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Frame Work of Sustainable Wastewater Treatment Methods and Technologies

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Abstract: Polychlorinated biphenyls and polycyclic aromatic hydrocarbons are examples of persistent organic pollutants (POPs), a class of man-made substances distinguished by their resistance to degradation, significant long-distance transport, and detrimental impacts on ecosystems and human health. Without industrialization, it is impossible to see human civilization advancing. However, a significant number of hazardous, bio accumulative, and persistent organic chemicals have emerged in the environment as a result of the last century's exponential population expansion and the quick development of the chemical, agrochemical, and petrochemical industries. One important strategy that could reduce the possible environmental effects of persistent organic pollutants (POPs) is the efficient removal of these contaminants from wastewater. Among the many methods documented for treating wastewater contaminated with organic compounds, the heterogeneous photocatalytic approach employing visible-light-responsive semiconductors has been described as an effective technology with promising POP removal capability. An overview of the most recent advancements in the design and synthesis of novel semiconductors with visible light-driven POP catalytic degradation is provided in this chapter. Details about the fundamentals of heterogeneous photocatalysis, visible light response pathways, and the photocatalytic capabilities of novel semiconductor materials are provided.

Keywords: Persistent Organic Pollutants; Heterogeneous Photocatalysis; Visible Light Response.

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I. Introduction

Economic expansion should be balanced with environmental sustainability and natural resource protection in order to promote the circular economy. In terms of sustainability, wastewater is a vital resource for a nation's ecological and economic development. In order to reduce the risks associated with a potential water crisis in the near future, it is necessary to rationally assess the need for wastewater treatment plants and the sustainability of existing facilities due to the growing significance of sustainable urbanization in developing nations and the rapid depletion of resources with the growing population. Wastewater treatment plays an important part in sustainable development in terms of safeguarding water resources, efficiently managing waste, and being open to the use of renewable energy. Increasing the proportion of safe and effective technologies for treating wastewater from homes and businesses is one of the expanded Sustainable Development Goals (SDG) targets.

The choice of wastewater treatment technology is a complicated, multifaceted issue that calls for a multicriteria assessment. Apart from the problem's intricacy, decision makers also have to weigh conflicting criteria, which appears to be additional difficulty. In order to choose the best wastewater treatment option over the course of treatment systems' lifetimes, a great deal of study has been conducted to evaluate the interplay between technological or economic viability and environmental effects. Among these, Molino-Senaite et al. offer a methodical approach based on scenario-based analytic network theory (ANP) and the analytic hierarchy process (AHP) to address the evaluation of environmental impact and economic viability in the process of evaluating alternatives. A multi-criteria decision-making technique (MCDM) that gave expert input priority has been used in recent years to conduct most of the research on the economic evaluation and environmental impacts of wastewater management options, such as wastewater treatment plants. Furthermore, some of these investigations should be conducted using accurate data rather than heterogeneous data, although practical concerns occasionally prevent this. Each of the aforementioned research offers a unique viewpoint to address the intricacy of the wastewater treatment plant technology selection process and uncertainties from dynamic surroundings.

II. Review of Literature

The wastewater management system is the cornerstone for safeguarding the contemporary environment and public health. In addition to achieving best practices for developing uniform standards for wastewater transfers from piping networks and treating them in treatment facilities, the system increases awareness of sustainability. Reaching the highest potential evaluation of operational, financial, and environmental efficiency is what determines the sustainability of wastewater treatment systems (Muga & Mihelcic, 2008).

Sustainability-affecting indicators were chosen based on their ability to detect or move toward balanced sustainability as well as their compatibility for various wastewater treatment systems (Nelms et al., 2007). A set of indicators has been proposed to achieve the dimensions necessary to achieve the overall sustainability of treatment system technologies that treat various wastewater discharges, assuming equal weights for the specific dimensions (environmental, social, economic, and technical) of the evaluated process. As can be seen below, the creation of indicators for these dimensions was utilized by numerous scientific sources (Smol et al., 2020).

