PERFORMANCE EVALUATION OF AQUATIC MACROPHYTES FOR MUNICIPAL WASTEWATER TREATMENT

Mumtaz Shah*, Hashim Nisar Hashmi* Naeem Ejaz* Abdul Razzaq Ghumman*

ABSTRACT

Municipal Sewage of Taxila was selected for evaluation and comparison of the performance of three aquatic macrophytes regarding sewage treatment. A bench scale laboratory model was developed and used for experimentation. Six experimental runs were conducted and each run laps over thirty (30) days. In each experimental runcontinuous monitoring of municipal sewage was done for each macrophyte specie. The aquatic macrophyte species used for the performance comparison were Water Hyacinth, Duckweed and Water Lettuce. Forperformance comparison four parameters including BOD_5, COD, Nitrogen and Phosphorus were selected. These parameters were monitored for both the influent and effluent sewage samples. During the entire study, the average reduction of 51% for BOD_5, 47% for COD, 19% for phosphorus, and 41% for nitrogen were found with water hyacinth. When the same sewage was treated with Duckweed the values came out to be 34% for BOD_5, 27% for COD, 16% for phosphorus and 18% for nitrogen. Similar trend was observed in the experiments with Water Lettuce as 33% for BOD_5, 29% for COD, 11% for phosphorus and 15% for nitrogen. Sewage treatment in macrophyte based system included both the anaerobic and aerobic microbial processes. The treatment is further followed by chemical conversions, sedimentation and volatilization. The highest pollutant removalswere observed for attemperature range of 15-38^{o}C and at pH variation between 6 and 9. In developing countries like Pakistan, where no importance is being given to municipal sewage treatment, the method found to be environmentally and financially sustainable.

Key Words: *Aquatic Macrophytes, BOD_5, Duckweed, Municipal Sewage, Wastewater Treatment.*

INTRODUCTION

The major portion of urban wastewater is water (i.e. about 99%) and rest portion consists of different organic and inorganic compounds. The main pollutants include, organic matter (OM), bacteria, heavy metals, oil and grease, suspended and dissolve solids and nutrients (Phosphorous and Nitrogen)[1]. The proportion of different constituents depends upon type of wastewater and also on temporal and spatial variations[2]. Due to rapid urbanization, development and improvement in living standards, there is a considerable increase in amount of wastewater originated from several activities[3]. Suitable wastewater treatment has been adopted by some communities, but many communities discharge their wastewater untreated into the natural environment due to lack convenient treatment systems available to them. Contaminants like heavy metals enter in anaquatic system through variouschannels including wastewater discharge from urban and industrial settlements and agricultural overflow.

Different waste watertreatment technologies are available but choice of any specific technology depends upon its site specific suitability and sustainability with regard to low capital and operational costs, and high efficiency for removal of heavy metals and organic matter.

Natural wastewater treatment systems are more suitable for developing countries.They are considered best suited options especially in tropical climates[4]. Natural systems consisting of macrophytes (wetlands) can be efficiently used for municipal wastewater treatment. Constructed wetlands are a feasible wastewater treatment option for developing countries[3]. The conventional activated sludge process with nitrification comes out to be the most expansive alternative to meet the DO standard of 4 mg/L. Waste stabilization ponds (WSP) technology is a low cost solution with 3.5 times less cost ascompared to the conventional process. Haider and Ali[5] studied the wastewater treatment of municipal wastewater of Lahore with different available for water quality man-

* University of Engineering and Technology Taxila.

agement of Ravi River. According to their study, low cost treatment options such as, Waste Stabilization Ponds and Wetlands can be used to maintain the required dissolve oxygen levelin River Ravi[5]. Shah and Hashmi[6] conducted experiments with water hyacinth (macrophytes), for treating municipal sewage. In their research they conducted 10 days experimental run and found considerable reduction in the concentration of BOD_5, COD, TDS, TSS and Faecal coliform[6]. Similarly, experiments were also conducted by Akhtar[7] on municipal sewage and found that about 60-70% reduction in the concentration of TDS, TSS, COD, Zinc and Iron were found in each experimental run[7].

The macrophytes have many benefits such as, self-sustainability, enhancement of treatment capacity with time, can be operated on solar/wind energy, production of oxygen and removal of carbon dioxide, opulent in biodiversity,and high degree of treatment with minimal maintenance[7]. Different types of wastewaters can be efficiently treated with macrophytes, due totheir nutrient absorbing capacity, less capital and operational costs,simplicity in use, low energy costs, process sustainability. Additionally, macrophytes harvested material have their own added benefits[8].

The aquatic plants contain various processes of wastewater treatment. The predominant effect include, filtration resulted due to physical effects of macrophytes tissues. This action provides surface area for attached microorganisms for their better growth. The wastewater treatment process in wetland is affected in different extends due to release of oxygen and plant uptake. Moreover, macrophytes also providehabitat for wild life[9].

In Pakistan, municipal wastewater is being discharged without any treatment in natural water bodies. Rapid industrialization and urbanization are the major causes of pollution of natural rivers and streams. As a result, pollution levels of water bodies are continuously increasing. Many complicated technologies to treat wastewater are available like rotating biological contactor (RBC), activated sludge process (ASP), and oxidation ditches (OD). All of these technologies are highly efficient, but have high capital, and operational costs. For developing countries like Pakistan, low costs biological treatment systems are preferred. Under present energy crisis in Pakistan, the availability of land, and tropical environment round the year should also be utilized for such treatment options. The performance can be further enhanced by using waste stabilization ponds containing macrophytes species. They have similar treatment mechanism as constructed wetland.

The treatment of wastewater by aquatic macrophyteshas been investigated for years[10]. However, their performance and degree of treatment is still unanswered. In this connection, a bench scale physical model was developed for treatment of municipal sewage of University of Engineering and Technology (UET), Taxila using macrophytes. The research aimed to observe performance of three different types of natively available macrophytes. $BOD_{5,}$ COD, and nutrients (PandN) were used as performance parameters.

MATERIAL AND METHODS

Municipal sewage from university main sewer linewas collected in a 2.28 m^3 (2280 liter) volume circular storage tank. The sewage collected in storage tank is then distributed to model component having dimensions 1.5m x 1.82m x 0.91m. Different macrophytes species were induced in it in different compartments. Layout of the experimental setup is shown in Figure-1.

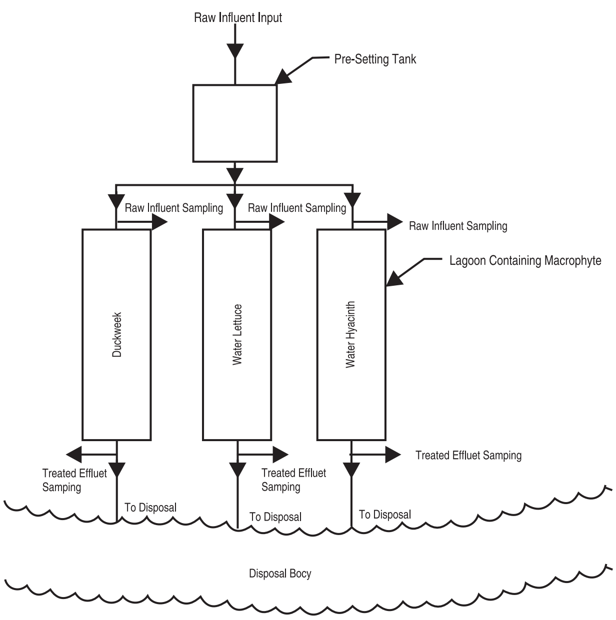
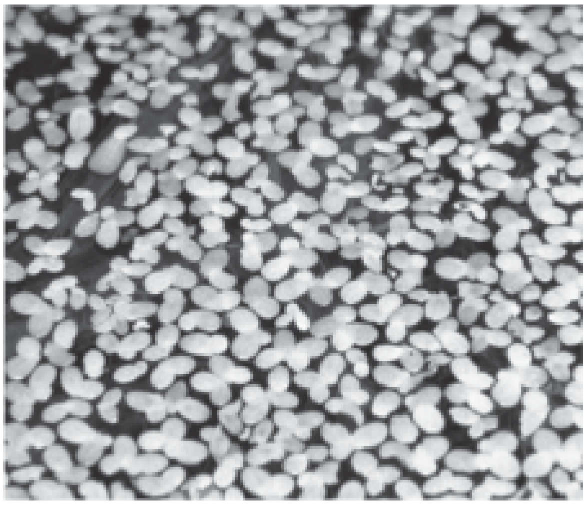
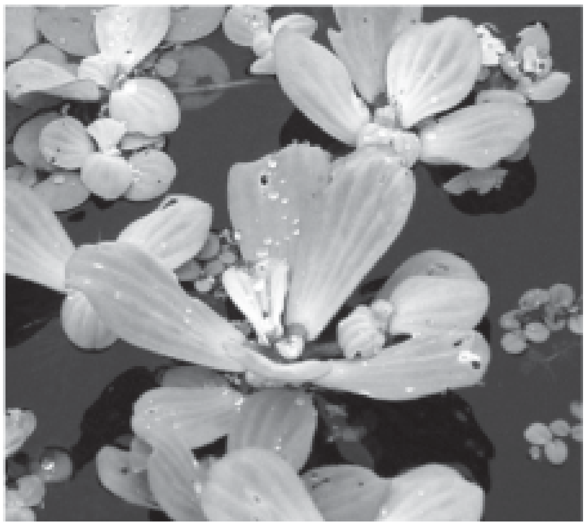


