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Floating constructed wetland for the treatment of polluted river water: A pilot scale study on seasonal variation and shock load

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HIGHLIGHTS

- Nitrification was the major route of NH_4-N removal in the FCW.
- C leaching from the hanging roots supported denitrification in the FCW.
- Nutrient removals were higher in dry season due to higher influent concentration.
- Maturity of the hanging roots controlled removals during shock loadings.
- FCW systems are potential technologies for polluted surface water treatment.

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ABSTRACT

This paper reports the performance of a pilot scale floating constructed wetland (FCW), employed for the treatment of polluted water collected from Buriganga river in Bangladesh. The FCW system included a tank for accommodating collected water and a floating mat with media, to support the growth of two macrophyte species *Phragmites australis* and *Canna indica*. Mean mass removal rates of 0.66, 0.76, 0.08, 0.51, 2.49 g/m^2 d were achieved for ammoniacal nitrogen (NH_4-N), total inorganic nitrogen (TIN), phosphorus (P), biochemical oxygen demand (BOD), chemical oxygen demand (COD), respectively by the FCW. Nitrogen removal was via nitrification-denitrification processes, whereas filtration–sedimentation appeared to influence phosphorus removal. The system achieved substantial *Escherichia coli* mortality rates, through protozoa predation and oxidation processes. Higher influent concentrations during dry period allowed greater removal of nutrients and *E. coli*. Hydraulic shock-loading experiment revealed critical interdependency between hanging roots maturity, input hydraulic, and pollutant loadings for maintaining stable performances.

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1. Introduction

The discharge of various industrial and domestic effluents into surface waterways is severely damaging the aquatic environment in Bangladesh [1]. Natural purification is a viable route for maintaining the ecological health of the waterways [2]. However, in Bangladesh the strength of effluent discharge and pollutant load on the waterways are substantially higher than in many other countries [1]. Considering that the natural self-purification capacity of a waterway is limited, excessive pollutant loadings can cause severe and prolonged degradation of water quality [3]. To protect the waterways, new regulations on wastewater treatment and discharge have been introduced. However, illegal wastewater discharge to local open channels has limited the effect of the new regulations. In addition to law enforcement, artificial strengthening of the purification ability of the water bodies is necessary for protecting the water environment.

Constructed wetland, a low-cost green treatment technology is a viable option to enhance the pollutant removal abilities of open water channels. Several studies [4,5] reported the potential application of subsurface flow wetlands, for improving the water quality of polluted rivers. However, the implementation of subsurface flow wetlands for polishing polluted surface waters in Bangladesh is difficult, due to the lack of available land areas on the banks of rivers, as they are often used for agricultural activities.

Under such circumstances, FCW can provide a balance between the necessity of treating polluted river waters and shortage of land

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areas for agricultural activities. FCW systems include emergent macrophytes, supported by water buoyant mat structures [6]. The stems of the macrophytes remain above the water surface; their roots developing through water column beneath the floating mats [7]. Microbiological population develops around the hanging roots, forming a complicated network of roots and biofilms. Such complicated mesh produce net removal of pollutants as water passes through the network.

Different types of wastewaters had been studied for potential treatment by the FCW systems [7]. However, using FCW to treat polluted river water has not been thoroughly investigated. To date, only a limited number of studies have investigated the FCW systems for the treatment of polluted open water channels [8]. Significant variations of pollutant concentrations in the polluted river during dry and wet periods are common, as observed in surface water channels. The influence of such variations on the effectiveness of FCW has not been critically examined. Shock loading pollutants is a common phenomenon in surface waters, caused by sudden increase of pollutant input by severe weather events in wet seasons, accidental pollutant spills or illegal discharges. Adverse impact of shock loading on the removal performances of subsurface flow wetlands had been reported [9], but previous studies have not carefully examined the effect of shock loading on FCW systems.

This study has been designed to assess the performance of a pilot-scale FCW, used for the treatment of polluted water collected from Buriganga river, which is one of the most polluted rivers in Bangladesh. The objectives of this study are two-folds: (a) to evaluate the routes and rates of the removal of nutrients, organics, and coliforms from the polluted surface water; and (b) to investigate the influence of seasonal variations and shock loadings on the removal.

2. Materials and methods

2.1. Collected river water

Polluted water was collected from Buriganga river near Najimuddir ghat, Keraniganj, Bangladesh, and transported to the experimental site. The river water was stored in a feed tank, before being dosed into the experimental FCW system.

