# Feasibility of Aquatic Plants for Nutrient Removal from Municipal Sewage in Smart Cities

**Mohd. Najibul Hasan, Abid Ali Khan, Sirajuddin Ahmed, Henna Gull, Mohammed Sharib Khan and Beni Lew**

**Abstract** An attempt was made to investigate the removal of nitrogen and phosphorous from municipal sewage using four aquatic plants (two emergent plants—*Typha latifolia and Phragmites australis* and two floating plants—*Eichhornia crassipes and Lemna gibba*). Batch studies were carried out in five reactors. Each batch reactor was having an effective volume of 49L. All batch reactors were fed with municipal sewage. The $NH_4$-N, $NO_3$-N and $PO_4$-P concentrations were measured at an interval of three days. Results of this study indicate that the highest removal efficiencies of $NH_4$-N were observed as 80% and $NO_3$-N and $PO_4$-P were 75% using the emergent plant (*Typha latifolia)* at an hydraulic retention time (HRT) of 21 days. The final value of treated effluent $NH_4$-N, $NO_3$-N and $PO_4$-P concentrations were found to be 7.5, 1.48 and 3.0 mg/L, respectively. The primary cause of the removal of nutrient from municipal sewage using *Typha* could be the presence of vigorous roots of this plant providing an expanded surface for microbial growth compared to other aquatic plants.

**Keywords** Municipal sewage · $NH_4$-N · $PO_4$-P · Aquatic plants · Dissolved oxygen

## 1 Introduction

The concept of aquatic plants-based treatment system is one of the smart ways to reduce the burden of pollution of water bodies and could be a possible way to reuse or achieve disposal standards for the municipal wastewater generated from smart city community. Lacking access to clean water and sanitation could be a common problem affecting human health throughout the smart cities like developing town.

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Centralized wastewater system, energy and cost-intensive technologies are ineffective to resolve the complex water-related problem [1]. There is a need to investigate and implement alternative treatment system for the current wastewater technology [2]. In the field of wastewater treatment, aquatic plants are one of the low-cost treatment concepts which have not been recognized yet for smart cities. The natural systems for the treatment of low-strength municipal wastewater are still one of the most economical and sustainable technologies widely used around the world due to its simple operation and user friendly [3, 4]. In general, these treatment concepts were used in a variety of geometrical shapes and sizes like constructed wetlands (CWs), lagoons waste stabilization ponds (WSPs) with or without aquatic weeds and frequently used for the treatment of municipal wastewater. This type of system is also effective to reduce the large amounts of nonpoint source pollutants that occurred by the rainfall and rain washing the village grounds and fields [5]. Researcher also reported that constructed and natural wetlands are often used for municipal wastewater effluent, i.e., single-residence septic tank effluent and at large municipal wastewater plants due to low cost of treatment [3, 6]. Various simultaneous processes like filtration, sedimentation, adsorption, bioconversion, combination of nitrification/denitrification, uptake by microorganism, wetland microphyte and microbial processes were occurring in natural systems for the removal of nutrients. The selection of aquatic plant in constructed wetlands should be based on strong vitality, pollution resistant, survive in aquatic and wet environment, diseases and pests [7]. Enormous studies are found in the literature on the performance evaluation of the constructed wetlands (CWs) based on geometry like dimension, area and substrate used. The role of plants is equally important but limited studied observed on fate of organic and nutrients removal for the treatment of municipal sewage [8].

An attempt was made to investigate the nutrient removal using four widespread aquatic plants, two emergent plants and two floating plants from municipal wastewater and feasibility for smart city.

## 2 Materials and Methods

### 2.1 Reactor Configuration

Five batch reactors were used for the present study. Each reactor was made of plastic material having cylindrical shape of diameter 35 cm and height of 51 cm. The effective volume of each reactor was 49 L. Various types of plants, i.e., emergent plants (*Typha Latifolia* and *Phragmites Australis)* and floating plants (*Lemna gibba* and *Eichhornia crassipes)*, were introduced in four different batch reactors. For emergent plants, the density of plant was kept six, while for floating plants, planting coverage area was maintained half of the sewage surface. One batch reactor was treated as control without any plant.

