential of bioremediation techniques in the treatment of wastewater from pharmaceutical industries:

Traditional treatment by wastewater treatment plants (WWTPs) is successful in decreasing the nitrogen and carbon concentration of wastewater in most circumstances. Furthermore, they have been found to be ineffective in eliminating misuse drugs, pharmaceuticals, and the effluent water discharges from WWTPs have been characterized as micropollutants. Another challenge to adopting chemical and physicochemical methods for treatment, apart from the undesirable by-products generate by the chemical. [13]

Bacterial bioremediation:

For the treatment of industrial wastewater, bacterial bioremediation is used widely. Several bacteria are used for such treatment, like B. subtilis, pseudomonas, endophytes, and some bacterial strains. A study was conducted by Das et al. in Tamil Nadu, India, where the sample in the pharmaceutical sector from nine different locations are collected in different forms like MEE (multiple-effect evaporator), ETP (effluent treatment plant), Cooling tower water, Condensate online water, S.T.P Water. [13]

Fungal bioremediation:

The strains of various fungal spores like Aspergillus niveus, Aspergillus fumigatus, and Aspergillus niger have potential for bioremediation. On the other hand, there are limitations in some strains because of their prolonged cycle of spore production. The Ascomycetes is well-known for its ability to eliminate COD from industrial wastewaters, including those produced by distilleries (Mohammad et al., 2006; Angayarkanni et al., 2003). Bardi et al. examined the impact on manufactured recalcitrant. [13]

5 Integration with Other Land Uses

The integration of water resources management strategies into land use planning processes can foster more holistic and effective approaches to environmental conservation. This integration involves incorporating water management strategies into land use planning to achieve sustainable resource management and environmental protection. Additionally, the use of decision support systems for land use planning can aid in the evaluation and selection of the best land use options based on environmental requirements, production costs, labour needs, and environmental impacts. These tools and approaches contribute to the development of sustainable land management practices that consider environmental, economic, and social factors. Furthermore, an integrated approach to land management, such as sustainable land management (SLM), emphasizes the importance of managing natural resources in a holistic manner to address environmental issues like deforestation, biodiversity degradation, desertification, and water quality degradation. This approach aims to promote sustainable land use practices that balance environmental conservation with socio-economic development. [14]

6 Case Studies and Examples

Domestic wastewater and surface runoff treatment implementations by constructed wetlands for Turkey: 25 years of experience

The project focuses on the implementation of constructed wetland (CW) systems for the treatment of domestic wastewater and surface runoff in Turkey over a span of 25 years. It was initiated in 1994 at the TUBITAK Marmara Research Center (TUBITAK MRC) and involved both laboratory and pilot applications of CW systems. The project aimed to promote the use of CW systems as a cost-effective and environmentally friendly treatment option for water contamination in Turkey. This project contributed to the understanding of CW systems' effectiveness in controlling water pollution and provided insights into the design, operation and challenges faced in implementing these systems in Turkey. [15]

7 Challenges and Limitations

Some of the challenges and limitations faced in the implementation of constructed wetland systems in Turkey include:

- *Operation and Maintenance: One of the biggest problems encountered was related to the operation and maintenance of the CW systems. Some systems were inactivated due to insufficient personnel allocated for their upkeep.*
- *System Selection: Incorrect system selection was a common issue, with some areas using vertical flow constructed wetland systems in harsh climates without proper insulation, leading to system failures.*
- *Structural Errors: Many treatment systems were found to have structural errors, such as using non-functional septic tanks for pre-treatment, leading to blockages and system failures.*
- *Gravel Size and Distribution: Issues with the size and distribution of gravel used in the systems, such as using gravel that was too large or too small, causing poor treatment efficiency or blockages.*
- *Lack of Monitoring: Limited monitoring data for real-scale CW systems, which hinders the transfer of knowledge and best practices to new systems.*
- *Limited Treatment Efficiency: In real-scale systems, treatment efficiency was lower due to various problems, such as incorrect design, wrong plant choices, and insufficient monitoring.*
- *Initial Investment Costs: The initial investment costs for CW systems were highlighted as a limitation, with gravel being a significant cost factor. The delivery distance of filling material also impacted the total cost.*

These challenges and limitations underscore the importance of proper planning, design, and maintenance of constructed wetland systems to ensure their effectiveness in treating wastewater and surface runoff. [15]

