Model of COD and PO_4 Reduction in Bima Bay Wastewater Using Innovations of *Ipomoea aquatica*, *Pistia stratiotes*, *Eichhornia crassipes* with EM4 as a Bioremediator

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Abstract. Water pollution remains a critical environmental issue in Indonesia, particularly exemplified by the algae bloom phenomenon in Bima Bay. As a potential solution, it is necessary to treat the water with phytoremediation, which involves the use of a combination of various aquatic plants. This study aims to evaluate the efficacy of *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes*, along with Effective Microorganism 4 (EM4) as a bioremediator, in reducing pollutants in Bima Bay. This study adopts a quasi-experimental pre-test-post-test control group design. Results show that the initial Chemical Oxygen Demand (COD) in the river water was 539.7 milligrams per liter (mg/L), while the phosphate (PO_4) concentration was 0.16 mg/L. Phytoremediation using the *Ipomoea aquatica* (water spinach), *Pistia stratiotes* (water lettuce), and *Eichhornia crassipes* (water hyacinth) plants has demonstrated the effective reduction of river water COD level by 5.3 mg/L to 95.5 mg/L. However, the method proved ineffective in reducing river water PO_4 level, with an increase of 0.03 mg/L to 0.32 mg/L. The Kruskal-Wallis test yielded statistically significant results, indicating notable differences in COD and PO_4 levels in river water across various measurement periods within each treatment group. The findings indicate that phytoremediation using *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes* with EM4 as a bioremediator is an effective approach for reducing COD levels in river water. However, this method proved less effective in reducing PO_4 levels, which may continue to pose challenges in addressing water pollution in Bima Bay.

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1 Introduction

Water pollution is a pressing issue in Indonesia. According to the Ministry of Environment and Forestry, only 5.35% of Indonesian rivers met quality standards in 2020, while the remaining 94.65% were categorized as heavily polluted (59.05%), moderately polluted (26.61%), or lightly polluted (8.87%). In parallel, the national Water Quality Index (WQI) dropped from 53.53 in 2020 to 52.82 in 2021, signalling a potential water scarcity and crisis. It is predicted that by 2045, 9.6% of Indonesia's population, particularly in Southern Sumatra, West Nusa Tenggara, and Southern Sulawesi, will face water scarcity [1]. At the local level, the aquatic environment is also subject to significant pollution, as evidenced by observations in Bima City. The research findings indicated the presence of pollution in Bima Bay, with the detection of elevated levels of lead (Pb) in the *Sonneratia alba* mangrove plant species, with 3.74 ppm in leaf tissues and 4.15 ppm in root tissues. Similarly, the *Rhizophora apiculata* species recorded 3.21 ppm Pb in leaf tissues and 0.19 ppm in root tissues [2]. Bima City's WQI indicates a continued deterioration in water quality, with a notable decline from 52.73 (moderate pollution) in 2020 to 24.55 (poor) in 2021 [3]. In late April 2022, a severe pollution incident in Bima Bay left the water resembling a desert across 10 hectares [4].

The initial findings from the Bogor Agricultural University (IPB) team indicated that the observed phenomenon in Bima Bay was an algae bloom caused by the rapid growth and subsequent death of the *Bacillariophyceae* class of phytoplankton due to a lack of oxygen, resulting in the formation of floating mats in the sea. It was further hypothesized that the "blooming" phenomenon is a result of a complex interplay of climatic and oceanographic processes, as well as the potential contribution of non-point source eutrophication [5]. The results of the study are corroborated by research findings indicating that the phenomenon was likely caused by a combination of algae blooming and eutrophication triggered by high nutrient content in seawater. As Asyriadin notes, eutrophication and high nutrient content in seawater are likely causes of the phenomenon observed in Bima Bay [6]. The addition of phosphate and nitrate fertilizers or manure to water bodies can result in the accumulation of nutrients, leading to eutrophication and a subsequent depletion of dissolved oxygen.

