Pollutant Removal Efficiency of Aquatic Plant Consortium in Floating Treatment Wetland for Municipal Wastewater

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Abstract

The aim of this study is to assess the effectiveness of a hybrid Floating Treatment Wetland (FTW) for the treatment of municipal wastewater by using Phragmites australis and Canna indica. Prior to the installation of the FTW, initial testing was conducted to identify the pollutant of interest. The performance of this system was monitored by analyzing the parameters mentioned above during the months of April to August. Throughout each phase, the system demonstrates high removal efficiency for the majority of parameters. Two way Anova was performed for multiple comparison between different phases and locations. The mature phase showed the maximum removal efficiency, with BOD 91%, COD 91% TSS 88%, TDS 48%, Total ammonia 75% nitrate 68%, phosphate 70%. The addition of a settling tank in the treatment process has proven to enhance efficiency, as it demonstrates effective removal of TSS, turbidity, and COD. This indicates that the implementation of primary treatment contributes to the overall efficiency of the FTW. The cost analysis showed that this system can treat 1m3 of wastewater with only 150 PKR which shows that this is cost effective technology. Therefore, the findings indicated that FTW has promise as a field-scale wastewater treatment method, offering a cost-effective technological solution. Moreover, it was recommended to investigate the long term potential of FTW on field scale.

Keywords: Floating Treatment Wetlands; Phytoremediation; Wastewater; Water Reuse; Irrigation

1 Introduction

The utilization of FTW has emerged as a prominent ecological solution, as evidenced by its increasing popularity to treat wastewater across the world [1]. The fundamental idea behind FTW systems is to simulate several naturally occurring processes in controlled environments for advantageous purposes, such wastewater treatment. The objective of FTWs is to replicate and improve the natural wetlands' functions. The performance of FTW is based on water depth, plant species, climatic conditions, type of wastewater and plant harvesting [2]. The FTW treat wastewater by different mechanism induced by plants, bacterial community and their mutual relationship. Plant root absorb the nutrients and accumulate them in their tissues and remove suspended particle matter from water. Plant roots also release chemical that aid to remove nutrients, maintain the pH balance. The natural pH helps to settle the dissolved particulate pollutants. The organic contaminants are removed through plant uptake and bacteria present on plant roots. The plants roots play important role that’s why plants with dense roots are suitable of FTW to achieve maximum efficiency [3].

Besides the phytoremediation, FTW provide the aesthetic and biodiversity enhancement services. Many studies showed that FTW provide significant and biological valuable habitat for wildlife, improve the ecosystem for aquatic animals, provide food, support aquatic plants [4]. Afzal et al., 2019 conducted on a full-scale study on FTWs in stabilization ponds in Faisalabad, Pakistan. The objective of the study was to assess the treatment performance of FTW over a period of three years. The system exhibited maximum removal efficiencies of 79% for COD, 88% for biological oxygen demand (BOD), and 65% for TDS. The performance of the wastewater treatment facility reached its peak in the second and third years of operation. During this period, approximately 60 million cubic meters of wastewater were successfully treated annually, at a cost of US$0.00026 /m3 [5].

The previous study on FTWs has been conducted primarily at the lab or microcosm scale. These studies have shown that FTWs can be effective in removing pollutants from water, but it is unclear how these systems would perform at full scale. This research fills the research gap by conducting a full-scale study of FTWs. In this study FTWs were constructed in a series of two ponds. This information could be used to design and implement FTWs for the treatment of wastewater and stormwater. The present study assessed the performance of full scale FTW system installed at 14000m2 area in Botanical Garden Jallo Park, Lahore for a period of 6 months periods. The wastewater from nearby village dumped to the pond. As per initial water sampling report wastewater contained organic, nutrients and microbiological pollutants.

2 Methodology

The study approach is implemented in a manner that effectively encompasses the analysis of nutrients and physicochemical parameters in municipal wastewater during the process of treatment using macrophytes. This study was funded by WWF-Pakistan. The approach utilized in this study encompassed the preparation, construction and installation of FTWs. The collection and examination of influent and effluent wastewater samples, and the evaluation of the system's performance by statistical analysis. The data was analysis through the application of multiple software. ArcGIS was employed extensively in the geospatial monitoring of the study area for the purpose of mapping. The graphical representation of the study was facilitated through the utilization of Microsoft Excel, while the creation of flow charts and flow diagrams related to the current investigation was accomplished using MS Word.