The International Union for the Conservation and Protection of Nature (IUCN) coined the term "sustainable development" in 1980 after adopting the strategic concept of biodiversity sustainability and protection (Li et al., 2023). This theory states that social, environmental, and economic factors should be considered while evaluating the various facets of human existence. The fundamental tenet of sustainable development is the interdependence of social, environmental, and economic elements. According to (Liu et al., 2023), sustainable development is defined as meeting present needs without sacrificing the capacity of future generations to meet their own.

In recent years, the concept of sustainability has drawn a lot of attention from environmental departments and organizations around the world, especially in light of the problems with pollution of the environment's fundamental components (soil, water, and air) and the sustainability needed for treatment methods (Razali et al., 2015).

In order to choose the optimal wastewater treatment options, Crawford & Eng, (2010) created a multi-criteria methodology based on the analytical hierarchy process (AHP) and ELECTRE II methodologies. For this application, they created a method with 20 options and 12 criteria; the economic, social, technological, and environmental aspects of sustainability were chosen.

A multi-criteria decision-making model (MCDM) was created (Obaideen et al., 2022) in order to choose the most effective wastewater reuse technology in Iran. Four criteria, sixteen sub-criteria, and five options are managed by their approach.

Objective of the Study

As far as the authors are aware, this is the first study to look at the sustainability of wastewater treatment techniques in Iraq using the MCDA paradigm.

1. One Field research will be conducted and the appropriate values of the several components that make up the four dimensions of sustainability (Environmental, Social, Economic, and Technical) will be documented in order to evaluate the sustainability of wastewater treatment methods in Iraqi cities.
2. To use the MCDA to evaluate the collected data and determine which of the four wastewater treatment methods—Conventional, Oxidation Ditches, Aeration Lagoons, and MBR—is the most sustainable (in terms of overall relevance).

III. Materials and Methods

Solids, organic material, and nutrients are eliminated from wastewater using integrated processes in the conventional wastewater treatment process. Many physical, chemical, and biological processes are usually combined to produce treated wastewater that meets certain standards. Common subprocesses including adsorption, photodegradation, coagulation-flocculation, ionic exchange, precipitation, biological, and membrane separation are all part of the wastewater treatment process.

1. *Adsorption Process*

Adsorption relies on subjecting the wastewater to a reactive adsorbent (one that is porous, has a large specific surface area, or has a specified functional group) for a predetermined amount of time. The depleted adsorbents can be reused repeatedly (with or without regeneration) after the water has been cleaned. The method is not appropriate for wastewater with high pollutant levels or high volumetric flow rates, even if it is straightforward and reasonably priced.

2. *Ion Exchange*

Another popular method for eliminating heavy metals from water is an ion exchanger, which switches between the ions in the liquid and solid. To help the metals with the free functional groups complete, the H+ is released from the resin's acidic group. If membrane regeneration is simple and inexpensive, the procedure is quick and cost-effective. Membrane fouling, the existence of free acid, which may reduce the system's overall efficacy because of its poor binding affinity, and the procedures in suitability for high metal concentrations are some of this method's disadvantages. Chemical agents are used in the precipitation process to create insoluble precipitates of the contaminants, and the resulting sludge is typically removed by filtration. In water and wastewater treatment facilities, it is a key technology. This technique's simplicity and inexpensive cost are its advantages, but when contaminant loads are high, its efficiency is rather low. It has a slow contact time, consumes precipitation agents, and generates a lot of sludge.

3. *Coagulation/Flocculation*

In order to allow the particles of the pollutants to agglomerate and stack on top of the contaminated wastewater, a coagulant—such as metal salts or polymers—is added during quick, brief mixing. We call this process flocculation or coagulation. These flocculants and polymers allow the large flocs to form larger aggregates that enhance their precipitation when there is little mixing. This approach is economical and simple to utilize. Low efficiency, sludge formation, and the need for sedimentation—a second post-treatment step—are the challenges, though. As natural coagulants, Moringa oleifera, Musa genus, and Tamarindus indica were recommended. Technologies based on membranes.

Membrane technology encompasses osmotic pressure-driven membrane processes (electrodialysis and liquid membrane), high pressure-driven membranes (reverse osmosis and nanofiltration), and low pressure-driven membranes (distillation, microfiltration, and ultrafiltration). The properties of the membrane (surface charge, pore size, pore distribution, degree of hydrophobicity/hydrophilicity), along with the pressure exerted, are the primary determinants of the process. Carbon, titanium, ceramics, polymers, and materials based on titanium oxide might all be used to create the membrane structures.