Figure 1: Bench Scale Study Model

a) Water Hyacinth



b) Duckweed



c) Water Lettuce

Figure-2: Different Types of Macrophytes[11]

Keeping in view of environmental conditions, natively available macrophytes were selected for the study. Three different types of macrophytes were selected i.e. Duckweed, Water Hyacinth and Water Lettuce as shown in Figure-2.

The research model was operated over a period of 18 months. Different influent and effluent parameters including Biochemical Oxygen Demand, Chemical Oxygen Demand, and Nutrients (Phosphorusand Ammonia nitrogen) were monitored as per Standard Methods for the Examination of Water and Wastewater.

RESULTS AND ANALYSIS

The pollutant elimination in macrophytes based system mainly occur due to sedimentation, plant uptake/removal efficiency, filtration, adsorption, microbial-mediated reaction and formation of solid compounds[11]. The removals of selected parameters for this study are explained along with experimental results in the following sections.

A. Biochemical Oxygen Demand (BOD_5):

The quantity of oxygen used by a microorganism in oxidation of organic matter is called BOD_5. Quiescent conditions, deposition and filtration in experimental model resulted in rapid removal of settleable organics. Soluble BOD_5 is mainly removed by attached and suspended microbial growth. 95-160 mg/L concentration of influent sewage present that it is a medium strength sewage. BOD_5 concentrations on 30^{th} day in every experimental run (ER) with Water Hyacinth as macrophytes specie are presented in Figure 3. With the same conditions when Duckweed was used as macrophytes the concentrations are shown in Figure 4. Afterwards, the observed concentrations from use of Water Lettuce as macrophytes gave 30^{th} day are presented in Figure 5.

During the experimentation a maximum removal of 51% was achieved for BOD_5 using water hyacinth. Variationof BOD_5 by systems having Water Hyacinth, Duckweed and Water Lettuce as macrophytesis are shown in Figure 3, 4 and 5. It can be seen in the figures that major removal of BOD_5 during experimentation occurs in first 10 days. The main reason for this kind of trend is plant uptake. Considerable plantgrowth was observed during all experiments. These results

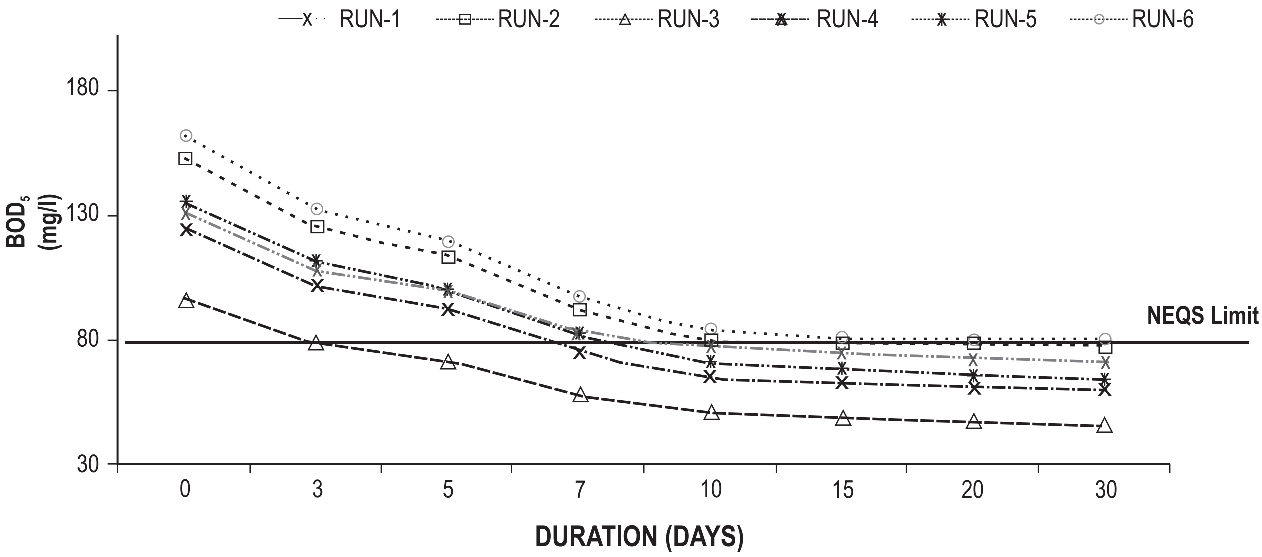


Figure 3: Variation of BOD_5 concentration in system having Water Hyacinth

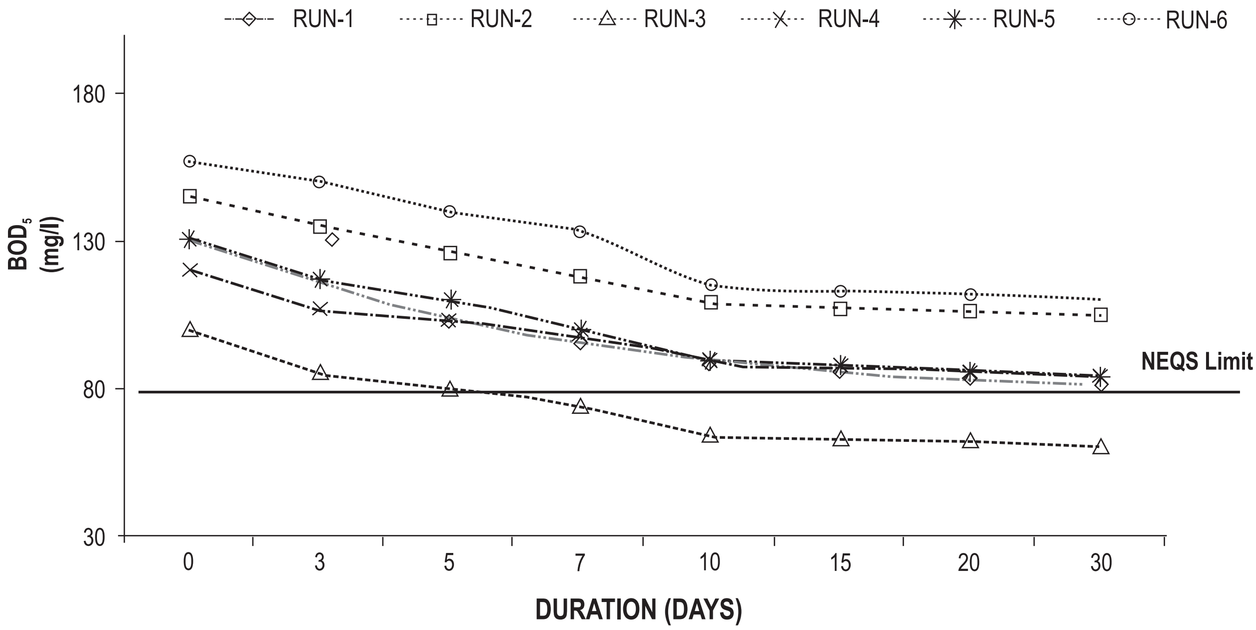


Figure 4: Variation of BOD_5 concentration in system having Duckweed

show that National Environmental Quality Standards (NEQS) for BOD_5 can be achieved in 10th day of each experimental run.

In order to see the effect of organic loading rate (OLR) on BOD_5 removal efficiencies, Figure-6 shows different removal efficiencies against different OLR. The optimum OLR was found to be 112-113kg BOD/ ha-d. In case of any further increase of OLR the system removal efficiency decreased.

