

Nitrogen removal by floating constructed wetland: Decontamination of the Buriganga River

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Abstract

Background: Buriganga is considered as one of the most important river in the country. But, its water quality has changed dramatically, which is responsible for creating unfavorable conditions for aquatic life. The main aim of this study was to investigate the removal capacity of pollutants mainly nitrogen present in the Buriganga river as the most polluted rivers in Bangladesh, by floating constructed wetland.

Methods: This study was conducted under constant and variable shock loadings in two phases, namely 'Phase I' and 'Phase II' during 11 and 10 weeks, respectively, in which about 180 L of raw water was dosed into the tank containing a floating mat, and pollutant concentrations in the river water influent from the system were tested over a period of 21 weeks.

Results: Floating treatment wetland (FTW) could sustain and remove about 31.25% and 19.23% of ammonia in the 9th and 10th weeks of Phase I, respectively, and 40.63% and 56.12% in the 17th and 18th weeks of Phase II, respectively. At first, ammonia was converted to ammonium, then, to nitrite, and finally, to nitrate. As the rhizosphere was denser and the biofilm was thicker in this study, so nitrogen removal efficiency during the application of shock loading in the 17th and 18th weeks of Phase II was considerable. The removal percentage of nitrite was 76.12 and 80%, respectively. In regular dosing of raw water in the 11th and 19th weeks in Phase I and Phase II, respectively, the total nitrate removal efficiencies from influent were 31.91 and 43.33%, respectively.

Conclusion: As water resources are limited, so improvement of water quality of the polluted Buriganga river would act as an important source of reusable water.

Keywords: Nitrogen, Nitrites, Nitrates, Ammonium compounds, Water quality, Wetlands, Bangladesh

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Introduction

The Buriganga river system is located in the southern part of the north central region of Bangladesh, passing through west and south of Dhaka, the capital of Bangladesh. Experts identified nine industrial areas in and around the capital city as the primary sources of river pollution: Tongi, Tejgaon, Hazaribagh, Tarabo, Narayanganj, Savar, Gazipur, Dhaka Export Processing Zone, and Ghorashal (1). The river receives wastewater from numerous number of sources along its way, which discharge industrial effluents, municipal sewage, household waste, clinical waste, and oils. According to irrigation, fishing and transportation, Buriganga is considered as one of the most important rivers in the country. But, its water quality has

changed dramatically, which is responsible for creating unfavorable conditions for aquatic life. Millions of liters of sewage, domestic waste, industrial and agricultural effluents act as toxic wastes and cause water pollution. Among different industries, textile industries account for discharge of nearly 56 million tons of waste and 0.5 million tons of sludge (2). Nearly 4 million people were exposed to the consequences of water pollution every day (3). The odor of the river varies from season to season. In dry season, it was found bad in some places whereas the condition was found a bit improved in wet season (4,5). Floating treatment wetland (FTW) is an innovative, new type of constructed wetland system, which was consistent with the mechanism of surface flow wetland. Therefore,



it could be considered as a water treatment technology which is consisted of a floating, porous platform on which plants were established for the purpose of remediating any number of water quality or habitat issues. Both plants and bacteria that live on the extensive network of roots served to bind and remove contaminants and nutrients, and therefore, leaving the water cleaner. These wetlands effectively worked on various wastewater parameters such as biochemical oxygen demand, chemical oxygen demand, Total suspended solids, dissolved oxygen, phosphate, nitrogen, turbidity, pH, alkalinity, redox potential, and also, effectively reduced the amount of *Escherichia coli* and *Salmonella* (6,7).