2.2. Construction of the pilot scale floating constructed wetland

The pilot scale FCW system had been established at Keraniganj industrial zone. Fig. 1 represents engineering diagrams and pictorial plates of the pilot scale system. The length, width and depth of the tank (to accommodate the water volume collected from river Buriganga) were 3.60, 1.16, and 1.14 m, respectively (Fig. 1a). The side walls (0.13 m thickness) of the water holding tank were constructed with brick, cement and sand materials. The bottom portion of the tank had been water sealed with brick flat soling and cement concrete. The water holding capacity of the tank was 4.43 m^3.

Locally available materials were selected for the construction of the floating mat. The outer edge of the floating mat was constructed with 4 inches diameter UPVC pipe (for achieving buoyancy). The length and width of the floating mat was 3.0 and 0.58 m, respectively (Fig. 1a). Nylon fiber mesh had been employed as the base material (of the floating structure) to support the load of media and macrophytes, and was further supported by four 1 inch diameter polypropylene random copolymer pipes (Fig. 1a). Dry straw (0.01 m depth) overlaid by saturated clay soil (0.03 m depth) were employed as the media, to foster the growth of macrophytes. The floating mat covered 57.0% of the free water surface inside the tank.

2.3. Macrophytes

Two types of macrophytes, *Phragmites australis* and *Canna indica*, were collected from local water channels, and planted into the media of the floating mat. After plantation the system was water logged for eight weeks, allowing the macrophytes to establish.

Fig. 1b and c provide pictorial plates of the early stage (i.e. 1 month after plantation), matured stage (i.e. 8 months after plantation) macrophytes, and development of hanging roots (below the floating mat) during such stages. Headley and Tanner [10] reported maximum root depths of four macrophyte species (i.e. *Carex virgata*, *Schoenoplectus tabernaemontani*, *Cyperus ustulatus* and *Juncus edgariae*) within 0.57–0.87 m. The hanging root depths (beneath the mat) of *Phragmites* and *C. indica* species in the experimental FCW was measured to be 0.84 and 0.76 m, respectively, that fall within the reported ranges [10] of the root development of other species.

2.4. Operation of the system

After macrophytes establishment, the wetland was fed with Buriganga river water for a total period of 24 weeks (March–September). Water quality analyses across the system were performed during the last 21 weeks of this period.

Collected river water was dosed manually (180 L/d) into the system once per day, 7 days a week. Collected river water flowed horizontally through the roots of the macrophytes towards outlet, maintaining a water depth of 0.99 m inside the tank (Fig. 1a).The system received a hydraulic loading (HL) of 59.0 mm/d during the first 8 weeks of the analyses period. Input HL was suddenly increased (phase I shock loading) five-folds (i.e. 295.0 mm/d) of the original HL (i.e. 59.0 mm/d) during week 9, followed by ten-folds increment (i.e. 590.0 mm/d) of the original HL during week 10. Such sudden HL increments were performed, to study the impact of consecutive shock loadings on treatment mechanisms of the pilot scale FCW.

During week 11, HL was dropped to initial loading conditions (i.e. 59.0 mm/d) and was continued up to week 16. In week 17, HL was again suddenly increased (phase II shock loading) 7-folds (i.e. 413.0 mm/d) of the initial loading (i.e. 59.0 mm/d), followed by 14-folds increment (i.e. 826.0 mm/d) of the initial loading (i.e. 59.0 mm/d) in week 18. Such consecutive sudden increments were performed, to evaluate the efficacy of the FCW to encounter higher shock loadings (when compared with previous shock loadings), during later stages of the operational period. In week 19, HL was dropped to initial conditions (i.e. 59.0 mm/d), and was continued until week 21 (end week of water quality analyses campaign).

2.5. Water quality analyses

During experimental campaign, water samples were collected on a weekly basis from the inlet and outlet of the pilot scale FCW system. Forty two sets of samples were collected during 21 weeks of experimental analyses. Water samples were transferred immediately (after collection) to water quality testing laboratory, Department of Public Health Engineering, Government of Bangladesh for further analyses. For each sample, analysis was carried out for pH, dissolved oxygen (DO), alkalinity, total suspended solids (TSS), turbidity, ammoniacal nitrogen (NH_4-N), nitrite (NO_2-N), nitrate (NO_3-N), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD),phosphorus (P) and faecal coliform (*Escherichia coli*). DO and pH values were measured by a HACH HQ40d probe. Alkalinity was measured by titrimetric method. TSS was measured with a portable HACH LXV (model 322.99.00002) meter, while turbidity was measured with a HACH 2100P turbidity meter.

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