The presence of nutrients in water bodies results in an increase in the distribution of phytoplankton within the aquatic environment. High concentrations of phytoplankton have been observed in coastal waters near residential areas. This is due to the fact that the aquatic environment receives input of pollutants from the land in the form of the results of anthropogenic activities, namely nitrates, nitrites, and phosphates (PO_4) [7]. In accordance with the aforementioned findings, the laboratory test results of samples obtained from Bima Bay during the algal bloom period revealed the presence of phosphate (PO_4) at concentrations ranging from 0.06 to 0.08 mg/L, which exceeded the permissible threshold for sea water quality standards [6]. The results of the Bima Bay sample testing conducted by ITB revealed total phosphate values ranging from 0.27 mg/L to 0.58 mg/L, along with ortho phosphate levels of 0.24 mg/L to 0.37 mg/L and COD levels of 16 mg/L to 32 mg/L [4]. The elevated phosphate and COD concentrations serve as indicators of the source of pollution in Bima Bay, which is presumed to originate from agricultural waste. The use of fertilizers and pesticides in rice fields near the river allegedly contributes to the elevated COD values [8]. Elevated COD and phosphate levels can significantly disrupt aquatic ecosystems, as evidenced by the algal bloom phenomenon.

Consequently, addressing the aforementioned water pollution requires the implementation of an appropriate remediation strategy. Phytoremediation, a method that uses aquatic plants to aid in the remediation process, offers a potential solution. This method harnesses the ability of plants to uptake, store, and bioaccumulate through their root systems [9]. Several aquatic plants have been shown to effectively reduce phosphate and COD levels in water, including *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes*. Studies have demonstrated that *Ipomoea aquatica* can reduce COD levels by 17.67%, while *Pistia stratiotes* can lower COD in wastewater by 60.07% [10]. Additionally, research indicates that *Pistia stratiotes* is capable of reducing phosphate (PO_4) levels by 39% and COD levels by 91% in laundry wastewater [11]. Similarly, the *Eichhornia crassipes* plant has been shown to reduce PO_4 levels in wastewater by 60% to 77.5% and reduce COD levels by up to 66.86% [12].

While numerous studies have confirmed the individual efficacy of *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes* in reducing PO_4 and COD levels, no research to date has explored the combined effects of these three plants in a single phytoremediation process. In their natural habitats, these three species are frequently observed coexisting in aquatic ecosystems. The objective of this research is to further examine the model of COD and PO_4 reduction in Bima Bay wastewater using a combination of *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes*. This research also incorporates EM4 as a bioremediator, which is expected to enhance the fermentation and decomposition of organic matter, thereby accelerating the decomposition of organic matter [13].

2 Method

This study employed a quasi-experimental method with a pre-test-post-test control group design, which involves the formation of a control group and a treatment group, which are then evaluated before and after the intervention [14]. In this study, the subjects were divided into one control group and two treatment groups. The treatment groups were distinguished by the EM4 mixture applied.

The study was conducted in Bima City and Bima Regency. Water samples were collected from the Padolo River, a major contributor to the pollution in Bima Bay. This river flows through densely populated areas and agricultural zones, making it a significant source of pollutants, including agricultural runoff. The upstream section of the river lies in Bima Regency, which is characterized by extensive agricultural activity. The river empties into Bima Bay, further exacerbating water pollution in the area. The samples were processed at the Regional Health Laboratory of Bima City, while the treatment itself was carried out in Bima Regency from June 20 to 29, 2023.

The tools utilized in this study include jerry cans for sampling as well as container boxes as the wastewater treatment media (containing wastewater and the plants). Additionally, bottles and sample boxes were employed for the transportation of samples. The materials utilized in this study are wastewater and biological materials, including *Ipomoea aquatica* (water spinach), *Pistia stratiotes* (water lettuce), *Eichhornia crassipes* (water hyacinth), and EM4 mixed with clean water as a bioremediator.