2.1 Study Area

Lahore is situated in the northeastern region of Pakistan. It is positioned along the banks of the Ravi River, which serves as a tributary of the Indus River. It holds the distinction of being the second-most populous city in the country. The climate in Lahore is characterized as subtropical, featuring relatively arid and moderate winters with occasional chilly temperatures at night. The summers in Lahore are quite hot and accompanied by precipitation due to the influence of the Indian monsoon. The monsoon season typically spans from the month of July through the middle of September. The region experiences an average yearly precipitation of 673 mm. The region under consideration spans an area of 1772 square kilometers and is now experiencing population growth, with a total of 13.54 million individuals (13,542,000). The study area chosen for investigation was the Botanical Garden located in Jallo Park, Lahore, spanning from February 23 to August 23. According to Nasar-u-Minallah (2020), Jallo Park, alternatively known as Jallo Wildlife Park, was established in 1978. It is geographically located at a latitude of 31° 34′ 21″ and a longitude of 74° 28′ 38″. The whole land area encompasses a substantial expanse of over 456 acres, equivalent to around 185 hectares. The pond located at the terminus of the park serves as a receptacle for the disposal of domestic wastewater originating from the adjacent village.

3 Analytical Techniques

3.1 Removal Efficiency

After results, % removal efficiency from inlet to outlet has been observed. The formula used to calculate the removal efficiency was in Eq.1

$$\frac{Cini-Cf}{Cin} X\ 100 \qquad (1)$$

Cin= Initial Concentration

Cf= Final Concentration

3.2 Water Sampling

The study was conducted for 6 months (Feb 23 -Aug 23), three samples were collected after a two-month interval. All samples were collected at a depth of 15 cm between 11:00 a.m. and 12:00 p.m. During the first sample prior to installation, all 32 water quality parameters were determined. Heavy metals were not detected in the initial testing. Nutrients and biological parameters are considered parameters of interest. The parameters were analyzed against NEQs for inland water. The samples were collected from the inlet of pond 1 for quality measurement of raw wastewater. The second sample was collected from the outlet of pond 1/ inlet of pond 2 for analysis of water treatment prior to FTW, and the third sample was collected from the outlet of pond 2 for post-treatment analysis. The floating mats covered 20% of the surface area of pond B. Based on the post-treatment results, the whole volume of 10,000 m3 of the FTW is being treated, which can be claimed as a benefit. The claim is backed by VWBA, research papers, and work initiated by the Principal Scientist of NIBGE. The annual flow of the wetland system was calculated based on site characteristics. The parameters derived from the inlet of the pond during the designated monitoring period are presented in Supplementary Table 3.1. During the sampling period, it was observed that all of the indicators exceeded the permissible threshold as outlined in the NEQS for inland water, other than TDS and total ammonia. The indicators encompassed in this study comprised EC, pH, DO, BOD, COD, TSS, TDS, nitrate, total ammonia and phosphate, TC, and FC. There are no NEQs for turbidity, EC, phosphate, TC, or FC.