B. Chemical Oxygen Demand (COD):

The amount of oxygen required to completely oxidize organic matter into CO_2, H_2O, and NH_3 is known as Chemical Oxygen Demand (COD)[12]. It is a measure of oxidation using potassium dichromate ($K_2Cr_2O_7$) alongwith silver and sulfuric acid. In case wastewater contains large quantities of non-biodegradable organic matter, the value of COD will become much higher

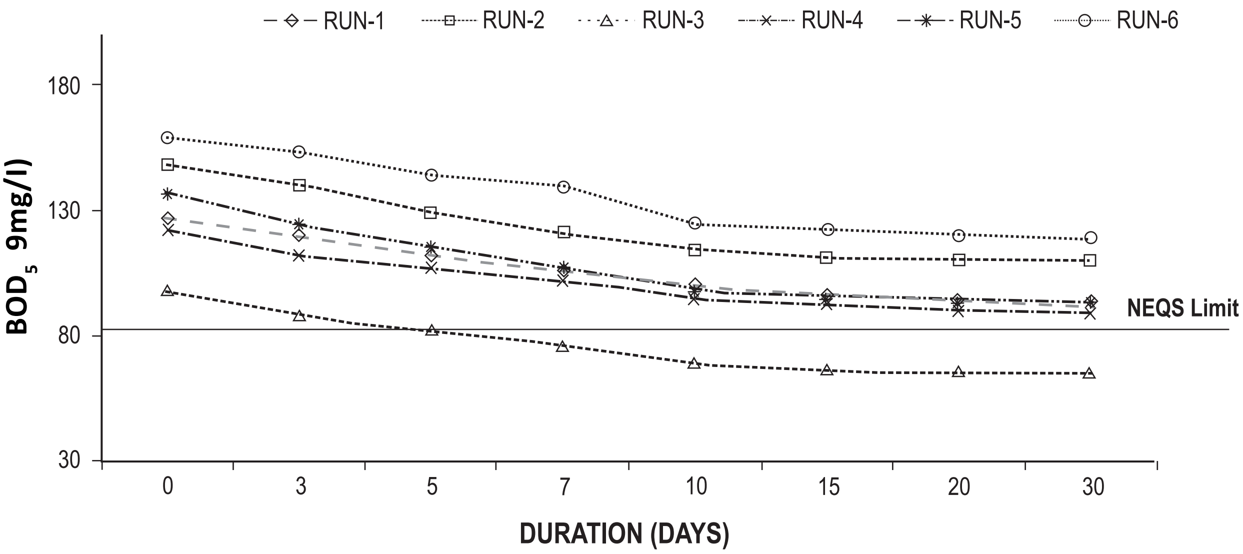


Figure 5: Variation of BOD_5 concentration in system having Water Lettuce

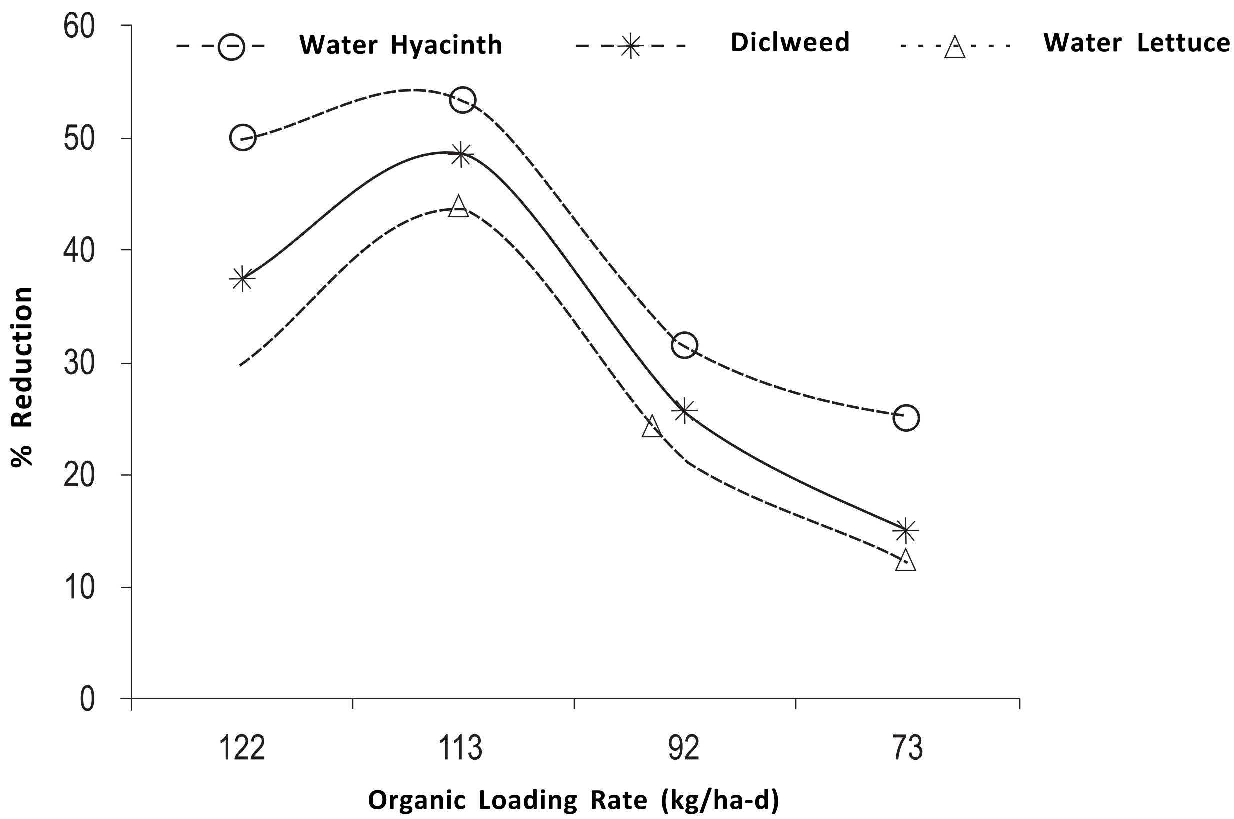


Figure 6: %BOD_5Reduction versus OLR

than the BOD value. The permissible value of COD as per NEQS isless than150 mg/L. It was found that 47% average reductionin COD influent value can be easily be achieved by using Water Hyacinth (Figure 7). On the other hand influent COD value has been decreased from 130.34 to 87.11 mg/L resulting in average reduction of 27% using Duckweed (Figure 8). Water Lettuce showed drop of influent COD value from 131.04 to 94.11 mg/L, thus giving an average reduction of 28.59% (Figure 9). It was observed that in first 10