Prior to the treatment, it is essential to prepare the bioremediator in the following manner: EM4 was combined with clean water in a 1:20 ratio (125 ml of EM4 and 2500 ml of clean water) and in a 1:40 ratio (250 ml of EM4 and 10,000 ml of clean water). Subsequently, the EM4 and clean water mixture is transferred to a jerry can and allowed to stand for seven days. This process is intended to stimulate the microbial activity within the EM4, thereby enabling these organisms to function at their optimal capacity when introduced to wastewater [13].

The experiment was divided into three groups:

Control : 5 liters of river water, planted with 10 *Ipomoea aquatica*, 10 *Pistia stratiotes*, and 7 *Eichhornia crassipes*, without the addition of EM4.

EM4 (1:20) : 5 liters of river water mixed with 1 liter of EM4 (1:20 ratio), planted with 10 *Ipomoea aquatica*, 10 *Pistia stratiotes*, and 7 *Eichhornia crassipes*.

EM4 (1:40) : 5 liters of river water mixed with 1 liter of EM4 (1:40 ratio), planted with 10 *Ipomoea aquatica*, 10 *Pistia stratiotes*, and 7 *Eichhornia crassipes*.

The samples were placed in sample bottles and transported to the laboratory using a sample box for analysis. Due to financial constraints, the samples were only analyzed once.

The data obtained from the laboratory tests were recorded and subsequently subjected to statistical analysis to determine the significance of COD and PO_4 reductions observed in each treatment. Prior to this, the data were tested for normality using the Saphiro-Wilk method. This was followed by the implementation of a non-parametric Kruskal Wallis test, given that the data exhibited non-normal distribution [15].

3 Results

3.1 Test Results of River Water Characteristics

Table 1 Test Results of Padolo River Water Characteristics

Parameter	Test Results (mg/L)	Quality Standard (mg/L)
COD	539.7	25
PO_4	0.16	0.2

The test results show that the COD level in the Padolo River water sample is 539.7 mg/L, which significantly exceeds the Class 2 river water quality standards as outlined in Government Regulation of the Republic of Indonesia Number 22 of 2021. However, the PO_4 concentration remains below the stipulated standard at 0.16 mg/L.

3.2 Effectiveness of Treatment on Pollutant Reduction

3.2.1. Effectiveness of COD Level Reduction

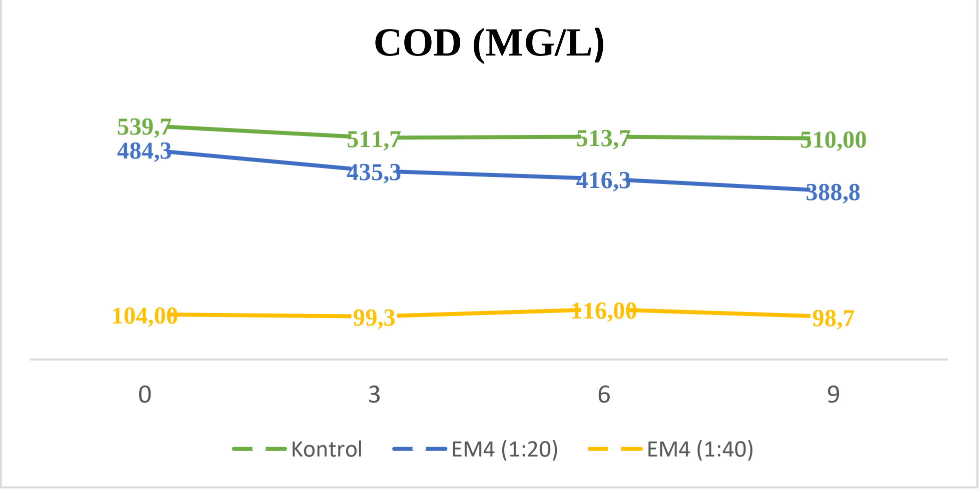

Fig. 1. COD levels during the treatment period

The data demonstrate that the treatment effectively reduces river water COD levels across all groups. The control group reduced river water COD levels by 29.7 mg/L, the EM4 (1:20) group reduced river water COD levels by 95.5 mg/L, and the EM4 (1:40) group reduced river water COD levels by 5.3 mg/L.

