Removal of Phosphate from Stormwater Runoff Using Bench Scale Constructed Wetland

Harsh Pipil, Shivani Yadav, Sonam Taneja, Harshit Chawla, Anil Kumar Haritash, and Krishna R. Reddy

Abstract Stormwater runoff originating from agricultural fields, garden, green belts, parks, etc. is susceptible to carry along phosphate in dissolved form in it. Presence of phosphate can lead to eutrophication in water the receiving bodies even if its concentration is < 0.1 mg/l. Natural or cultural eutrophication has led to significant adverse effect on water quality around the globe. The present study was undertaken to determine the efficacy of *Phragmites* based constructed wetland for the removal of phosphate from stormwater runoff under Indian conditions. The study was conducted under natural environmental conditions to evaluate the role of meteorological parameters. It was observed that *Phragmites* based wetland could efficiently remove the phosphate from stormwater with an efficiency as high as 96% at hydraulic retention time (HRT) of 24 h. The increase in ambient temperature increases the phosphate removal efficiency of *sp*. It leads to the conclusion that *Phragmites* removes phosphates from synthetically prepared stormwater runoff in a CW cell which it is a sustainable and eco-friendly technique to remove phosphate from stormwater runoff. This process does not require energy from external source is required for its operation.

Keywords Phragmites · Constructed wetland · Stormwater · Runoff · Phosphate

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1 Introduction

India is second most populous and seventh largest country in world in terms of its land mass which is approximately 2.4% of world's total land [1]. Most of the Indian population lives in rural India, though a significant migration of population towards urban India was seen in last few decades. This has increased burden on existing water resources due to limited water resources. Uneven distribution of rainfall, change in land use pattern and climate change has caused scarcity of freshwater [2]. Rainwater is considered as the source of purest form of water but its interaction with earth's surface makes it polluted and unfit for use. As a consequence, stormwater runoff contains suspended impurities such as silt, sand, clay, and floating impurities like plastics, tree branches and leave. It also contains dissolved impurities in it such as nutrients and heavy metals [3, 4]. Among the nutrients such as phosphate and nitrate, former one is a critical pollutant that can lead to eutrophication of receiving water body such as a lake or a pond in urban areas [5]. Studies in India has shown that stormwater runoff contains phosphate in urban stormwater runoff [6, 7]. Despite of being contaminated, the strength of pollutants and impurities in stormwater runoff is relatively lesser than domestic wastewater. Stormwater can be treated before it can get further contaminated. Thus, it is necessary to use water purification technique to treat this stormwater runoff. This will help in reducing the demand and supply gap of freshwater. The technique Water Sensitive Urban Design (WSUD) have been successfully implemented in developed countries like United States of America, Canada, Australia and New Zealand, etc. [8]. There is an urgent need for the development and exploration for feasibility of WSUD techniques such as gross pollutant trap (GPT), vegetated swale, rain garden, wetlands, tree pits, etc. in developing country like India [9]. This present study focuses on removal of phosphate from synthetically prepared stormwater runoff.

2 Methods and Materials

2.1 Wetland Configuration and Its Analysis

The present study was undertaken on a bench scale constructed wetland (CW) cell, located in Delhi Technological University, Delhi. *Phragmites* were planted in CW cell built up of brick masonry which was CW cell was 110 cm long, 80 cm wide with height of 45 cm. Depth of bed substrate was of 35 cm with 10 cm of free board (Fig. 1). Substrate had specific gravity (G) 2.7, void ratio (e) 0.67 and bulk density (ρ) of 1782 kg/m^3. The substrate was filled with homogenous mixture of sand, silt and gravel to provide the scope for easy root penetration, and better hydraulic conductivity through the bed without difficulty. Initially, 20 plants were planted uniformly distributed in CW cell which increased to 180 plants at the end of study. The cell was flushed with distilled water until no phosphate was obtained in effluent before the start of experiment. Stormwater runoff was prepared synthetically using analytical grade (AG) di-hydrogen orthophosphate (KH_2PO_4) for varying influent PO_4^{3-} concentration (5, 10 and 20 mg/l). It was fed into the cell from the top daily and effluent was collected after hydraulic retention time (HRT) of 24 h from the outlet valve provided at the bottom. Available phosphate (AP) and total phosphate (TP) analysis was carried out for both influent and effluent collected daily using spectrophotometric method (Labtronics make LT-290 Model spectrophotometer). Ratio of ferric ion (Fe^{3+}) to ferrous ion (Fe^{2+}) was also studied to determine the redox conditions pertaining in the system and the possibility of phosphates being getting bound to iron present in substrate. Observations of pH, electrical conductivity (EC) and total dissolved solids (TDS) were analysed using the Orion Make (USA, Model: A329) multi-meter.

The phosphate removal efficiency was calculated using the Eq. 1

$$Removal\,efficiency(\%) = \frac{(C_i - C_f)}{C_i} \times 100 \quad (1)$$

where, C_i is initial phosphate concentration (mg/l), C_f is phosphate concentration after HRT of 24 h at effluent end (mg/l).