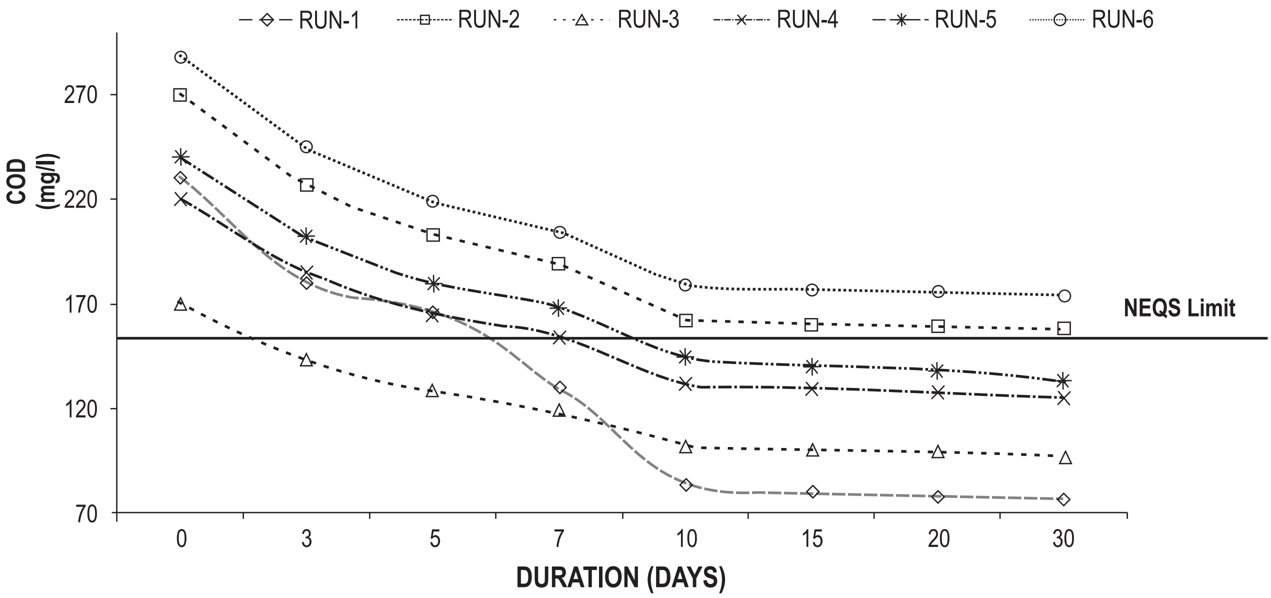


Figure 7: Variation of COD concentration in system having Water Hyacinth

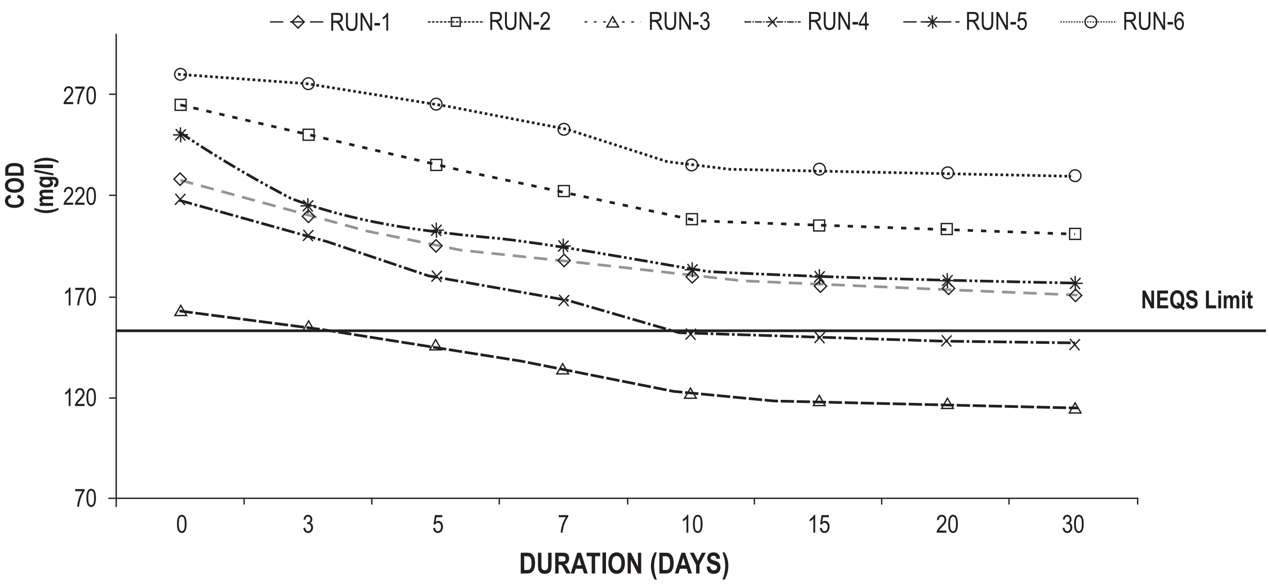


Figure 8: Variation of COD concentration in system having Duckweed

days of experiments 30-40% of reduction of COD occurred. These results show sufficient plant growth and efficient treatment performancedue to well-developed root system. The main component of COD degradation is attributed tomicro-organisms. Symbiotic relationship exists between microorganisms and plants. Reduction of level of COD in municipal sewage using Water Hyacinth, Duckweed and Water Lettuce are shown in Figures 7, 8 and 9 respectively.

C. Ammonia Nitrogen (NH_3-N)

High concentrations of nutrients ranging are present in municipal sewage[12]. The problematic nutrients whose treatment is essential to avoid their adverse impacts the receiving water body are "N" and "P". Over production of phytoplankton is mainly due to excess of nutrients in the water body, whichmay ultimately resultin O_2 depletion and eutrophication problems.

Nitrogen (N) enters wetland in two forms i.e. i) dissolved inorganic-N, and ii) organic-N. Ammonification, nitrification, de-nitrification and ammonia vola-

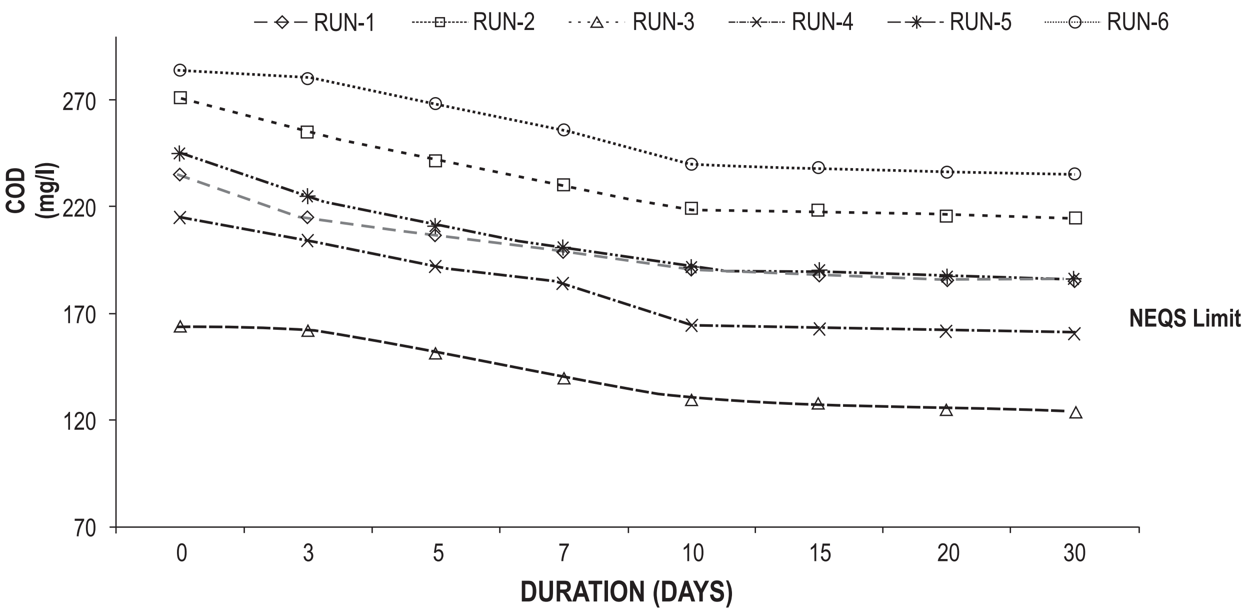


Figure 9: Variation of COD concentration in system having Water Lettuce

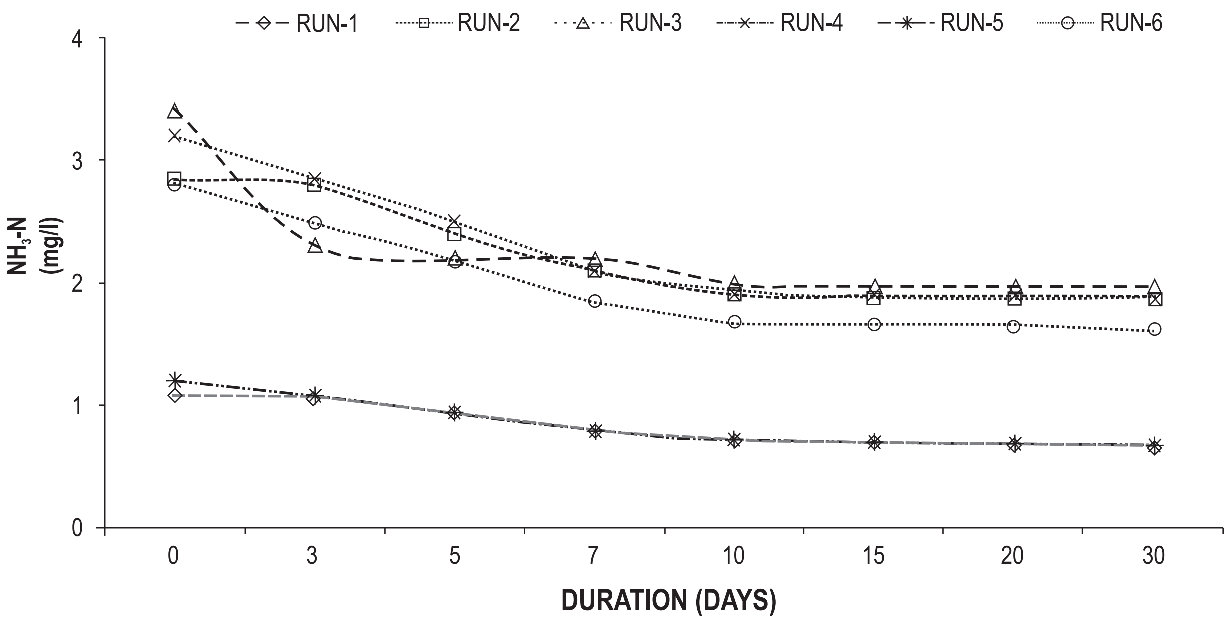


Figure 10: Variation of Nitrogen concentration in system having Water Hyacinth

tilization are the processes by which Particulate forms of N are removed.The composition of "N" in sewage is about 25% organic and 75% in ammonium. The organic-N is mostly converted into NH_3-N, and after microbial oxidation it is further converted to nitrate-N (NO_3-N).