3.2.2. Effectiveness of PO_4 Level Reduction

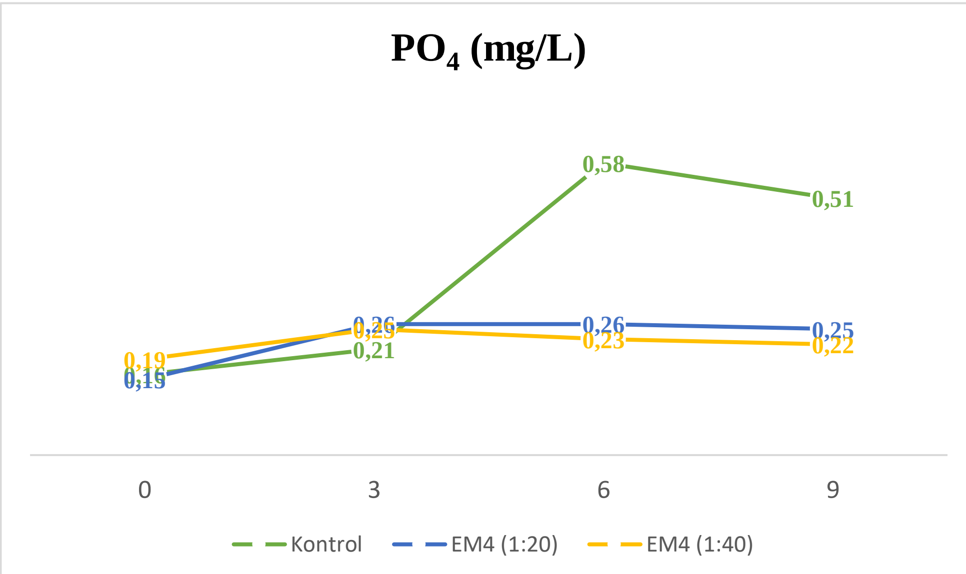

Fig. 2. PO_4 levels during the treatment period

As illustrated in the figure, the treatment regimen proved ineffective in reducing the concentration of PO_4 in river water across all treatment groups. The control group exhibited an increase of 0.32 mg/L in river water PO_4 levels, while the EM4 (1:20) group demonstrated a 0.06 mg/L rise and the EM4 (1:40) group exhibited a 0.03 mg/L increase.

3.3 Results of Data Analysis

3.3.1. COD

Table 2 Saphiro-Wilk Test Results for COD

Days	Treatment Groups	*Sig. value*	Test Results	Conclusion
0	Control	0.637	H_0 is accepted	Data is normally distributed
	EM4 (1:20)	0.000	H_0 is rejected	Data is not normally distributed
3	Control	0.000	H_0 is rejected	Data is not normally distributed
	EM4 (1:20)	0.298	H_0 is accepted	Data is normally distributed
	EM4 (1:40)	0.463	H_0 is accepted	Data is normally distributed

Days	**Treatment Groups**	***Sig. value***	**Test Results**	**Conclusion**
6	Control	0.000	H_0 is rejected	Data is not normally distributed
	EM4 (1:20)	0.000	H_0 is rejected	Data is not normally distributed
9	Control	1.000	H_0 is accepted	Data is normally distributed
	EM4 (1:20)	0.328	H_0 is accepted	Data is normally distributed
	EM4 (1:40)	0.000	H_0 is rejected	Data is not normally distributed

The Shapiro-Wilk test results show that the p-value is less than 0.05 for the control group on days 3 and 6, the EM4 (1:20) group on days 0 and 6, and the EM4 (1:40) group on day 9. This indicates that the null hypothesis (H_0) is rejected, suggesting that the data are not normally distributed. As a result, the non-parametric Kruskal-Wallis test was used to assess the differences.