Three layers of different strata/media, i.e., gravels (20–40 mm), at the bottom followed by fine gravels (1–2 mm) and sand mixed with mud (0.0039–0.065 mm) above it were made in each batch reactor that was obtained from vicinity of the campus of university. The gravels, coarse sand and silt were thoroughly washed with tap water until the supernatant solution was clear. The emerging plants, i.e., *Typha latifolia* and *Phragmites australis*, were procured from nursery, while floating plants, i.e., *Lemna gibba* and *Eichhornia crassipes*, were collected from Okhla barrage at Yamuna River near Kalindi Kunj, New Delhi. The collected aquatic plants were washed to remove dirt and other adhesive materials introduced in the reactors. The sewage was brought to laboratory from the sewer pumping station Batla House, New Delhi.

## *2.2 Experimental Protocol*

Experimental setups (batch reactors) were operated at the ambient temperature varied from 20 to 32 ±5 °C, with a light intensity of 1500 Lx during day time. Initially, all the batch reactors were filled with municipal sewage and kept for fifteen days for the stabilization of plant. Later, sewage in the reactors was replaced with fresh municipal sewage. The present study was performed for 45 days. The depth of the municipal sewage above the top surface was maintained constant by keeping 60 mm height avoiding the evaporation intervention. During the course of the study, this height was maintained by adding freshwater in the reactors. The porosity of the reactors was found to be 40% which was calculated after the stabilization of plants in the reactors.

**Analytical Procedure**

Samples were analyzed to determine the concentration of ammonia ($NH_4^+$ -N), nitrate ($NO_3^-$ -N) and phosphate ($PO_4$-P) at an interval of three days. All samples were analyzed in triplicate according to the Standard Methods for Examination of Water and Wastewater [9].

# 3 Results and Discussions

## *3.1 Emergent Plant (*Typha latifolia *and* Phragmites australis*)*

The influent and effluent concentrations and percent removal for $NH_4$-N, $NO_3$-N and $PO_4$-P were monitored in the batch studies planted with *Typha latifolia* and *Phragmites australis* with an interval of three days.

## $NH_4$-N and $NO_3$-N

Figures 1 and 3 show the variation of ammonium concentration in reactors planted by *Typha latifolia and Phragmites australis and Temporal variation of $NO_3$-N by Typha latifolia and Phrgamites australis respectively*. The result indicates that there is a significant reduction in $NH_4$-N and $NO_3$-N. The reduction in $NH_4$-N reached to 7.5 and 11 mg/L from 38 mg/L in reactor planted by *Typha latifolia and Phragmites australis*, respectively, and similarly, $NO_3$-N reduced to 1.48 and 1.76 mg/L from the initial value of 6 mg/L. The regression coefficient $R^2 = 0.85$–0.89. Removal of ammonia and nitrate was influenced by temperature that varied from 20 to 38 °C. During start-up, the removal efficiency of $NH_4$-N and $NO_3$-N was significantly higher with both types of plants. From Figs. 1 and 2, removal of $NH_4$-N was observed about 75–80% and $NO_3$-N about 71% at HRT of 21 days by *Typha latifolia and Phragmites australis* planted reactor and 21–45 days, varied from 71 to 90%. The graph shows less variation in removal after 21 days, the reasons is dead lives or plant litter decomposition. Figure 2 shows the variation in removal of $NH_4$-N and $NO_3$-N in control reactor. Results were statistically found significant, and the percentage removal of nitrogenous pollutants in planted reactors is significant ($p > 0.05$) (Fig. 2).