In this study, the values for N were measured in different set of experiments. The results are shown in Figure 10, 11, and 12. The average reduction of 41% for nitrogen (i.e. from 2.421 to 1.452 mg/L) was found with water hyacinth, and areduction from 2.37 to 1.95 mg/L(18% average reduction) found with Duckweed. Similarly, reduction with Water Lettuce was found to be 2.42 to 2.09 mg/L(15% average reduction).

Highest degree of removal was found with water hyacinth then from duckweed and water lettuce based systems. The removal of "N" can also follow volatilization which is favored by high pH, nitrification under aerobic conditions and de-nitrification under anaerobic conditions. In our experiments, nitrogenremoval

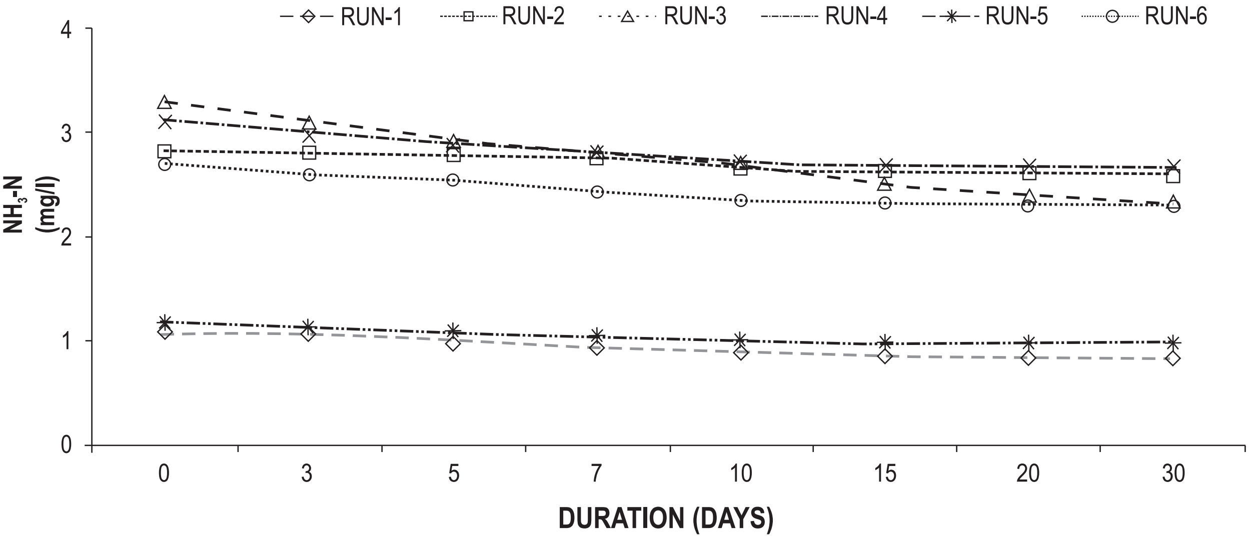


Figure 11: Variation of Nitrogen concentration in system having Duckweed

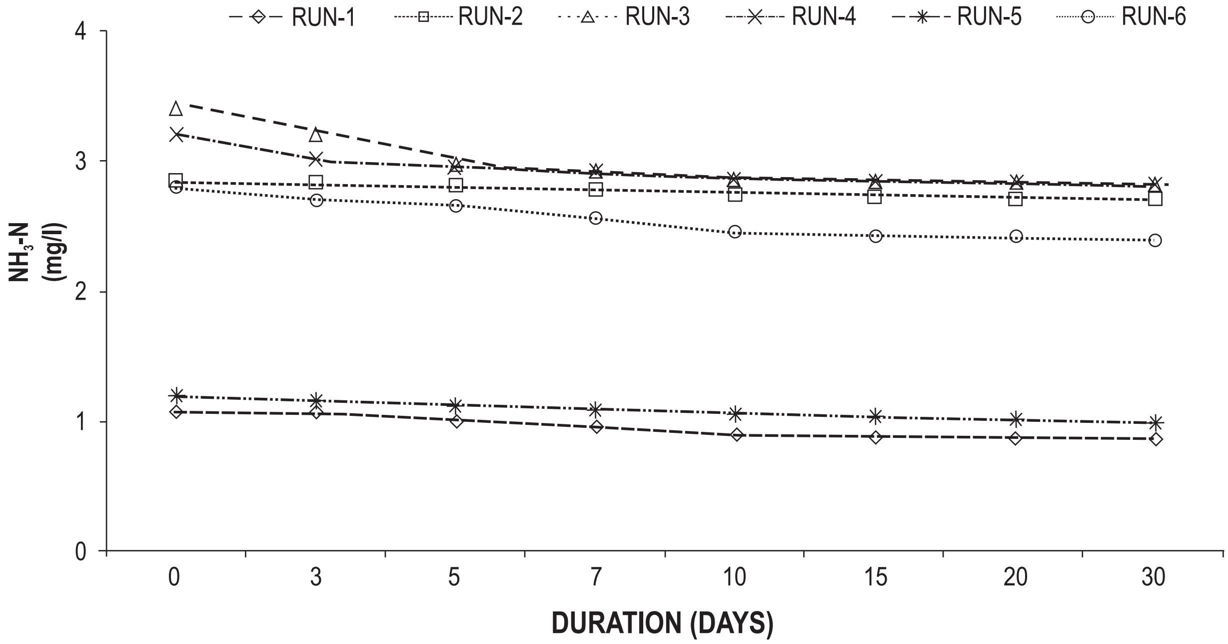


Figure 12: Variation of Nitrogen concentration in system having Water Lettuce

was occurred by volatilization as pH of sewage was higher than 6.5. It wasfoundduring the study that theratio between plant biomass and model volume plays an important role due to the contact between roots and wastewater contaminants. The major decline in influent values was found in all the experiments in first ten days. Reduction of Nitrogen is much higher by Water Hyacinth as compared to Duckweed and Water Lettuce based systems.

D. Phosphorus (PO_4^{-3})

Plant growth is also affected by "P"and is also essential for metabolic reactions in animals/plants. Organic phosphorus is a mass of living plants and animals, their by-products, and their remains. Phosphorus is also known as limiting nutrient in freshwater systems. Scarcity of phosphorus can be clarified by attraction to soil particles andorganic matter.