3.3 Data Analysis

The data was analysis through the application of multiple software. ArcGIS was

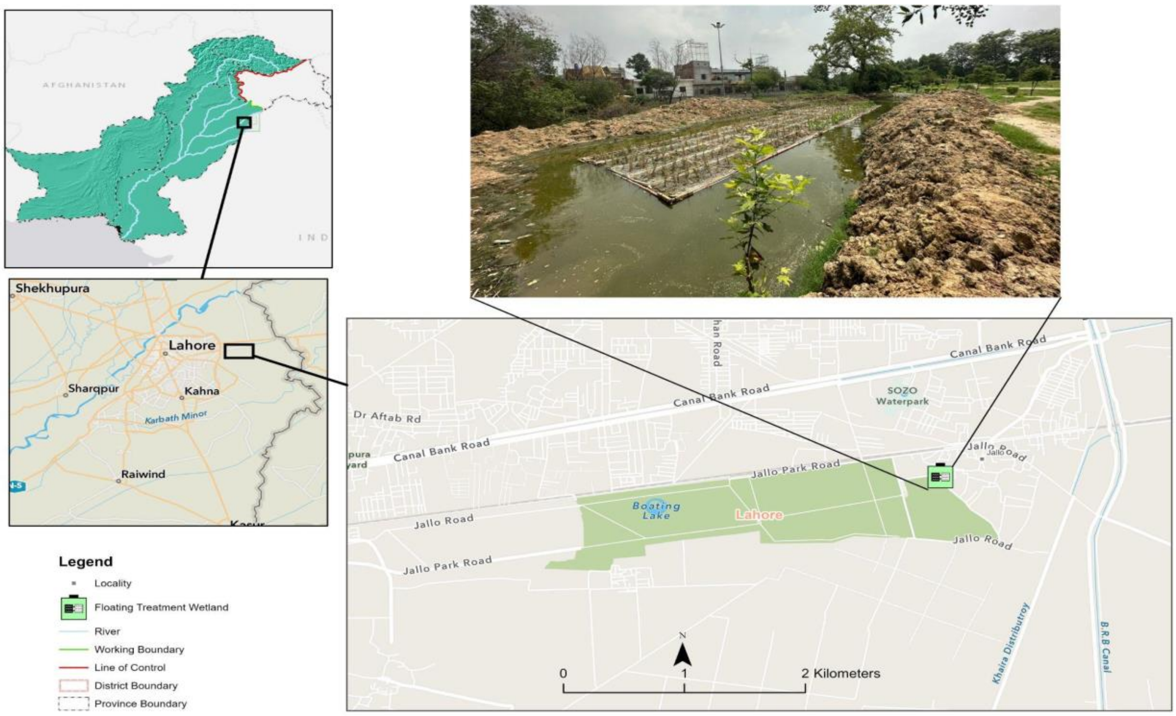

Fig. 1: Study Area Map

employed extensively in the geospatial monitoring of the study area for the purpose of mapping. The graphical representation of the study was facilitated through the utilization of Microsoft Excel, while the creation of flow charts and flow diagrams related to the current investigation was accomplished using MS Word and Visio.

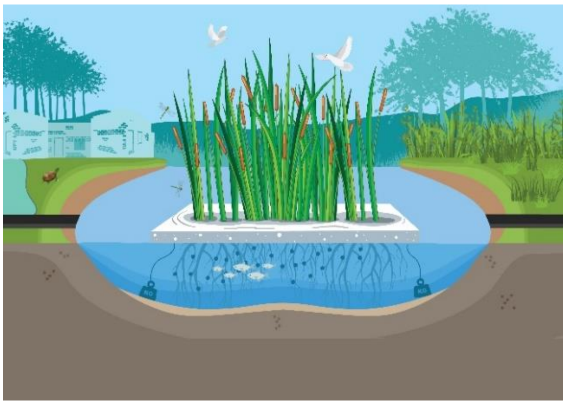

Fig. 2: Floating Treatment Wetland Design

3.3.1 Statistical Techniques

Statistical analysis was conducted using IBM SPSS 16. A two-way ANOVA test was performed to measure the significant difference among treatments and phases. Post-hoc Tukey's HSD test function was used for multiple comparisons. The differences were considered significant at $p > 0.05$. The parameters were dependent variables, whereas location and phases are two independent variables.

4 Results

4.1 Wastewater Characterization

The domestic wastewater was characterized on the basis of quality of the sample concentration before FTW installation. It was necessary to estimate the parameters so that pollution load could be assessed, which was required to measure the efficiency of FTW. The parameters, such as temperature, pH, COD, BOD, turbidity, TSS, TDS, EC, TAN, nitrate, and phosphate were determined. Cadmium, arsenic, lead, chromium, nickel, calcium, magnesium, sodium, potassium, and zinc were also tested in the sample. Depending on the results, heavy metals were not detected in the sample; that's why heavy metals were not tested for further sampling.

4.2 Temporal performance of the FTWs

The duration of the treatment period was segmented into three distinct phases; each indicate the performance of the FTWs. The first phases classified as the initial phase (February 2023 to April 2023), the intermediate phase (April 2023 to June 2023), and the mature phase (June 2023 to August 2023). The implementation of the FTWs yielded favorable outcomes in terms of diminishing TSS, TDS, BOD, COD, and nutrient levels in the discharged Wastewater.

4.3 Physicochemical Parameters

During the initial phase, when the plants were in their early phase of growth, the rate of removal was seen to be low. Additionally, it was found that all the parameters, except for turbidity, TDS, and TSS, were high. However, turbidity and TSS exhibited removal efficiencies of 80%, 80%, and 8%, respectively. TDS was within the NEQs range, and the removal rate was low. The phenomenon of turbidity reduction occurs when suspended particles attach to the roots. The roots of plants serve as filtration mechanisms, effectively extracting suspended particulate matter from water. These particles attach to the roots, resulting in a direct reduction in water turbidity [6]. The existence of a settling tank facilitates the process of particle removal through sedimentation; whereby suspended particles settle at the bottom. As the settling time increases, the removal rate also increases. During the intermediate phase, the majority of the values were high, with the exception of pH, TDS, and turbidity. The TSS, which initially met the established threshold, has now exceeded the allowable limit to a small extent. The cause of this occurrence can be attributed to the large load of TSS at the inlet.