4. *Biological Processes*

One common method for treating wastewater is biological treatment. The procedure entails cultivating, enriching, and activating the diverse beneficial microorganisms (bacteria, algae, and fungus) that are already present in the wastewater or certain bacteria that are received from an external source in order to break down different biodegradable contaminants in wastewater. Biological processes use little energy, are inexpensive, and are environmentally benign. Carbon dioxide, biomass, and water are the primary products of an aerobic treatment. Methane and carbon dioxide are the primary byproducts under anaerobic circumstances. Reactive functional groups on the microbe, including as carboxyl, phosphate, amino, and hydroxyl, are part of the mechanism in addition to catabolism events. These groups attract and react with different pollutants. The main disadvantages of these approaches are their length and control problems.

IV. Results and Analysis

A wastewater treatment plant's strategic planning for sustainable development is a very complex task. It requires constant work in many areas, and at the improvement stage, sustainability concepts based on the triple bottom line must be applied. When trying to strike a balance between social well-being, environmental preservation, and economic viability in the context of wastewater treatment, the task becomes even more difficult. The required hardness for freshwater aquaculture of a number of species is less than 500 mg/L. The average hardness in the deep and medium depth zones was lower (~250 mg/L), even though the overall hardness was less than 300 mg/L throughout the operation. The hardness seems to rise in the shallow area during dry seasons. This could be explained by greater evaporation brought on by a larger hydrophyte population, which would increase water loss through transpiration and raise the concentration of these ions in the water (Figure 1). Before tackling tank rehabilitation and the freshwater issue in peninsular India, it is necessary to comprehend the historical and current conditions of these tanks. Freshwater has no physical substitute, unlike food and energy sources, hence water management must be approached more forcefully in semi-arid areas of India with low rainfall (350–800 mm) and considerable interannual variability. In order to guarantee improved water management, we try to comprehend the construction, operation, and evolution of human-dominated water harvesting tanks over time, concentrating on their essential ecological and financial significance. Growing urbanization is engulfing an increasing number of these centuries-old tanks as they become less significant as the primary supply of water.

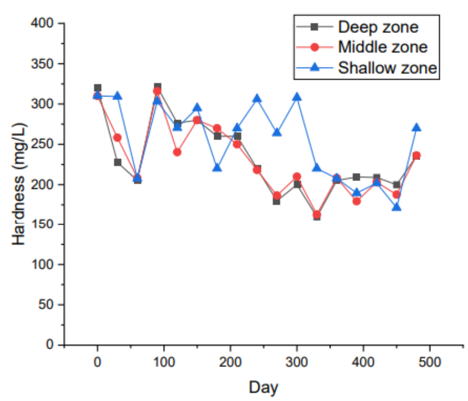

Figure 1: Hardness in Tanks

For the health of the lake, three more crucial water quality factors have to be taken into account. These included inorganic phosphate, total inorganic nitrogen, which is a mixture of amm-N, nitrate-N, and nitrite-N, and biological oxygen requirement.