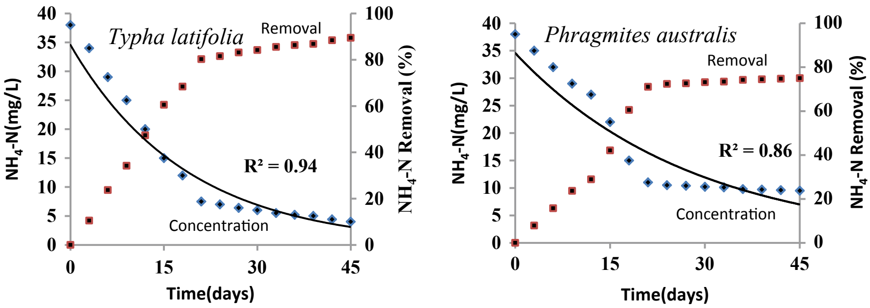


**Fig. 1** Temporal variation in $NH_4$-N by *Typha latifolia* and *Phrgamites australis* planted reactor

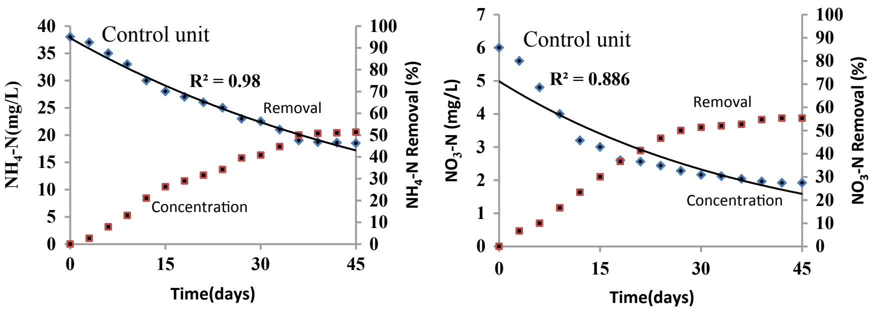


**Fig. 2** Temporal variation of $NH_4$-N and $NO_3$-N by control reactor

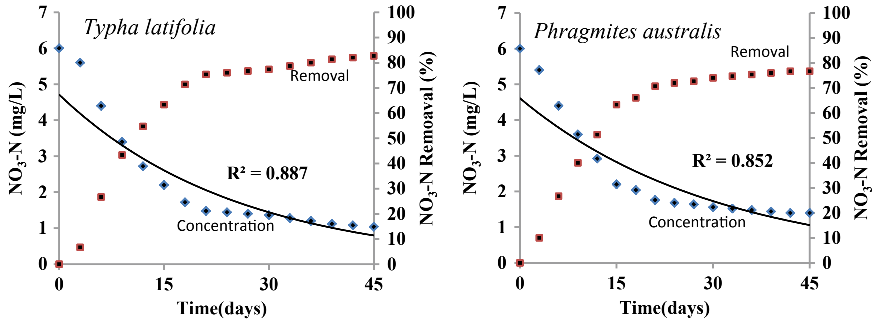


**Fig. 3** Temporal variation of $NO_3$-N by *Typha latifolia* and *Phrgamites australis* planted reactor

## $PO_4$-P

Figure 4 shows the variation of phosphorous removal in batch reactors having *Typha latifolia and Phragmites australis*; graph trends show 21 days retention time is an appropriate period for satisfactory removal. The removal of $PO_4$-P was observed greater than 70% and reduces to 3 mg/L from the initial concentration of 12 mg/L at an HRT of 21 days. The removal efficiencies of $PO_4$-P achieved in present study at an HRT of 21 days were 75 and 73% by *Typha latifolia and Phragmites australis* planted reactors were higher than the removal reported by [10] against of 50% removal efficiency in constructed wetland vertical type flow. The higher removal of $PO_4$-P might be due to the high density of plant and high HRT. The highest removal may also be due to the $PO_4$-P adsorbed in the media bed, rather than in the plant as sand used in this study contain oxides of Fe, Al and Ca. These minerals could enhance the phosphorous retention due to chemical adsorption and precipitation in wetlands. Other possible cause of $PO_4$-P removal might be the adsorption in algal and microorganisms that utilize phosphorous as an essential nutrient and contain phosphorous in their tissues. Results of this study were well