The optimal pH of wastewater is achieved by the microbial breakdown of organic matter and in vegetated treatments, which is attributed to the release of acidic root exudates from vegetation and carbon dioxide (CO2) production resulting from root respiration [7]. Plants also generate bioactive compounds that contribute to the enhancement of sorption and sedimentation mechanisms. These chemical substances also play a beneficial role in maintaining the pH balance, thereby facilitating the settling of TDS. The increase in humic content in water leads to the adsorption or precipitation of contaminants in the form of insoluble substances. The removal efficiency of all parameters exhibited improvements, indicating a positive correlation between removal efficiency and plant growth. During the mature phase, the highest removal efficiency is attained as most of the parameters are within the permissible range. The concentration of DO was slightly low; however, there has been a positive improvement observed. The improvement of DO levels can be attributed to the release of oxygen into the water by plant roots during photosynthesis serves as another reason for the enhancement of DO [8]. In addition, the presence of Phragmites also plays a role in enhancing the oxygen levels. The presence of thick roots is crucial for the efficient removal of pollutants, as they serve as effective biosorbents. Moreover, the presence of roots facilitates the assimilation of carbon compounds by microbial colonies, contributing to the lowering of both BOD and COD. During this particular period, the plant development exhibited a robust and aggressive nature, as seen by the extension of the root network towards the bottoms of the ponds [9]. Consequently, the root network served the purpose of functioning as a biological filter. Phosphorus elimination occurs via processes such as sorption, settling at the bottom, and physical entrapment within the roots. The exclusion of phosphate-cation interactions, specifically with calcium, iron, and aluminum in sediments, is facilitated by the combination of oxidizing conditions and a neutral pH range of 6.2–8.3 in the rhizosphere. The nutrients are removed by the process of direct intake, hence contributing to a reduction in nutrient levels. Canna indica has a substantial biomass, hence facilitating enhanced nitrification and the mitigation of ammonia and nitrate levels in wastewater [10]. The microbacterial population exhibited a high value throughout each phase, and after treatment, a significant reduction has been observed. These trends show that a reduction took place in the second pond in which floating mats were deployed. The first pond contributes to the removal of COD, turbidity, and TSS, and maximum reduction is observed from the initial to the mature phase.

4.4 Plant Growth

During the initial phase of this study, it was seen that all of the plants exhibited robust growth and displayed intensive development of their root networks towards the lower regions of the ponds. In summary, Phragmites australis exhibited an earlier attainment of peak output compared to Canna indica. During the mature phase, the biomass of plant net exhibited either stability or a minor reduction, Phragmites australis exhibited the highest biomass production.

5 Discussion

5.1 % removal efficiencies

The removal efficiency from inlet to outlet has been calculated for initial (April), Intermediate (June) and mature (August) phase. Results show positive outcomes with passage of time. During April mostly parameters are above the permissible limits other than turbidity, TDS TSS. During June removal efficiency has improved than previous phase. Overall, the results show progress in removal efficiency but BOD, COD, TSS total coliform and fecal coliform was still high. In August, removal efficiency is improved and overall parameters are under permissible limits. TC reduce from 20% to 52% and FC 22% to 87% which should to be reduced further.

5.1.1 Initial Phase

During the initial phase, when the plants were in their early phase of growth, the rate of removal was seen to be low. Additionally, it was found that all the parameters, except for Turbidity, TDS and TSS were high. However, Turbidity and TSS exhibited removal efficiency OF 80%, 80% and 8% respectively. TDS was within NEQs range and removal rate was low. The phenomenon of turbidity reduction occurs when suspended particles attach to the roots. The roots of plants serve as filtration mechanisms, effectively extracting suspended particulate matter from water. These particles attach to the roots, resulting in a direct reduction of water turbidity [11]. The existence of a settling tank facilitates the process of particle removal through sedimentation, whereby suspended particles settle at the bottom. As the settling time increases, the removal rate also increases.