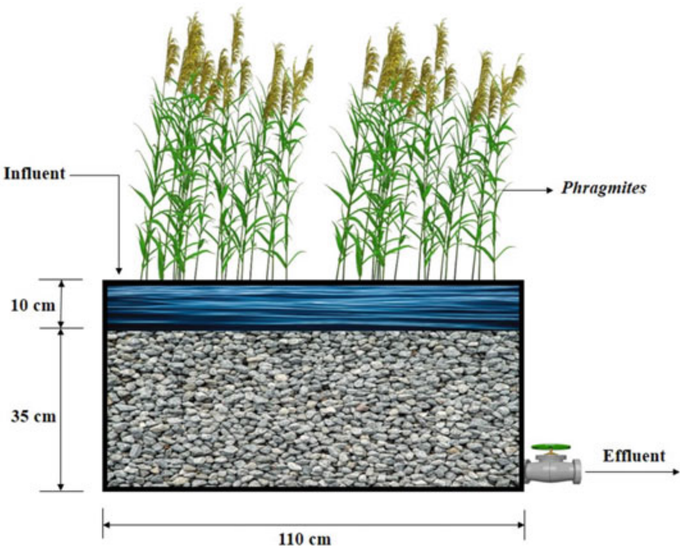

Fig. 1 Schematic description of configuration of CW cell used during the study

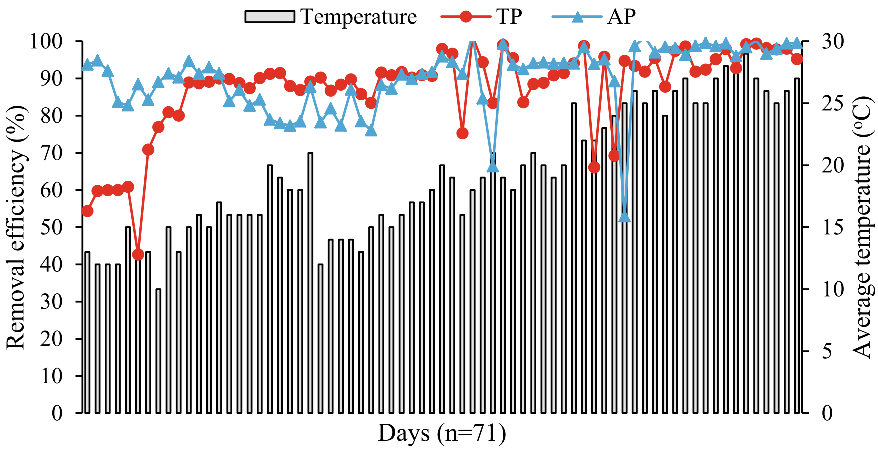

Fig. 2 Available and total phosphate removal efficiency (%) with average ambient temperature (°C) during study

3 Results and Discussion

3.1 General Observations

The ambient minimum, maximum and average temperature for Delhi, India, was noted during the present study. The temperature ranged between 2 and 42 °C. The average minimum and maximum temperature was found to be of order 13.6 °C and 26.8 °C, respectively. This represents the sub-tropical climatic conditions in India under which the study was undertaken. Average temperature profile along with available phosphate (AP) and total phosphate (TP) removal efficiency is represented in Fig. 2. The average sunshine hours also ranged between 8 and 10 h. Wet precipitation (mm) was received in small spells during the study which had negligible influence on the study due to dilution. It was also observed that the phosphate removal efficiency varied with temperature.

3.2 AP Removal Study

The available phosphate removal follows the trend summer > spring > winter > autumn (Figs. 3 and 4). It can be attributed towards the increase in average daily sunshine hours, rise in ambient temperature that has enhanced the water updraft of plant *sp.* which resulted in increase in evapotranspiration. The metabolic activity of the plant also increases in the presence of sunlight through photosynthesis. This highlights possible reason for enhanced AP removal efficiency in summers. The increase in daily sunshine hours resulted in increase in AP removal efficiency in

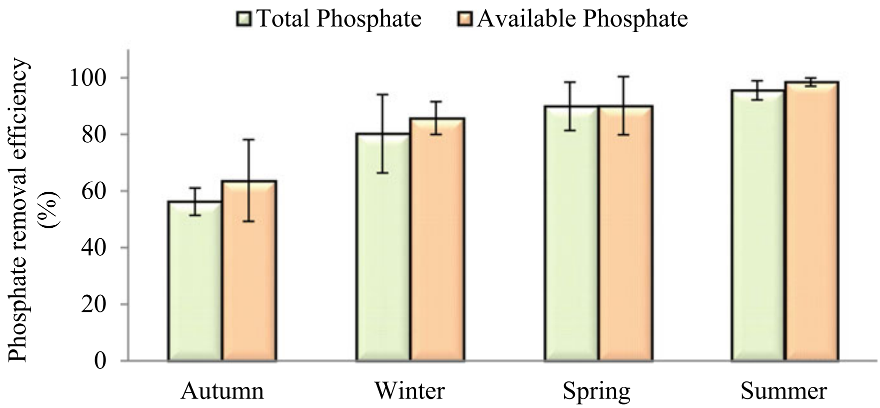

Fig. 3 Average available phosphate (AP) and total phosphate (TP) removal efficiency in various seasons during study