In the USA, the characteristics of nitrogen (N) and phosphorus removal were studied during the 2-year operation of a free water surface flow wetland of 900 m² with hydraulic loading. The main source of water as an urban watercourse which was contaminated with urban and industrial wastewater. Since the main purpose was to assess water treatment of contaminated water for use of general purpose, therefore, attention was focused on the removal of contaminants and harmful chemicals by harvesting plants (*Phragmites australis* and *Typha orientalis*) at the end of each growing season (8). The prospect of these types of wetlands in Bangladesh is enormous; they are easy to construct, require very low maintenance, and their fabrication is very cost-effective. Emergent plants act as artificial mats, and ultimately, form wetland basins or cells. This is not similar to the treatment using floating-leaved plants such as *Eichhornia crassipes* (water hyacinth) (9), *Pistia stratiotes* (water lettuce), *Lemna spp.* (duckweed) or *Azolla spp.* (water fern) or where natural floating islands had been established (10). This system is formally known as “floating treatment wetlands” or “constructed floating wetlands” or “floating mat constructed wetlands”. ‘Effluent’ is considered as the water that is being treated at any stage within the wetland and ‘inflow’ is considered as the water entering the wetland through effluent, and ‘outflow’ is considered as effluent leaving the wetland. Basins where there was open water but no islands, were known as free water surface wetlands (10).

A cross-sectional study in China showed that in a successive sequence system of the floating-bed constructed wetland (FBCW), horizontal subsurface flow constructed wetland (HSFCW) and surface flow constructed wetland (SFCW) were constructed for the inner-city tributary treatment in the cold regions of North China. The study area was Yitong River, in which the designed capacity and the hydraulic loading of the system was 100 m³/d and 0.10 m³/m²d, respectively. The hydraulic retention time was about 72 hours. It was conducted between April and October 2016. The results showed that the multiple wetland ecosystem could successfully remove industrial chemical waste particles like chemical oxygen demand, ammonia nitrogen, total nitrogen, total phosphate, and suspended

solids at average removal rates of 74.79%, 80.90%, 71.12%, 78.44%, and 91.90%, respectively (11).

A study in Brazil showed that emergent plants removed about 3.95 mgP/m² pollutants daily, which is responsible for removal of about 30.6% pollutants by artificial wetlands, while removal of the rest 69.1% pollutants are done by other means like substrates and microorganisms. The results indicate that in artificial wetlands, nitrogen rather than other pollutants was removed by other means like substrates and microorganisms (12).

Materials and Methods

In order to observe the capacity of removal efficiency of ammonia, nitrite, and nitrate by FTW under constant and variable shock loadings, the total system was organized into 4 following parts:

- Dosing and shock loading
- Configuration of floating wetland system
 - Configuration of tank
 - Configuration of floating mat
- Plants
- Arrangement and sampling

Dosing and shock loading

Raw river water was collected from Buriganga river located in Dhaka, Bangladesh, and dosed into the FTW system. The study was conducted in two phases, namely ‘Phase I’ and ‘Phase II’ during 11 and 10 weeks, respectively. 180 L of raw water was dosed into the system each day of the weeks in both phases. A shock load of 900 and 1800 L was dosed into the system in the first day of the 9th and 10th weeks individually and in the order that already mentioned in Phase I. Similarly, a shock load of 1260 and 2520 L was dosed into system in the 17th and 18th weeks in Phase II.

Configuration of floating wetland system

A rectangular concrete tank was used to replicate the plants on a large scale. A floating mat was used as a media for the growth of microbial community. The system used for this purpose was a rectangular airtight UPVC platform on which a mat was setup where a variety of plants were allowed to grow while their roots were submerged in water. In the first part, emergent plants (primarily Oriental Sword) were planted. It was constructed in such a way that could facilitate the growth of roots underwater.

Configuration of tank

The concrete tank had a rectangular shape (length= 3.60 m, width = 1.17 m, height = 1.14 m) with an opening which had been fitted with a pipe of 1-inch diameter. The outlet was used for collecting samples. The FTW was placed between the tank. The tank was filled initially with 20% raw water and 80% fresh water. The capacity of tank was 2500 L.

Configuration of floating mat

The floating mat as a primary structural element was an infrastructure of four high-performance UPVC pipes of 4-inch diameter, interconnected with four PVC angles and made airtight. The mat had a 10 ft length × 3 ft width. First, PVC platform was constructed for infrastructural and buoyant support, and then, the net was placed into the angled PVC pipe. Afterwards, the net was filled with straw. It was further filled with saturated clay soil. The tank was filled with up to 20% raw water and 80% fresh water. After mat construction, necessary plants were planted on the mat. Then, a waterlogged period of 20-25 days was provided.