5.1.2 Intermediate Phase

During the intermediate phase, the majority of the values still high, with the exception of pH, TDS, and turbidity. The TSS, which initially met the established threshold, has now exceeded the allowable limit to a small extent. The cause of this occurrence can be attributed to the large load of TSS at the inlet, whereas the removal efficiency remains consistent throughout all phases. The optimal pH of wastewater is achieved by the microbial breakdown of organic matter and in vegetated treatments, which is attributed to the release of acidic root exudates from vegetation and carbon dioxide (CO2) production resulting from root respiration [12]. Plants furthermore generate bioactive compounds that contribute to the enhancement of sorption and sedimentation mechanisms. These chemical substances also play a beneficial role in maintaining the pH balance, hence facilitating the settling of TDS. The increase of humic content in water, leading to the adsorption or precipitation of contaminants in the form of insoluble substances [13]. The removal efficiency of all parameters exhibited improvements , indicating a positive correlation between removal efficiency and plant growth.

5.1.3 Mature Phase

During the mature phase, the highest removal efficiency is attained as the most of the parameters are within the permissible range. The concentration of DO was slightly low, however there has been a positive improvement observed. The improvement of DO levels can be attributed to two factors. Firstly, the movement of water from one pond to another contributes to the increase in DO. Secondly, the release of oxygen into the water by plant roots during photosynthesis serves as another reason for the enhancement of DO. In addition, the presence of P. Austrails in the second pond also plays a role in enhancing the oxygen levels. The presence of thick roots is crucial for the efficient removal of pollutants, as they serve as effective biosorbents [14]. Moreover, the presence of roots facilitates the assimilation of carbon compounds by microbial colonies, so contributing to the lowering of both BOD and COD [15]. During this particular period, the plant development exhibited a robust and aggressive nature, as seen by the extension of the root network towards the bottoms of the ponds. Consequently, the root network served the purpose of functioning as a biological filter. Phosphorus elimination occurs via processes such as sorption, settling at the bottom, and physical entrapment within the roots. The exclusion of phosphate-cation interactions, specifically with calcium (Ca), iron (Fe), and aluminum (Al) in sediments, is facilitated by the combination of oxidizing conditions and a neutral pH range of 6.2–8.3 in the rhizosphere. The nutrients are removed by the process of direct intake, hence contributing to a reduction in nutrient levels. Canna indica has a substantial biomass, hence facilitating enhanced nitrification and the mitigation of ammonia and nitrate levels in wastewater. The microbacterial population exhibited high value throughout each phase, and even after undergoing treatment [16]. This suggests that additional enhancements are necessary in order to effectively address bacterial contamination. Multiple studies have provided evidence to support the notion that ultraviolet (UV) radiation has a substantial impact in diminishing bacterial populations within aquatic environments [17].

6 Conclusion

The potential applicability and benefits of FTWs in developing countries are enormous. Keeping in mind the need for clean water in developing countries, FTWs, can be used to solve problems of water pollution without investing into the extra labor of attaining sites for remediation, manpower, and finances. The future holds many fields of study revolving around FTWs. With the increasing knowledge of FTWs, there are better chances of manipulating their design and usage for better efficiency. Floating treatment wetlands also enhance the performance of the different methods of water treatment that are already being employed like wastewater stabilization ponds. A hindrance in the establishment of FTWs in developing countries is the difficult acquisition of sufficient land due to dense urban populations. This problem is solved well by using FTWs that are employed on already present reservoirs of water. These wetlands can be designed and maintained as per the size of the pond or water body for which they are established. Conclusively, there is an immense need for well-qualified and passionate scientists, managers, and engineers, who can think and deliver for a better future that has environmental protection, conservation of natural water resources.

7 Recommendation

- FTWs have a limited treatment capacity, and the size of the wetland needs to be carefully designed to ensure that it can handle the volume of wastewater being treated. For large-scale applications, multiple FTWs may need to be installed in parallel to achieve the necessary treatment capacity.
- Constructing and installing large FTWs can be challenging and expensive, particularly if they are located in areas with difficult access. The use of modular designs can help to reduce construction and installation costs and improve scalability.
- The maintenance requirements of FTWs can increase with size, as larger systems require more frequent plant trimming, nutrient monitoring, and sediment removal. Adequate resources and infrastructure are needed to ensure that FTWs can be effectively maintained and managed.
- The cost-effectiveness of FTWs for large-scale wastewater treatment systems needs to be evaluated, including the costs of construction, installation, operation, and maintenance. The cost-effectiveness of FTWs can be affected by a range of factors, including the cost of land, the availability of suitable materials, and the cost of labor.

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