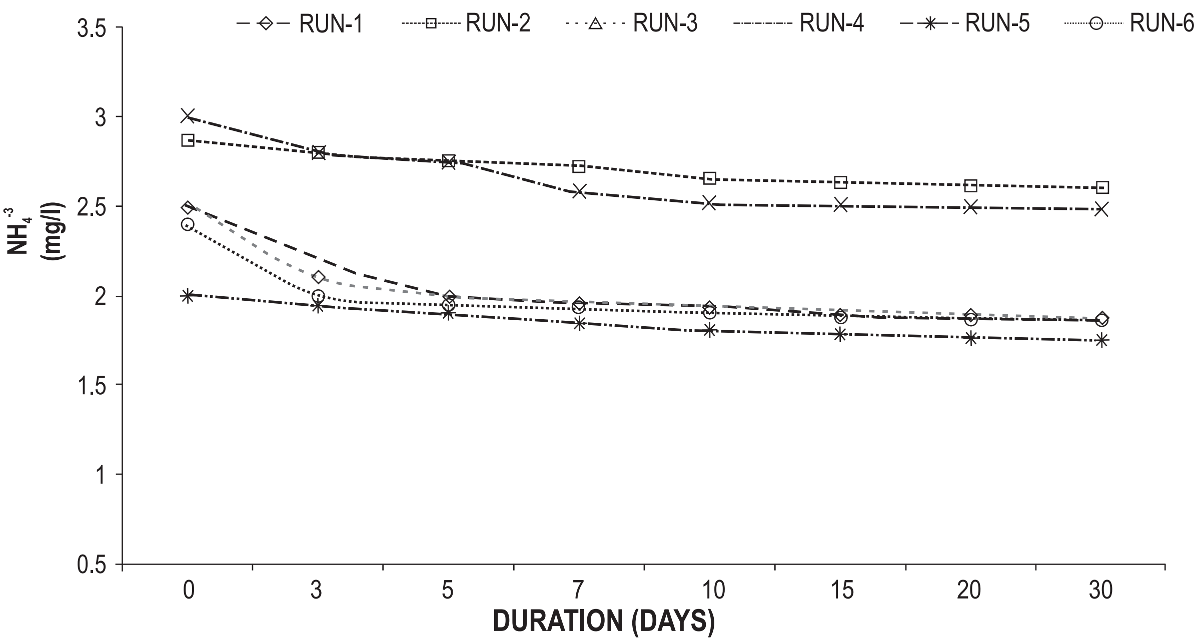


Figure 13: Variation of Phosphorus concentration in system having Water Hyacinth

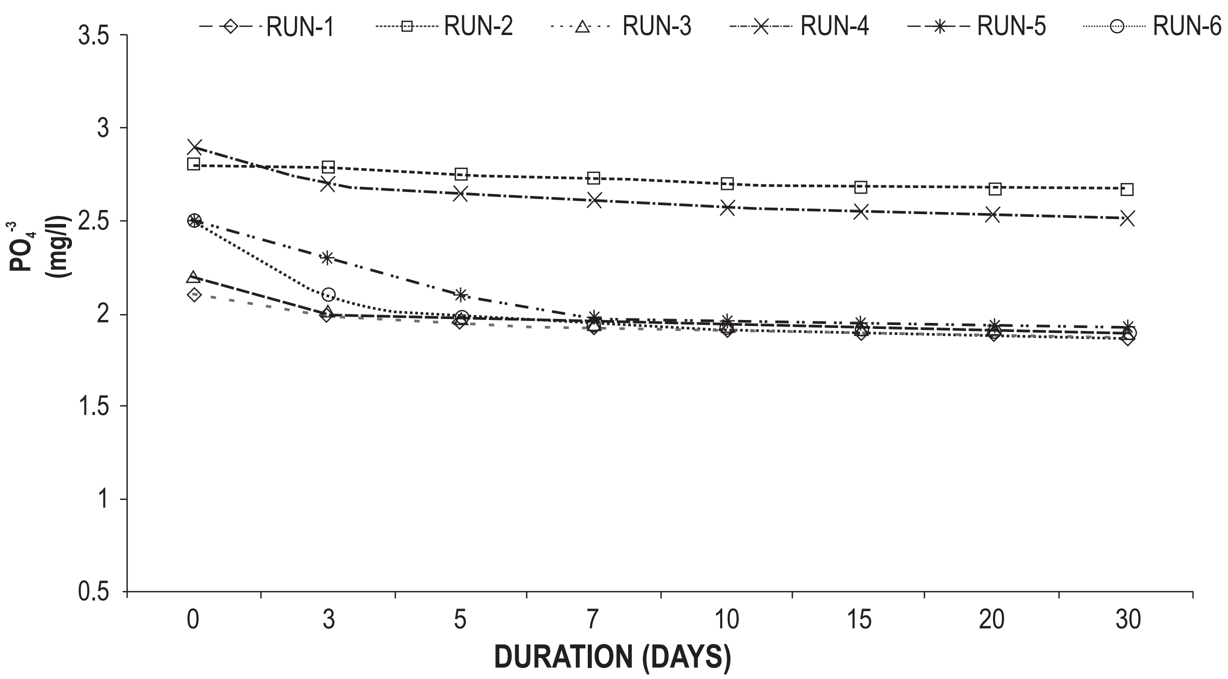


Figure 14: Variation of Phosphorus concentration in system having Duckweed

Aquatic plants quickly remove free available "P". Plants growth is accelerated by excessive concentrations of P. 10% of "P" was removed by primary treatment, and 20% "P" removal occurs in secondary treatment removes only 30%. Additional quantity of "P" can be removed by tertiary treatment. The technologies available for "P" removal includes biological removal and chemical precipitation[13].