Table 3 Kruskal-Wallis Test Results for COD

Days	**Treatment Groups**	***Asymp. Sig***	**Test Results**	**Conclusion**
0	Control EM4 (1:20) EM4 (1:40)	0.023	H_0 is rejected	There are differences in COD levels in river water
3	Control EM4 (1:20) EM4 (1:40)	0.027	H_0 is rejected	There are differences in COD levels in river water
6	Control EM4 (1:20) EM4 (1:40)	0.023	H_0 is rejected	There are differences in COD levels in river water
9	Control EM4 (1:20) EM4 (1:40)	0.027	H_0 is rejected	There are differences in COD levels in river water

The Kruskal-Wallis test results for the COD variable indicate that the null hypothesis (H_0) is rejected, indicating a significant difference in COD levels in water. The discrepancy in COD levels is contingent upon the statistical significance of the analytical outcomes and the statistical significance at various measurement points (0, 3, 6, and 9 days) for each substance concentration treatment, including the Control, EM4 (1:20), and EM4 (1:40) groups.

3.3.2. PO_4

Table 4 Saphiro-Wilk Test Results for PO_4

Days	**Treatment Groups**	***Sig. value***	**Test Results**	**Conclusion**
0	EM4 (1:20)	0.000	H_0 is rejected	Data is not normally distributed

Days	**Treatment Groups**	***Sig. value***	**Test Results**	**Conclusion**
3	Control	0.000	H_0 is rejected	Data is not normally distributed
	EM4 (1:20)	0.000	H_0 is rejected	Data is not normally distributed
	EM4 (1:40)	0.000	H_0 is rejected	Data is not normally distributed
6	Control	0.000	H_0 is rejected	Data is not normally distributed
9	Control	0.000	H_0 is rejected	Data is not normally distributed
	EM4 (1:40)	0.000	H_0 is rejected	Data is not normally distributed

The results of the Shapiro-Wilk test indicate that the p-value is less than 0.05 for all treatment groups. This suggests that the null hypothesis (H_0) is rejected, indicating that the data are not normally distributed. Therefore, the Kruskal-Wallis test was used to determine differences between the groups.

Table 5 Kruskal-Wallis Test Results for PO_4

Days	**Treatment Group**	***Asymp. Sig***	**Test Results**	**Conclusion**
0	Control	0.029	H_0 is rejected	There are differences in PO_4 levels in river water
	EM4 (1:20)			
	EM4 (1:40)			
3	Control	0.032	H_0 is rejected	There is a difference in level PO_4 on water
	EM4 (1:20)			
	EM4 (1:40)			
6	Control	0.020	H_0 is rejected	There is a difference in level PO_4 on water
	EM4 (1:20)			
	EM4 (1:40)			
9	Control	0.023	H_0 is rejected	There is a difference in level PO_4 on water
	EM4 (1:20)			
	EM4 (1:40)			

The Kruskal-Wallis test results for the PO_4 variable indicate that the null hypothesis (H_0) is rejected, thereby demonstrating a statistically significant difference in PO_4 levels in river water. The discrepancy in PO_4 levels is contingent upon the statistical significance of the analytical outcomes and the statistical significance of the measurements taken at 0, 3, 6, and 9 days for each concentration of the substance under investigation, which were designated as Control, EM4 (1:20), and EM4 (1:40).