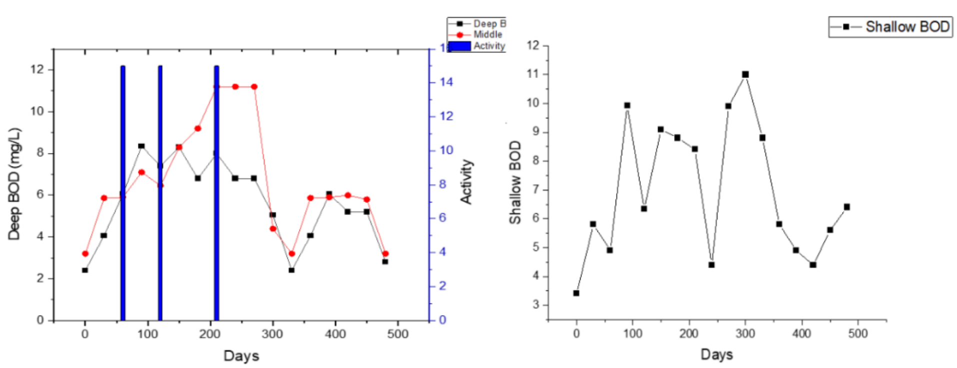

Figure 2: BOD in Deep, Medium, and Shallow Portions of the Tank

These are the kinds that are bioavailable. Fish were also added, and the deep and middle zones of the tank—designated by the blue lines I and III—were the sites of the primary de-weeding operation. It was anticipated that deeper zones would experience the majority of the effects of the fish introduction (II blue line), with medium depth coming in second. It was anticipated that these treatments would have no effect on the shallow zone. Significant changes occurred following any action requiring physical entry or mild disturbances into the water body, as evidenced by the BOD pattern.