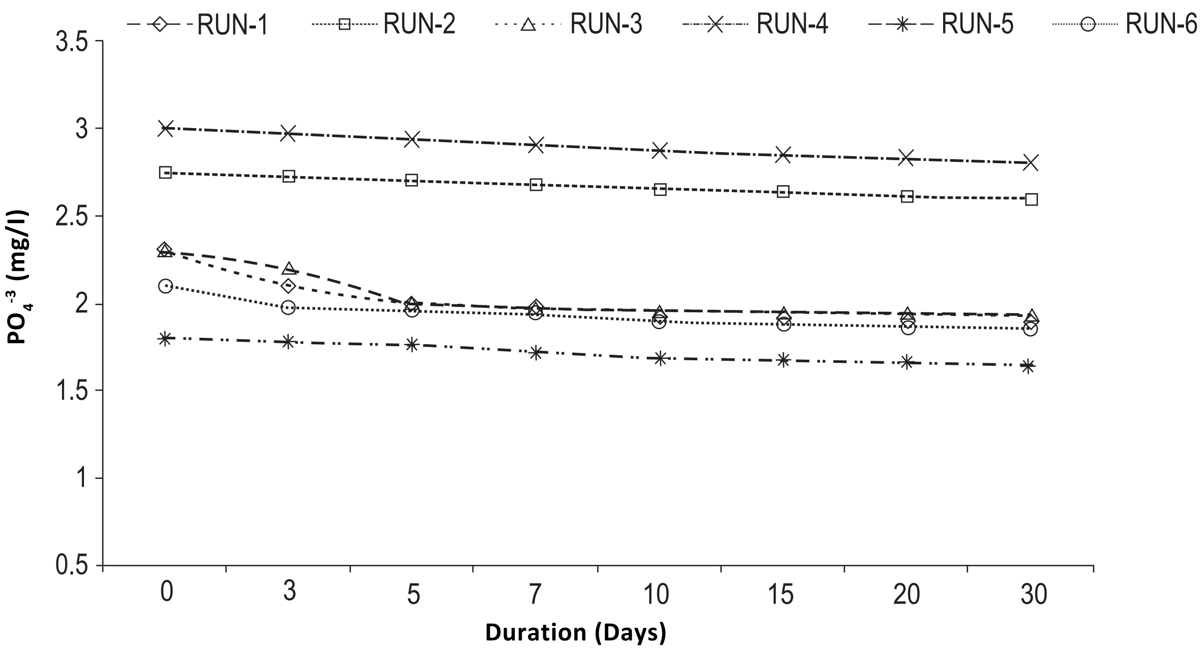


Figure 15: Variation of Phosphorus concentration in system having Water Lettuce

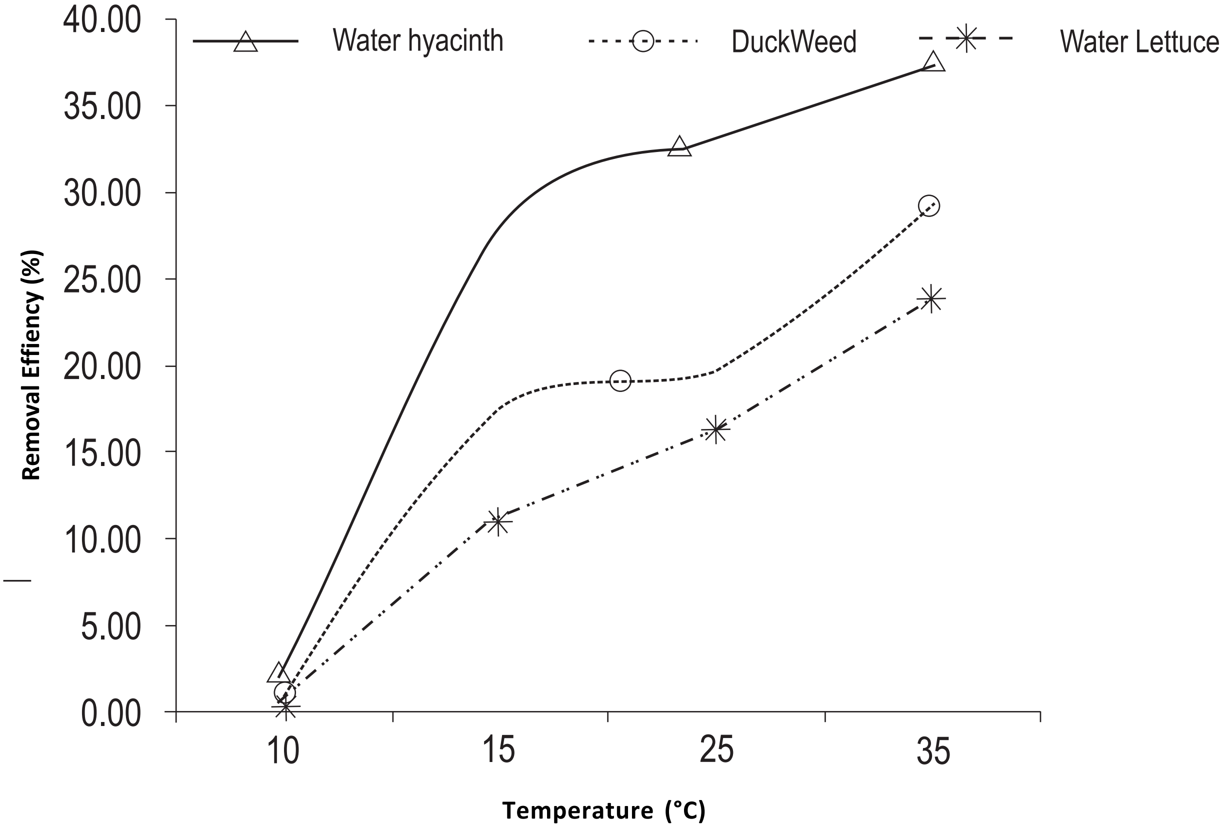


Figure 16: % Reduction of BOD_5 versus Temperature Variations

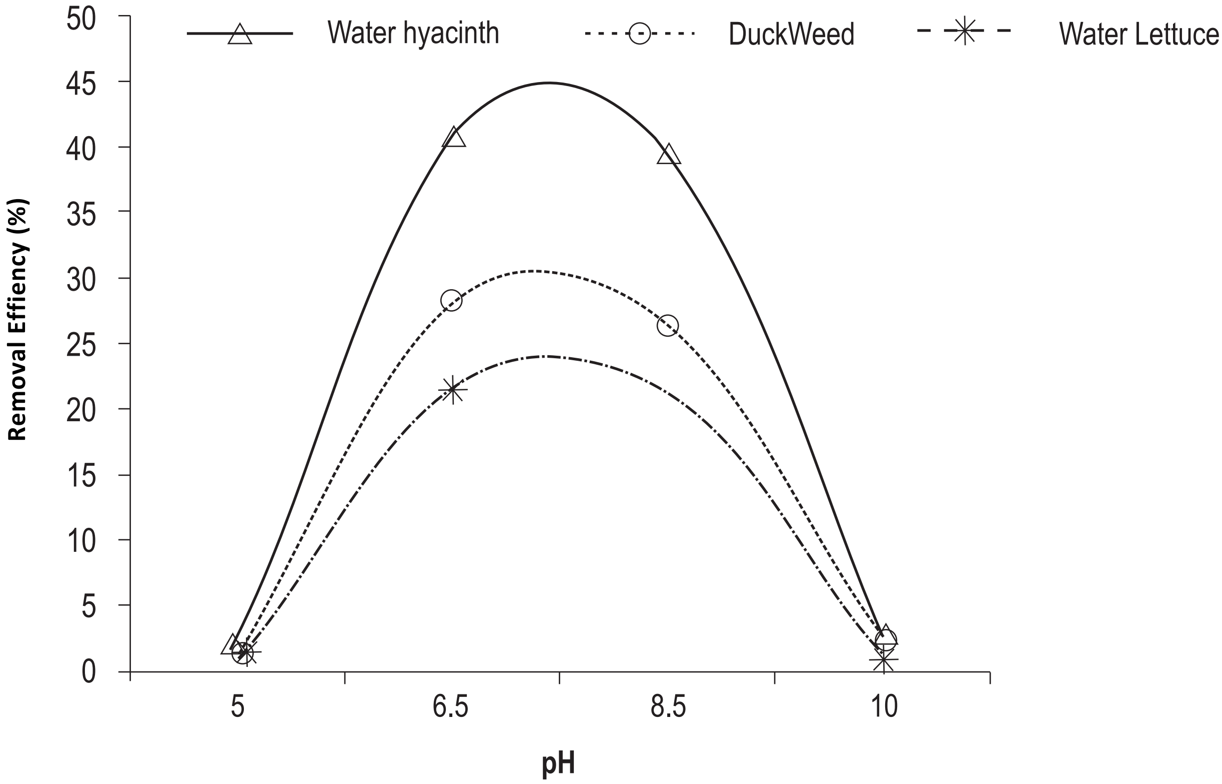


Figure 17: Percentage Reduction of BOD_5 versus pH

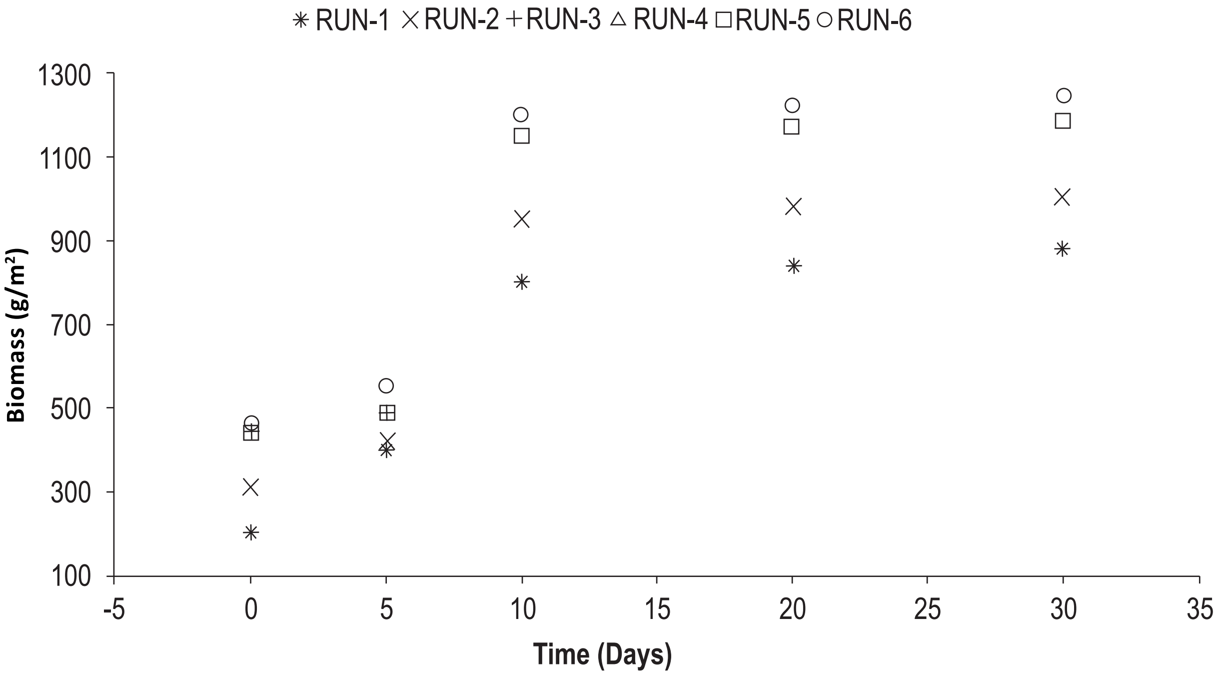


Figure 18: Development of Water Hyacinth in Model

The results of phosphorus removal from municipal sewage using Water Hyacinth, Duckweed and Water Lettuce are shown in Figures 13, 14 and 15 respectively. During experimental period of thirty days Water Hyacinth showed maximum “P” removal of 19%; Duckweed showed 16% average reduction;and Water