4 Discussion

The test results for the characteristics of the Padolo River water revealed a COD level of 539.7 mg/L, which significantly exceeds the Class 2 river water quality standards set forth in Government Regulation Number 22 of 2021 [16]. The COD value represents the total quantity of oxygen required to oxidize all organic matter present in the water sample, including both decomposable and non-decomposable organic matter [9]. The findings of the COD values during the occurrence of algae blooms in Bima Bay ranged from 16 to 35 milligrams per liter (mg/L), as reported by Institut Teknologi Bandung [4]. This high COD value points to a severe pollution issue in the river, likely originating from domestic and agricultural activities. The results of the research conducted in the Batanghari River tributaries revealed elevated COD values in the downstream region, which are presumed to originate from domestic and agricultural waste pollutants, including detergents, fertilizers, and pesticides. Furthermore, it is postulated that the upstream pollution resulting from the application of fertilizers and pesticides in rice fields near the river has led to elevated COD values [8]. The presence of elevated COD levels in water can result in a reduction in oxygen content, thereby disrupting the aquatic ecosystem [17].

The findings of this study also indicated that the PO4 concentration of Padolo River water was 0.16. The PO_4 value of Padolo River water remains below the quality standard for Class 2 river water, as defined in Government Regulation Number 22 of 2021, which is 0.2 mg/L [16]. Although the PO_4 concentration complies with river water quality standards, this result indicates that it is higher than the research findings in Bima Bay after an algae bloom, which amounted to 0.062 mg/L in sample 1 and 0.080 mg/L in sample 2 [6]. This discrepancy is due to the differing quality standard values for river water (0.2 mg/L) and sea water (0.015 mg/L). Furthermore, the PO_4 levels in Bima Bay are not solely derived from the Padolo River; they can also originate from overflowing waters from other rivers. Bima Bay is the estuary of several rivers in Bima Regency and the City of Bima. Additionally, it was determined that during the algae bloom in Bima Bay, the seawater samples exhibited total phosphate concentrations ranging from 0.27 to 0.58 mg/L and orthophosphate levels between 0.24 and 0.37 mg/L, both of which exceeded the permissible limits set forth in the seawater quality standards [4]. The phosphate present in water is in the form of orthophosphate (PO_4). The concentration of orthophosphate in water is indicative of its fertility [18]. The greatest potential for contamination of phosphate levels in river water arises from agricultural activities, particularly the use of rice fields and forests, which have been found to contribute 39.31 mg/L [19].

The findings of this study show that the treatment of river water using *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes* in conjunction with the EM4 bioremediator results in a significant reduction in COD levels, with an average decrease of 5.3 mg/L to 95.5 mg/L observed after nine days of treatment. The findings of this study align with the results of prior research indicating that *Ipomoea aquatica* can reduce wastewater COD levels by 17.67%, while *Pistia stratiotes* can reduce wastewater COD levels by 60.07% [10]. Other research indicates that *Eichhornia crassipes* can also reduce COD levels by 66.86% [12]. Despite the promising results, further research is necessary to confirm the long-term effectiveness of these treatments on a larger scale or in natural river environments.

Additional findings from this study indicated a significant reduction in COD levels following the introduction of EM4 bioremediator on day 0. Specifically, the EM4 (1:20) group exhibited a reduction from 539.7 mg/L to 484.3 mg/L, while the EM4 (1:40) group demonstrated a further decline to 104 mg/L. This occurs due to the fact that EM4 facilitates the fermentation and decomposition of organic matter in wastewater. The presence of protease enzymes produced by various types of microbes, including bacteria, moulds, and yeasts, contained in EM4 facilitates the breakdown of proteins into ammonia, nitrite, nitrate, CO2, and H2O [20]. The substances that have been broken down by the bacteria in EM4 are then utilized by plants as food.

The Kruskal-Wallis test was employed to analyze the data regarding the COD levels in water. The results indicate that the null hypothesis (H_0) is rejected, suggesting that there are significant differences in the COD levels of the water samples collected at various time points

(0, 3, 6, and 9 days) across the three treatment groups (Control, EM4 [1:20], and EM4 [1:40]). These results suggest that each treatment has a distinct impact on COD levels at different points in time. The efficacy of reducing COD levels in various groups and time points demonstrates that remediator plants are capable of remediating water COD levels through the photosynthesis process, whereby oxygen is produced, thereby enabling the utilization of oxygen needs to degrade organic substances present in wastewater [11].