Plants

Plants used in the system were collected from local water bodies and nurseries. Plants used in the systems are listed below:

Phragmites australis: It is widely found in temperate and tropical regions. It is used in constructed floating wetland where bioremediation bacterial action on the surface of roots and leaf litter removed some of the nutrients in biotransformation. It is a helophyte, especially common in alkaline habitats, which can tolerate brackish water.

Canna indica: It could be used for the treatment of industrial wastewater through constructed wetlands. It was effective for removal of high organic loads, dye

and chlorinated organic compounds from paper mill wastewater. It could be also used for beautification.

Sample size, sample characteristics, and analysis methods

After dosing of 180 L raw water in the wetland system, the effluent was collected in a high-density polyethylene bottle from the outlet of the tank. The collected samples were tested for nitrogen compounds (ammonia, nitrite, and nitrate). Raw river water was collected from Buriganga River located in Dhaka, Bangladesh, and dosed into the FTW system. The study was conducted in two phases, namely 'Phase I' and 'Phase II', during 11 and 10 weeks, respectively. The level of nitrogen compounds (ammonia, nitrite, and nitrate) was measured in the lab using water and wastewater monitoring and analysis methods (4th Edition) (13).

Results

The FTW was able to achieve high removal rates of nitrogen compounds (ammonia, nitrite, and nitrate) under constant and variable shock loadings. The total removal rates of nitrogen compounds (ammonia, nitrite, and nitrate) are shown in Table 1. The ammonia concentrations in the influent and effluent for Phase I and Phase II are shown in Table 1 and Figure 1. The nitrite concentrations in the influent in Phase I and effluent in Phase I are presented in Table 1 and Figure 2. The nitrate concentrations in the

Table 1. Weekly distribution of concentrations of nitrogen compounds in the influent and effluent flows, and removal percentage of these compounds by floating constructed wetland

Week	Nitrogen (Nitrate)			Nitrogen (Nitrite)			Nitrogen (Ammonia)		
	Influent (mg/L)	Effluent (mg/L)	Removal (%)	Influent (mg/L)	Effluent (mg/L)	Removal (%)	Influent (mg/L)	Effluent (mg/L)	Removal (%)
1	8.1	7.2	11.11	-	-	-	39	3.64	90.67
2	12.5	6.6	47.20	-	-	-	58.5	2.21	96.22
3	6.5	25	0.00	-	-	-	17	8	52.94
4	6.8	12	0.00	-	-	-	31.2	17.6	43.59
5	9.3	30	0.00	-	-	-	74	39	47.30
6	20	15.2	24.00	-	-	-	26	1.5	94.23
7	13.4	8.2	38.81	-	-	-	26	5.2	80.00
8	4.8	5.7	0.00	0.016	0.05	0.00	7.02	1.54	78.06
9	7.3	2.9	60.27	0.016	0.02	0.00	2.08	1.43	31.25
10	4.3	3.2	25.58	2.75	0.56	79.64	2.6	2.1	19.23
11	4.7	3.2	31.91	0.44	0.04	90.91	2.86	0.78	72.73
12	4.3	3	30.23	1.68	0.43	74.40	2.8	1.6	42.86
13	0.53	0.26	50.94	1.86	0.42	77.42	2.38	0.69	71.01
14	0.9	7	0.00	0.3	0.016	94.67	0.78	0.65	16.67
15	4.2	2.4	42.86	0.26	0.07	73.08	0.26	0.62	0.00
16	0.7	0.9	0.00	0.016	0.016	0.00	0.91	0.52	42.86
17	0.96	0.59	38.54	0.067	0.016	76.12	1.28	0.76	40.63
18	0.4	0.1	75.00	0.08	0.016	80.00	0.98	0.43	56.12
19	3	1.7	43.33	0.09	0.016	82.22	0.84	0.58	30.95
20	6.8	2.3	66.18	0.09	0.02	77.78	0.9	0.72	20.00
21	5.4	2.8	48.15	0.07	0.016	77.14	1.08	0.6	44.44