8. Future Directions and Recommendations

The future challenges and perspectives in the implementation of constructed wetlands encompass technological, operational and regulatory aspects. Technological challenges involve optimizing design parameters for pollutant removal, developing new materials and integrating advanced monitoring and control systems. Operational challenges include maintaining wetland vegetation, managing sludge and sediments and preventing clogging and bio fouling. Regulatory challenges involve developing standardized design guidelines, establishing performance criteria and promoting policy frameworks that support constructed wetlands. To address these challenges, advancement in material science, sensor technology and machine learning are crucial, along with best management practices for maintenance and management and development of standardized design guidelines, performance criteria and policy frameworks. [18]

9 Conclusions

Natural wastewater treatment offers a promising avenue for sustainable and eco-friendly water management. By leveraging the power of natural processes and organisms, these methods can achieve effective wastewater treatment while minimizing environmental impact. The diverse range of natural treatment approaches available caters to different needs and scales, making them particularly suitable for developing countries and rural areas. As we strive towards a more sustainable water future, promoting and implementing natural wastewater treatment solutions will be crucial.

Reference

1. *Samer, M. (2015). Biological and chemical wastewater treatment processes. Wastewater treatment engineering, 150(10.5772), 61250.*
2. *Singh, R. K., Tirth, V., & Singh, M. (2022). Wastewater treatment processes with special reference to activated sludge process in indian conditions for water use sustainability. In Wastewater Assessment, Treatment, Reuse and Development in India (pp. 227-238). Cham: Springer International Publishing.*
3. *Nathanson, J. A. and Ambulkar, . Archis (2024, April 19). wastewater treatment. Encyclopedia Britannica. https://www.britannica.com/technology/wastewater-treatment*
4. *Hassan I, Chowdhury SR, Prihartato PK, Razzak SA. Wastewater Treatment Using Constructed Wetland: Current Trends and Future Potential.* Processes. *2021; 9(11):1917. https://doi.org/10.3390/pr9111917*
5. *Hartig, T., Van Den Berg, A. E., Hagerhall, C. M., Tomalak, M., Bauer, N., Hansmann, R., ... & Waaseth, G. (2011). Health benefits of nature experience: Psychological, social and cultural processes. Forests, trees and human health, 127-168.*
6. *Shanahan, D. F., Astell–Burt, T., Barber, E. A., Brymer, E., Cox, D. T., Dean, J., ... & Gaston, K. J. (2019). Nature–based interventions for improving health and wellbeing: The purpose, the people and the outcomes. Sports, 7(6), 141.*
7. *Bonham-Corcoran, M., Armstrong, A., O'Briain, A., Cassidy, A., & Turner, N. (2022). The benefits of nature-based therapy for the individual and the environment: an integrative review. Irish Journal of Occupational Therapy, 50(1), 16-27.*
8. *Kafle, A., Timilsina, A., Gautam, A., Adhikari, K., Bhattarai, A., & Aryal, N. (2022). Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. Environmental Advances, 8, 100203.*
9. *Wang, M., Zhang, D. Q., Dong, J. W., & Tan, S. K. (2017). Constructed wetlands for wastewater treatment in cold climate—A review. Journal of Environmental Sciences, 57, 293-311.*
10. Lu, S., Zhang, X., Wang, J., & Pei, L. (2016). Impacts of different media on constructed wetlands for rural household sewage treatment. *Journal of Cleaner Production*, *127*, 325-330.
11. Bhatt, P., Bhandari, G., Turco, R. F., Aminikhoei, Z., Bhatt, K., & Simsek, H. (2022). Algae in wastewater treatment, mechanism, and application of biomass for production of value-added product. Environmental Pollution, 309, 119688.
12. Gloyna, E. F., & World Health Organization. (1971). *Waste stabilization ponds*. World Health Organization.
13. Gupta, V. K., Ali, I., Saleh, T. A., Nayak, A., & Agarwal, S. (2012). Chemical treatment technologies for waste-water recycling—an overview. *Rsc Advances*, *2*(16), 6380-6388.
14. *Kalogiannidis, S., Kalfas, D., Giannarakis, G., & Paschalidou, M. (2023). Integration of water resources management strategies in land use planning towards environmental conservation. Sustainability, 15(21), 15242.*
15. *Gunes, K., Masi, F., Ayaz, S., Tuncsiper, B., & Besiktas, M. (2021). Domestic wastewater and surface runoff treatment implementations by constructed wetlands for Turkey: 25 years of experience. Ecological Engineering, 170, 106369.*
16. *Hassan, I., Chowdhury, S. R., Prihartato, P. K., & Razzak, S. A. (2021). Wastewater treatment using constructed wetland: Current trends and future potential. Processes, 9(11), 1917.*
17. *Makopondo, R. O., Rotich, L. K., & Kamau, C. G. (2020). Potential use and challenges of constructed wetlands for wastewater treatment and conservation in game lodges and resorts in Kenya. The Scientific World Journal, 2020.*