The findings indicated that the application of *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes* with EM4 bioremediator did not result in a notable reduction in PO_4 levels in river water after nine days. The PO_4 level of river water exhibited an increase following the phytoremediation process, reaching 0.51 mg/L in the control group, 0.25 mg/L in the EM4 (1:20) group, and 0.22 mg/L in the EM4 (1:40) group. The elevated phosphate levels observed in the control group, which did not employ EM4, can be attributed to the presence of deceased and decomposing plant matter. This organic matter serves to enrich the nutrient content of the water, with phosphate being one such nutrient [12]. In the group that used EM4, the increase in PO_4 levels was also due to the greater number of microorganisms present in the EM4 bioremediator, resulting in an increased production of phosphorus [21].

These findings diverge from those of previous studies, which have indicated that phytoremediation with the use of *Pistia stratiotes* can result in a reduction of phosphate content by 50.75% [22]. The results of the research into the treatment of laundry waste demonstrated that the use of *Pistia stratiotes* was effective in reducing PO_4 levels by 39%. The *Eichhornia crassipes* plant has been demonstrated to effectively reduce phosphate levels by 66.67% [23]. The use of *Eichhornia crassipes* has been proven to effectively reduce PO_4 levels in wastewater, with a reduction of 60% observed with five plants, 77.5% with ten plants, and 65% with fifteen plants [12]. The discrepancy between the findings of this study and those of previous studies may be due to the need for further investigation into the potential of phytoremediation to reduce PO_4 levels in wastewater on a larger scale or in a natural aquatic environment.

The Kruskal-Wallis test was employed to analyze the data pertaining to PO_4 levels in water. The null hypothesis (H0) for the PO_4 variable was rejected, indicating that there were statistically significant differences in water PO_4 levels at various measurement times (0, 3, 6, and 9 days) for each treatment group (Control, EM4 [1:20], and EM4 [1:40]). This result suggests that each treatment may exert a distinct influence on PO_4 levels throughout the measurement period. The phosphate content of water is typically derived from various sources, including residual fertilizer runoff from agricultural activities, human and animal waste, soap constituents, vegetable processing, and the pulp and paper industry. Furthermore, phosphate is a pollutant that can impair water quality. The presence of excessive phosphate in water can also result in nutrient enrichment or eutrophication. Eutrophication can cause waters to experience gradual aging and facilitate biomass growth [24]. Therefore, to prevent the algal blooming phenomenon from recurring, it is essential to safeguard the aquatic environment from contamination by domestic and agricultural waste that can elevate phosphate levels.

5 Conclusion

The findings of this study reveal that the COD level of Padolo River water is 539.7 mg/L, exceeding the threshold for river water quality standards. In contrast, the PO_4 level is 0.16 mg/L, which remains within the acceptable range for river water quality standards. Phytoremediation using *Ipomoea aquatica*, *Pistia stratiotes*, and *Eichhornia crassipes* effectively reduced the COD levels in the control group by 29.7 mg/L, the EM4 (1:20) group by 95.5 mg/L, and the EM4 (1:40) group by 5.3 mg/L. However, the method proved ineffective in reducing PO_4 levels in river water. In the control group, PO_4 levels increased by 0.32 mg/L, while in the EM4 group (1:20), they increased by 0.06 mg/L and in the EM4 group (1:40), they increased by 0.03 mg/L. The results of the statistical tests, which employed the Kruskal-Wallis test, indicated that there were notable disparities in the COD and PO_4 levels present in the river water. The discrepancy in the COD and PO_4 levels under consideration is contingent upon the magnitude of the significance value associated with the analysis outcomes and the significance value observed at various measurement times (0, 3, 6, and 9 days) for each substance concentration treatment, encompassing the Control, EM4 (1:20), and EM4 (1:40) groups.

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