summer season, while its removal efficiency was least in autumn season. Also, the removal efficiency of AP is greater than TP. This attributes to easy availability of AP in synthetic stormwater runoff from CW cell. Also, adsorption by bed substrate as well as plant uptake are the possible mechanism towards the removal of phosphate from CW cell. Studies have shown the bed sediments gets saturated of nutrient with time and thus, cannot remove the nutrient from stormwater runoff for longer duration [10, 11]. In the present study, the AP removal efficiency increased with increase in sunshine hours and ambient average temperature. Thus, not only bed substrate was involved in removal of AP but plants also played a significant role in its removal efficiency.

3.3 TP Removal Study

The TP removal efficiency also follows the trend summer > spring > winter > autumn (Figs. 3 and 4). However, AP removal efficiency > TP removal efficiency since, AP is more readily available to taken up by the plants while TP remains in bound form and cannot be easily taken up by the plant. TP removal was maximum in summer while it is lowest in autumn. This can be attributed towards the sunshine hours and average ambient temperature. In summer season, the maximum temperature rose to 42 °C with increased daily sunshine. This has led to increased photosynthetic activity and metabolism of plant. Also, the increase in updraft of phosphate from CW cell in summer enhanced the TP removal as compared to other seasons.

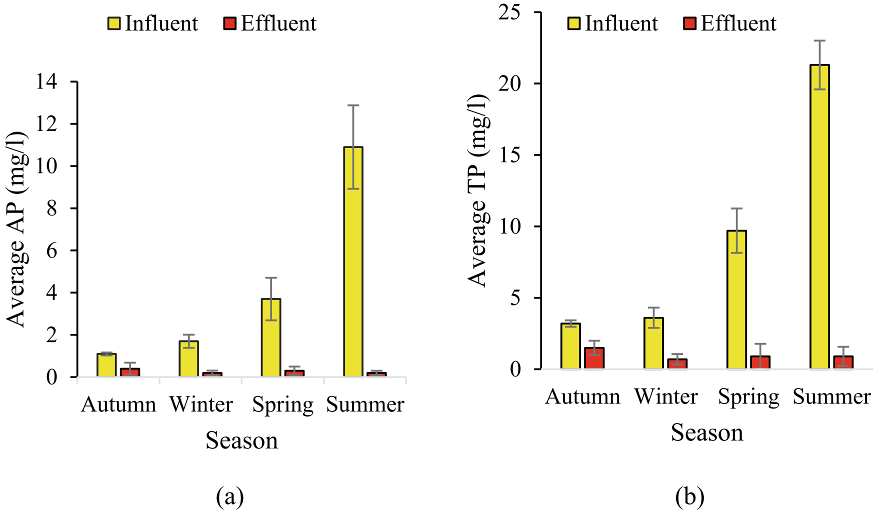

Fig. 4 Seasonal variation of average concentration of, **a** available phosphate (AP); and **b** total phosphate (TP)

3.4 Reduction–Oxidation Study

Redox conditions persisting in the CW cell was analysed on the basis of ferric to ferrous ratio. It was found that the ratio of ferric to ferrous ion (Fe^{3+}/Fe^{2+}) is < 1.0. Higher ferrous values than the ferric ion concentration shows that reducing conditions are dominating in the CW cell during the study. During reducing condition, the iron present in the form of ferrous in substrate of the wetland cell will not bind with the phosphate. This relates to the fact that the phosphates are not removed by bed sediments by its combination with iron.

4 Conclusion

It can be concluded that *Phragmites* can survive in wide range of temperature in Indian sub-tropical weather conditions. This plant can effectively remove the phosphates over a wide range of influent concentration which shows its ability towards shocks and its threshold capacity. The plant *sp.* survived, multiplied and its density also increased in CW cell. Overall, phosphate removal efficiency followed the trend autumn < winter < spring < summer season for both available phosphate (AP) and total phosphate (TP). There is a positive co-relation between its efficiency to remove phosphate and the increase in influent phosphate concentration. The removal efficiency also increased with the increase in average ambient temperature and sunshine hours which is related to more updraft of water by plant. Also, rise in temperature an sunshine hours increased the photosynthesis and metabolic activities of plant. The ratio of ferric to ferrous ion (Fe^{3+}/Fe^{2+}) is < 1.0 which shows that reducing conditions are dominating in the CW cell. The plant *sp.* can be harvested to make manure from it since it has phosphate present in it. It can also be used as sink of carbon through carbon sequestration and can be used for thatching in rural India. Also, the overall process of phosphate removal does not require any energy input from external sources. Thus, it can be said that the process is sustainable towards removal of phosphate from urban stormwater runoff.

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