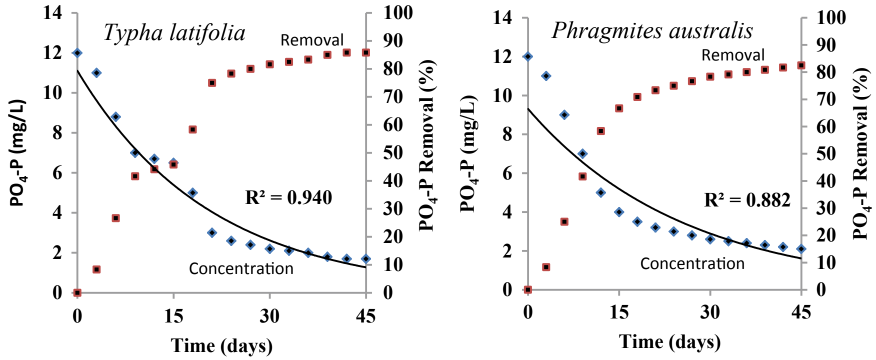


**Fig. 4** Temporal variation of $PO_4$-P by *Typha latifolia* and *Phrgamites australis* planted reactor

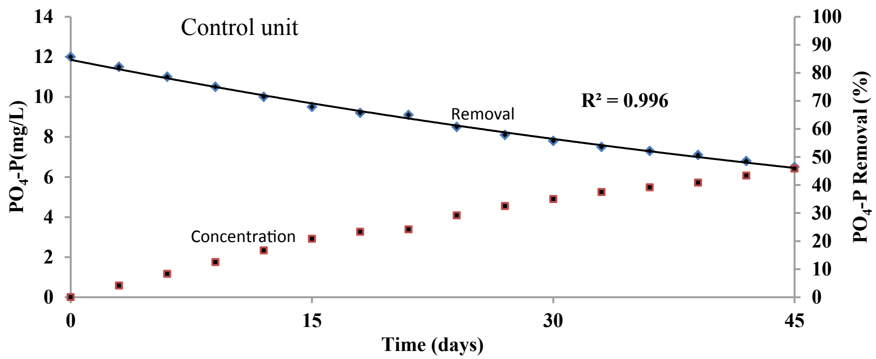


**Fig. 5** Temporal variation of $PO_4$-P by control reactor

supported by one-way ANOVA with significant difference ($p < 0.05$) for removal of *Typha latifolia and Phragmites australis*-based reactor. The removal by *Typha latifolia*-based reactor was higher compared to *Phragmites australis*-based reactor. The overall phosphorous removal efficiency of *Typha latifolia*-based reactor was observed significantly good based on comparison with control reactor (Fig. 5).

## *3.2 Floating Plants (*Eichhornia crassipes *and* Lemna gibba*)*

In the batch studies planted with *Eichhornia crassipes* and *Lemna gibba,* the influent and effluent concentrations along with percent removal for $NH_4$-N, $NO_3$-N and $PO_4$-P were analyzed.

**Variation of $NH_4$-N and $NO_3$-N**

Figures 6 and 8 shows the variation of $NH_4$-N and $NO_3$-N concentration in batch reactors planted two different plant species, viz. *Lemna gibba* and *Eichhornia crassipes*. Results show the removal of $NH_4$-N and $NO_3$-N was higher in *Lemna gibba*-based batch reactor compared with *Eichhornia crassipes.* The $NH_4$-N removal efficiency in *Lemna gibba*-based batch reactor at HRT of 21 days observed 68%, and an initial concentration of 38 mg $NH_4$-N/L reduced to 12 mg $NH_4$-N/L with same reactor. The removal of $NO_3$-N was 68%, and the final concentration was observed as 1.92 mg/L (Fig. 7).

Results were well supported by statistically evaluation using single-way ANOVA and found that the removal of $NH_4$-N and $NO_3$-N significant ($p > 0.05$) difference from control reactor.