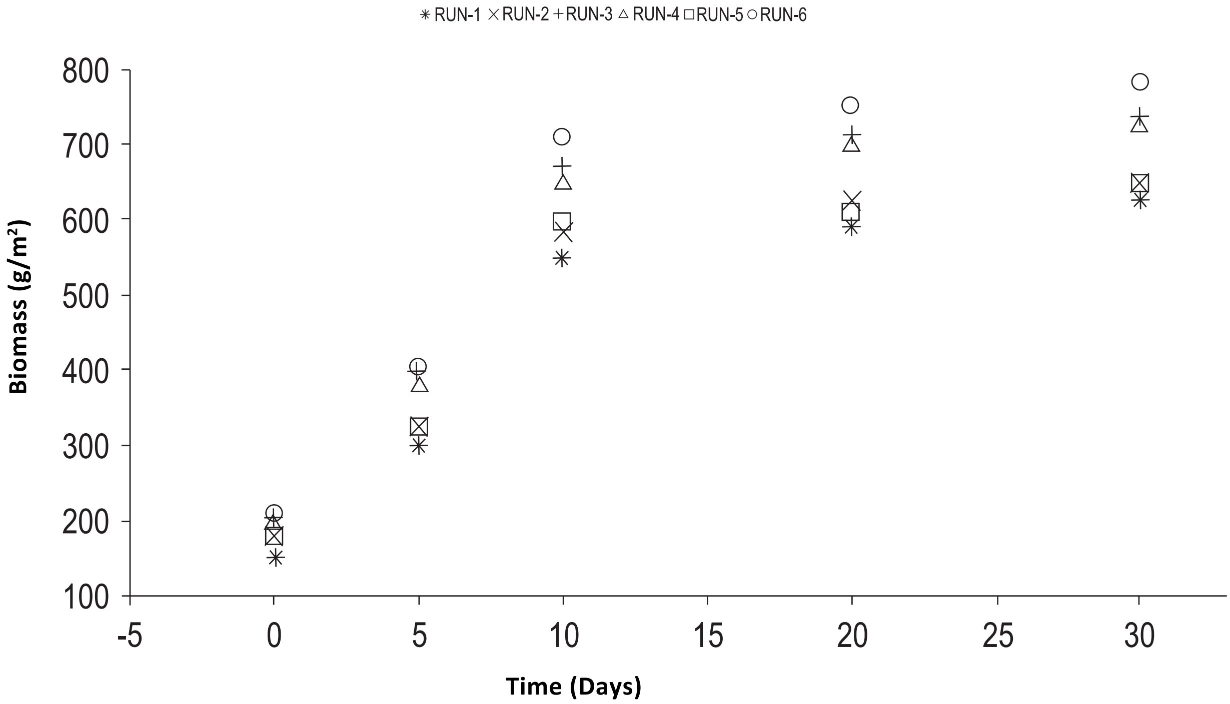


Figure 19: Development of Water Lettuce in Model

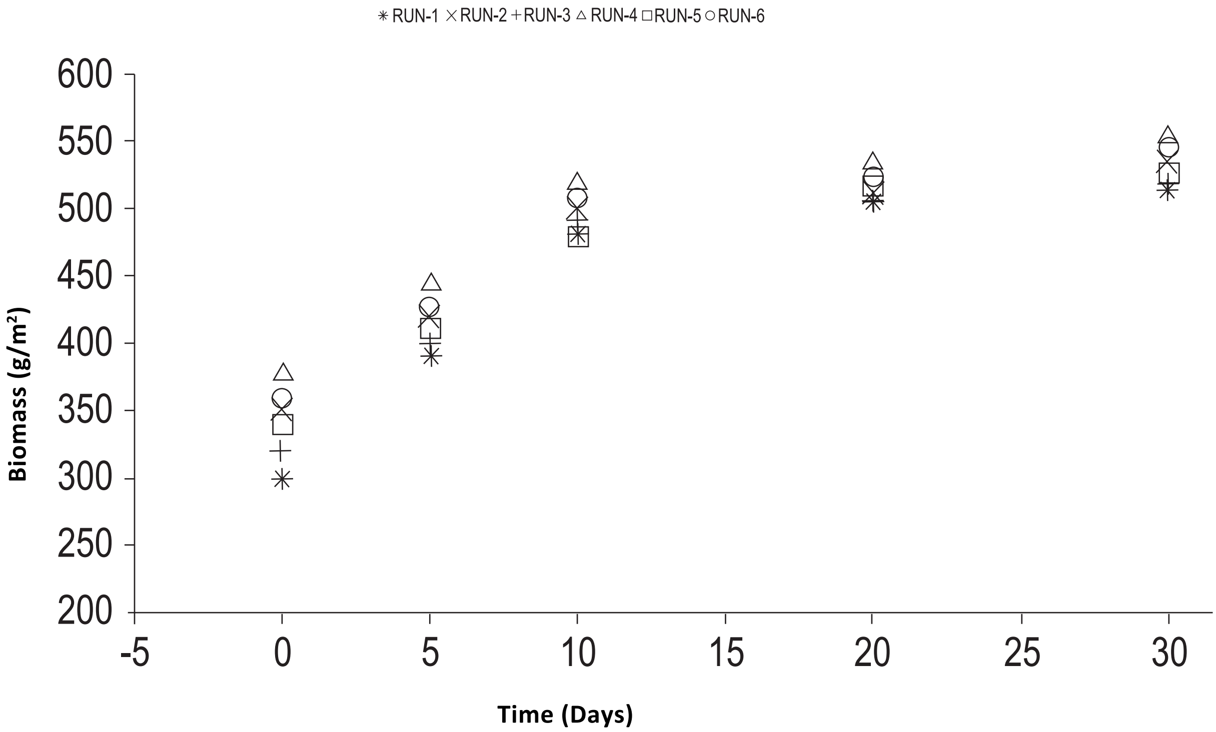


Figure 20: Development of Duckweed in Model

Lettuce showed 11% average reduction. The highest degree of removal was obtained by Water Hyacinth. The removal of "P" is due to synergistic effect. Both micro-organisms and plants utilize "P" as an essential nutrient, and they contain "P" in their tissues. Removal of total phosphorus is due to filtration of particulate matter through the roots, uptake of soluble "P" and settling processes. The study results revealed that Water Hyacinth can treat the sewage even at lower phosphorous concentrations.

E. Performance Affecting Factors

i) Temperature:

Temperature variations may affect the performance of macrophytes for wastewater treatment. Therefore, to check their performance with varying temperatures, additional experiments were performed. Performance variations under different temperature conditions with Water Hyacinth, Duckweed and Water Lettuce regarding BOD_5 removal are shown in Figure 16. PH was maintained as 7.5 for all the experiments. Macrophytes showed no growth at temperature below 10^{o}C, therefore, there was no nutrients uptake by the plants was observed. The most feasible and suitable working temperature of 15-38^{o}C showed efficient performance for sewage treatment bymacrophytes.

ii) pH:

The effects of pH variations on performance of macrophyteswere also studied in laboratory. During these experiments, the temperature was kept constant at 25^{o}C. It was observed that macrophytes performance in terms of BOD_5 removal was negligible at pH below 5. These results show that acidic environment is not suitable for plant growth.

It was observed that performance improves by gradually raisingpH but upto 7.5; further increase in pH revealed retardation of macrophytes performance in terms of BOD_5 removal. The results of pH variation on macrophytes performance are shown in Figure 17. Negligible BOD_5 removal was observed at pH of 10. Therefore, 6-9 is best suitable values of pH for macrophytes performance.

F. Biomass Productivity

Production of biomass is one of the most important parameters. The production of aquatic macrophytes is much higher than any of terrestrial plants/ agricultural crops. This is because macrophytesdo not affect fromwater deficiency. High photosynthetic efficiency and tolerance to environmental fluctuations are major characteristics of aquatic macrophytes. Their growth and production depends upon their uptake of nutrients. The substantial amounts of nutrients isstored in plant biomass,which enables high productivity of macrophytes. During the study, measurements of biomass for Water Hyacinth, Water Lettuce and Duck weed were made after fifth, tenth, twentieth and thirtieth day of each experimental run. These results areshown in Figures 18, 19 and 20. Major increase in the plant biomass was found in the first ten days of experiments with a gradual decrease afterwards. Thus optimum period for harvesting comes out to be eight to ten days.

CONCLUSION

Water Hyacinth was found to bemost effective in terms of pollutant removal as compared to Duckweed and Water Lettuce. The removals of 51% for BOD_5, 47% for COD, 41% for Nitrogen and 19% for Phosphorus were achieved with Water Hyacinth. On the other hand, Duckweed showed overallremoval efficiencies of 33.4%, 27%, 18%, and 16% for BOD_5, COD of, Nitrogen,and Phosphorus respectively. The efficiencies of Water Lettuce came out to be 33%, 29%, 15%, and 11% for BOD_5, COD, Nitrogen and Phosphorus respectively.

Aerobic and anaerobic microbiological conversions, sorption, sedimentation, volatilization and chemical transformations were the major processes in pollutant removal. Performance of macrophytes was affected by pH variation, and found optimumat pH of 6-9. Another vital factor that affects the performance is temperature, it was found that macrophytes performance is negligible below 10^{o}C and have optimum performance at temperature ranging between 15 and 38^{o}C.

Pre-treatment of sewage is effective before treatment with macrophytes. The performance of macrophytes has been found encouraging and comparable with any other conventional system. Under local conditions, this low cost option of sewage treatment by macrophytes needs to be further investigated for sewages of different strengths.

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