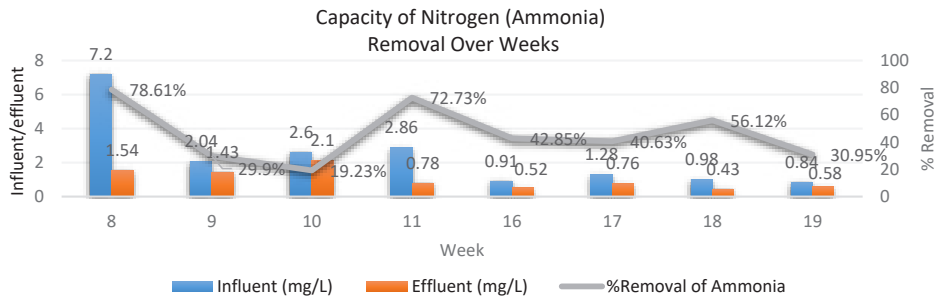


Figure 1. Nitrogen (ammonia) removal capacity over weeks.

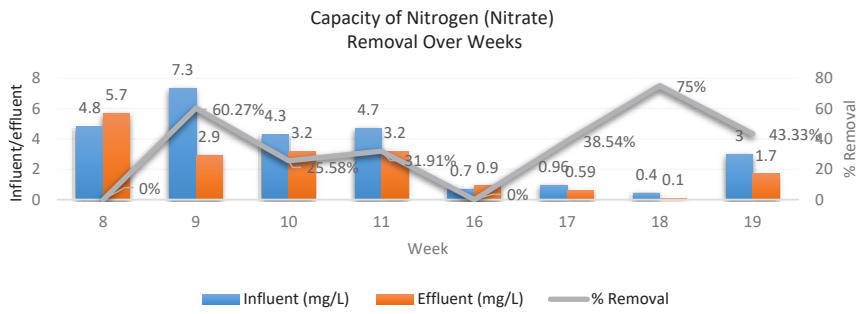


Figure 2. Nitrogen (nitrate) removal capacity over weeks.

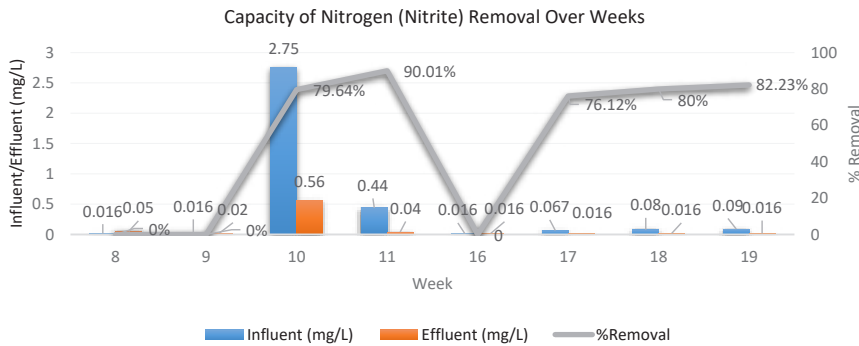


Figure 3. Nitrogen (nitrite) removal capacity over weeks.

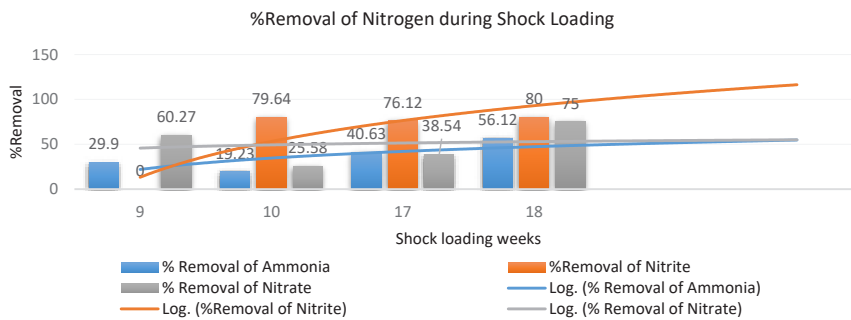


Figure 4. Removal percentage of nitrogen during shock loading.