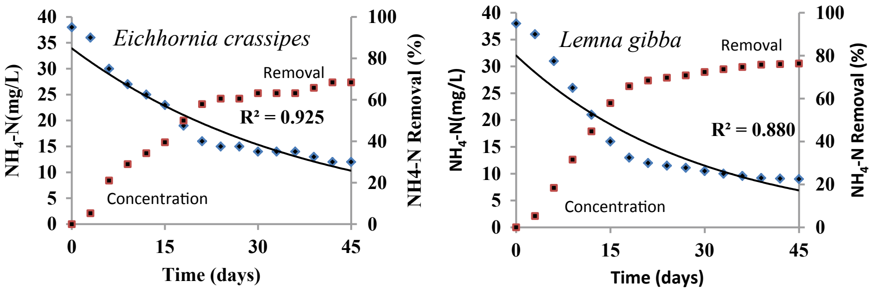


**Fig. 6** Temporal variation in $NH_4$-N by *Eichhornia crassipes* and *Lemna gibba* planted reactors

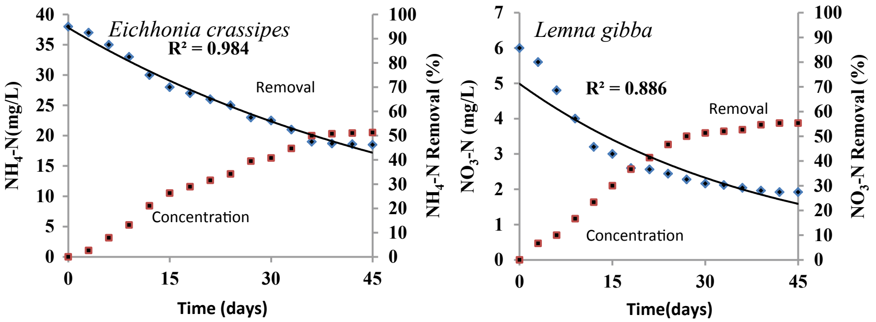


**Fig. 7** Temporal variation of $NH_4$-N and $NO_3$-N by control reactor

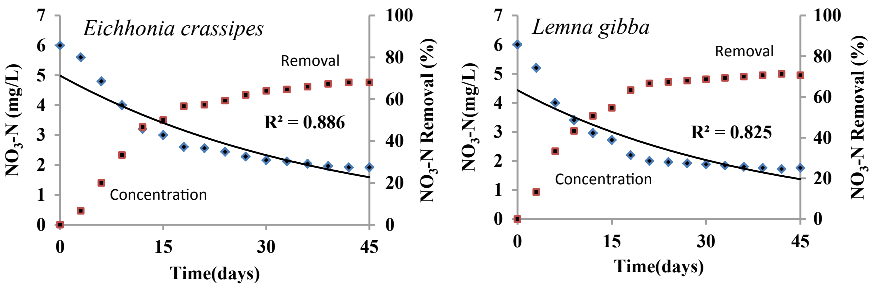


**Fig. 8** Temporal variation of $NO_3$-N by *Eichhornia crassipes* and *Lemna gibba* planted reactor

## Variation of PO4-P

Figure 9 shows the variation of phosphorous removal by *Lemna gibba* and *Eichhornia crassipes*. Initially, the $PO_4$-P concentration of municipal sewage was 12 mg/L and at retention time of three weeks. The concentration of $PO_4$-P reduced to 4.4 and 5.7 mg/L in batch reactors having *Lemna gibba* and *Eichhornia crassipes*, respectively, with regression coefficient of $R^2$ = 0.89–0.92. The removal

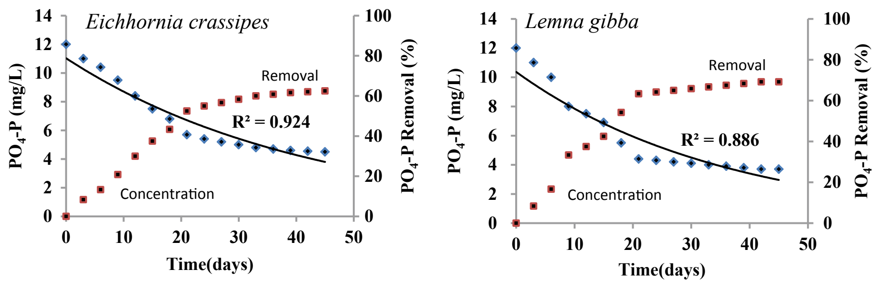


**Fig. 9** Temporal variation in $PO_4$-P by *Eichhornia crassipes* and *Lemna gibba* planted reactors

efficiency was achieved as 63 and 53% by *Lemna gibba* and *Eichhornia crassipes*. The trend of nutrient removal during retention period of 21–45 days observed scantly due to dead leaves and plants.

## 4 Conclusions

Batch studies investigated the comparison of the performance of emergent and floating plant for the removal of nutrients from municipal sewage. The highest removal of nutrients in terms of $NH_4$-N, $NO_3$-N and $PO_4$-P was observed in Typha latifolia plant species at an HRT of 21 days.

- The highest removal of the $NH_4$-N was 80, and $NO_3$-N and $PO_4$-P were 75%, and the final treated effluent concentration was reduced to 7.5, 1.48 and 3.0 mg/L, respectively.

Results inferred that the aquatic weeds are the promising option for the treatment of municipal sewage for small communities due to lower capital cost, easy operation and maintenance and highest removal in nutrients. However, further studies are required at demonstration scale in order to upscale the technology.

## 5 Acknowledgement

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