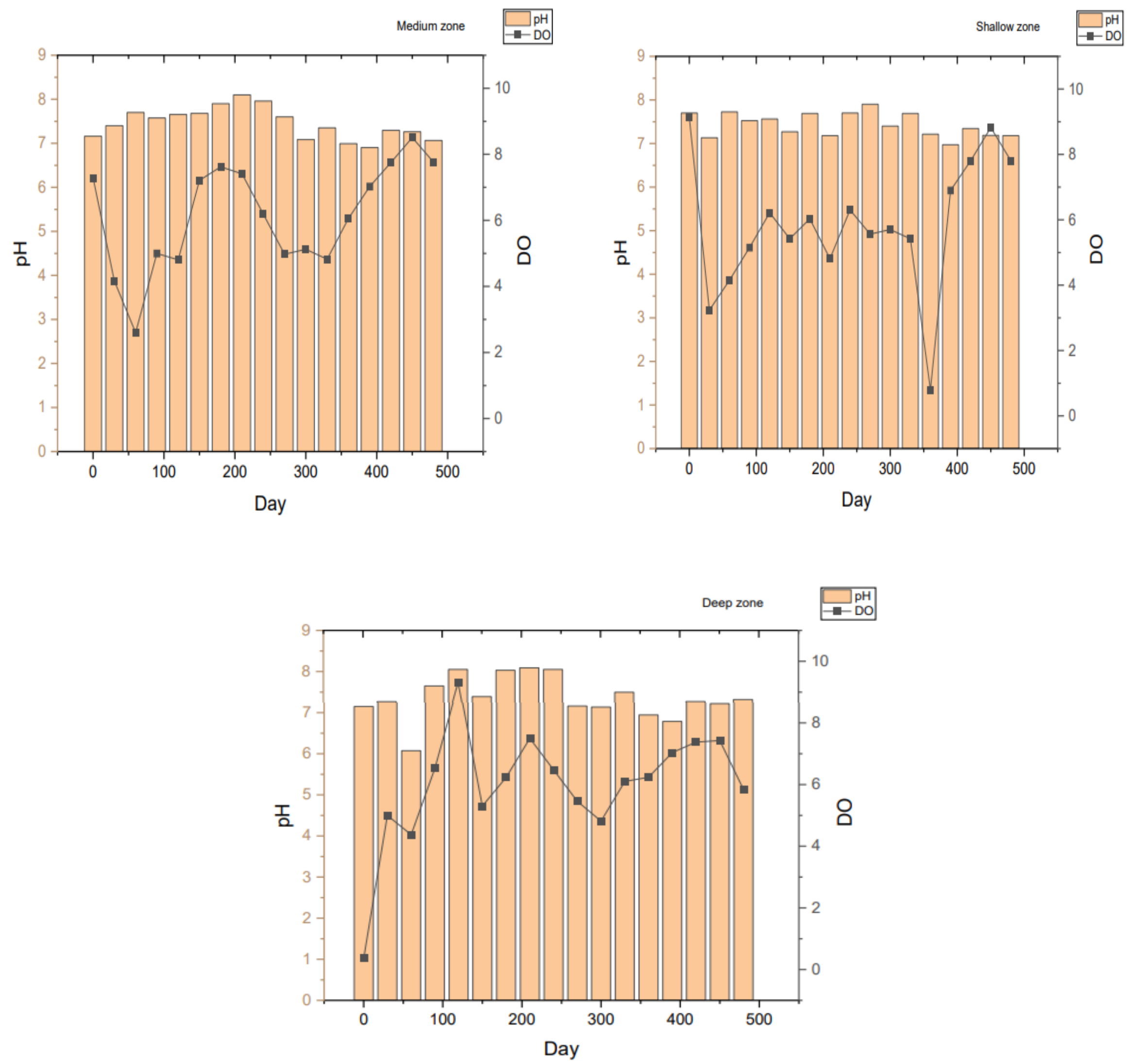

Figure 3: Temporal Variation in pH and DO

Water with a pH between 6.5 and 8.5 is OK. Throughout the study time, the pH at all three sampling locations was close to neutral, reaching about eight in the afternoon, as shown in Figure 3.

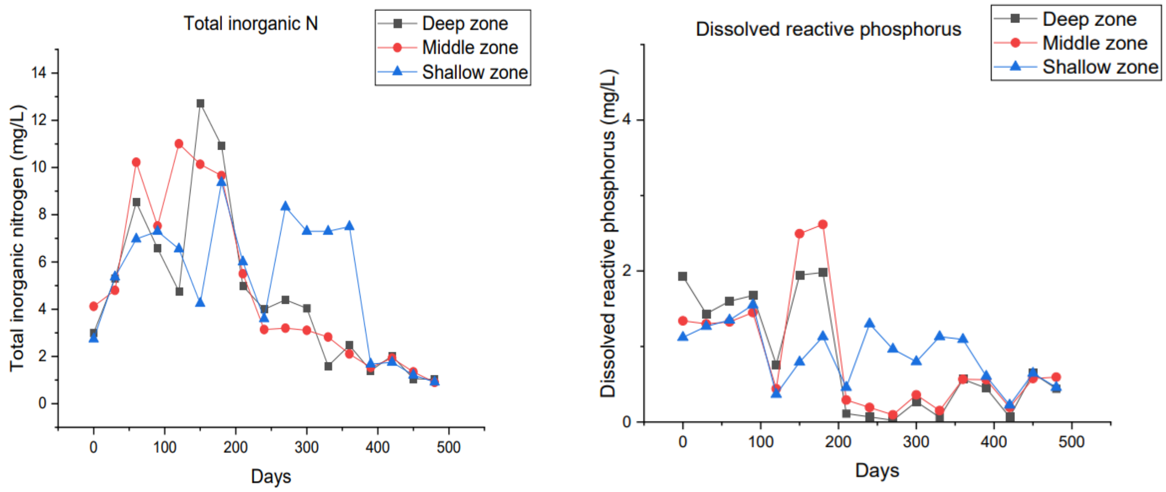

Figure 4: Dissolved Reactive Phosphorus

As previously mentioned in this study, the increased trend may be ascribed to two factors: the death and decay of hydrophyte vegetation that flourished in the first year of operation, as well as contributions of these chemical species from sludge and silt that were not fully removed during the initial physical restoration. This suggests that this issue should be addressed in the initial months after restoration, after which the levels will drop and be suitable for lake water management.

V. Conclusion

Urban wastewater frequently has a significant negative impact on urban edge water bodies, particularly inadequately treated sewage that enters and degrades them. According to sustainability standards, these wastewaters must be locally treated and recycled, and the impacted waterbodies must be restored to restore not only water quality but also a greater degree of aquatic and aqua-faunal diversity. The aforementioned phenomena has a significant impact on artificial surface water bodies, often known as Kere or tanks, in semi-arid areas of the Indian peninsula. There are more than 100,000 of these bodies of water, and many of them are probably in danger. Thus, this study aims to address the demand for new knowledge, environmentally friendly water treatment methods, and eco-restoration options. The "Village Tanks" lose their significance as water sources as a result of urban peripheral effluent seeping into them and the ensuing neglect, drying up, or eutrophication that occurs as many Southern Indian cities become more urbanized and tiny villages, towns, and cities "engulf" neighbouring villages. In the past, the majority of restoration projects used earthwork primarily to remove the sludge and silt. Until comprehensive sewerage and runoff networks are established, this condition persists for decades. Waterbodies that lack a guaranteed water source must be restored during this interregnum, which necessitates the development of innovative wastewater conditioning systems to handle locally running urban-fringe wastewater (UFWW).

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