influent in Phase I and effluent in Phase I are shown in Table 1 and Figure 3. In regular dosing of raw water in the 8th and 11th weeks in Phase I and in the 16th and 19th weeks in Phase II, the total removal capacity of ammonia and its concentrations in the influent and effluent are described in Table 1 and Figure 4. The results of this study demonstrated the efficiency of FTWs as a low-cost and energy-efficient wastewater treatment technology for refining polluted open water bodies in Bangladesh. After gaining maturity, the system would be able to remove more than 90% of the total ammonia, nitrite, and nitrate in the influent flow.

Discussion

The physicochemical process of ammonia volatilization requires a pH higher than 8.0 to maintain the symmetry between gas and hydroxyl forms. pH values higher than 9.3 lead to the persistence of ammonia and ammonium ions in a one-to-one ratio (14).

A cross-sectional study in China showed that in a successive sequence system of the FBCW, HSFCW and SFCW were constructed for the inner-city tributary treatment in the cold regions of North China. The study area was Yitong River, in which the designed capacity and the hydraulic loading of the system was 100 m³/d and 0.10 m³/m²d, respectively. The hydraulic retention time was about 72 hours. Time schedule was between April and October 2016. The results showed that the multiple wetland ecosystem could successfully remove industrial chemical waste particles like chemical oxygen demand, ammonia nitrogen, total nitrogen, total phosphate, and suspended solids at average removal rates of 74.79%, 80.90%, 71.12%, 78.44%, and 91.90%, respectively (11). In ammonification process, organic nitrogen is converted to ammonia, catabolized to amino acids, and releases energy, and has been used by some microbes for formation of new biomass (15). The formation of amino acids to ammonia depends upon some factors like temperature, pH, C/N ratio, available nutrients, and soil conditions. The majority of ammonification is done by anaerobic and obligate anaerobic mineralization (16) at an optimal temperature of 40-60°C and pH between 6.5 and 8.5 (17-20). The results of this study confirmed the efficiency of FTWs as a low-cost and energy-efficient wastewater treatment technology for refining contaminated open water bodies in Bangladesh.

In 2015, a study in the USA showed that in budding season, the removal of N and P increased from 47.1% and 17.6%, in the 1st year to 52.3% and 32.4%, in the 2nd year, respectively. When they compared the wetland overall process, they found that some plants like *T. orientalis* and *P. australis* regenerated more vigorously and contributed more to nutrient removal (8).

Finalization of maturity system lead to the removal of almost total of ammonia, nitrite, and nitrate in the influent

flow. Denitrification is the first mechanism of removing nitrogen in wastewater wetlands (18). Normally, low amounts of nitrate are found in domestic wastewater, for this reason, nitrification as well as the amount of dissolved oxygen is of great importance for proper denitrification (19). The removal efficiency of all wastewater wetlands varies between 40 and 50% (20) depending on the treatment procedure like primary or secondary treatment (21,22).

Conclusion

FTW could effectively remove nitrogen compounds (ammonia, nitrite, and nitrate) under constant and variable shock loadings. However, to reach definitive conclusions about the feasibility of Buriganga River water treatment by constructed wetland process in Bangladesh, further extended study are required. It is recommended to increase the length of system parallel to flow for providing long retention time, to use bank of Buriganga for proper application of the system, and to increase the test period to acquire adequate data for development of models.

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Competing interests

The authors declare that they have no conflicts of interests.

Ethical issues

During the study period, no human or animal faced with any types of physical violence. This study did not create any situation which might lead to environmental pollution. The authors certify that this manuscript is the original work of the authors, all data collected during the study are presented in this manuscript, and no data from the study has been or will be published separately.

Authors' contributions

MTI and EH contributed to conception and design, execution and data collection. IH and ARM contributed to data analysis and interpretation. All authors were involved in drafting the article and revising it critically for important intellectual content.

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