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Performance of a reed bed system for faecal wastewater treatment: case study

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Abstract

Reed bed systems (RBS) have potential to treat wastewater, and being interested in such green wastewater infrastructures, an RBS has been installed for the first time in Bangladesh to treat faecal wastewater, which comes from a low-cost community latrine at a refugee camp in Cox's Bazar area. An anaerobic baffle reactor was set followed by the RBS, which was operated continuously for four months at five different retention times (3–7 days). The RBS was found to retain, on average, about 92% of 5-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD), 69% of PO_4^{3-} and 52% of NO_3^-. Importantly, the effluent concentration met the national environmental standard for all except for PO_4^{3-}. Thus the optimum hydraulic retention time in RBS has been selected to be 3 days when the PO_4^{3-} ion has been reduced at maximum rate. High positive correlation ($p > 0.9$) was observed between PO_4^{3-} and NO_3^- concentrations in effluent water as well. The results of this study, thus, partly support the RBS as an effective green solution for faecal wastewater treatment.

Key words: ecological engineering, faecal sludge management, reed bed, wastewater treatment, water reuse

Highlights

- The studied Reed Bed System (RBS) was designed for 14 low-cost community latrines used by nearly 500 refugees.
- The efficiency of the RBS to reduce oxygen demand and NO_3^- is satisfactory.
- This case study suggests the design modification of RBS to enhance PO_4^{3-} removal efficiency.

INTRODUCTION

The demand for freshwater is increasing with increased world population, which is responsible for the conversion of the natural environment into constructed lands. Along with the direct effect of land conversion, freshwater quality is degrading, and on the other hand, water demand is increasing. In fact, more than 5 million people die every year due to poor water quality, and about 33% of the people in the world currently have faced moderate water stress. It is expected that freshwater stress may affect about 2.3 billion people by 2025 (World Health Organization 2006), and at least one-fourth of the world's population by 2050 (World Water Assessment Programme (United Nations) 2003).

In poor and developing countries (such as Ghana), where sewerage systems are not available or partly available, human excreta are commonly disposed of in on-site systems such as septic tanks (STT), cesspools, and pit latrines. Faecal sludge (FS) produced in these units needs to be periodically removed (Rohilla *et al.* 2019). It is characterized by high solids, organic and enteric microorganism

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content, often large quantities of grit and grease, a great capacity to foam upon agitation, and often poor settling and dewatering characteristics (Polprasert *et al.* 1998). Discharge of the untreated sludge to watercourses or land may degrade the environment, cause public health risks, and generate odour nuisance (Strauss *et al.* 1997).

Subsurface flow constructed wetlands (e.g., reed bed systems (RBS)) are biological wastewater treatment systems designed to mimic natural wetlands, require low investment, operational and maintenance costs by cultivating the emergent plants (e.g. reeds, bulrushes, and cattails) on growing media, and maintain ecological values (Kadlec *et al.* 2000; Yoon *et al.* 2001). RBS can reduce the biochemical and chemical oxygen demand of wastewater, and retain wastewater pollutants (specifically, NO_3^- and PO_4^{3-} ions) (Vymazal 2009; Guo *et al.* 2017), which depends upon the physical and biogeochemical properties of reeds and growing media, hydraulic loading rate of wastewater, and existing environmental factors, such as temperature, pH and redox potential (Saeed & Sun 2017). In fact, the hydraulic loading rate of wastewater and sludge quantity rate are crucial components to design wastewater treatment processes. To predict this hydraulic loading and sludge quantity rate, various soft computing systems such as the feed forward back propagation neural network, radial basis function neural network, adaptive neuro-fuzzy inference system, hybrid wavelet-gene expression programming, wavelet-model tree, wavelet-evolutionary polynomial regression models and so on have been applied recently with high potential (Najafzadeh & Zeinolabedini 2018; Najafzadeh & Zeinolabedini 2019; Zeinolabedini & Najafzadeh 2019). Moreover, to evaluate the performance of such faecal sludge management systems passively, the indicators of faecal pollution in treated effluent wastewater may guide the decision makers on the potential opportunities of faecal wastewater reuse (Crusberg & Eslamian 2016).

However, the prediction of the above-mentioned rates has not been considered in this study as the RBS was installed without prior prediction. In fact, the RBS along with other supportive reactors was installed at a refugee camp in Cox's Bazar, Bangladesh, because the camp had only community pit latrines without any faecal sludge management system. The general practice was to dump the sludge in a hole dug near the latrines. This practice was not only unhygienic but also might have the risk of sludge spillover leading to a nearby canal during the rainy season. Moreover, due to limited space and exaggeration of kitchen gardening activities, it was difficult to identify suitable space for dumping faecal sludge. Moreover, the introduction of the faecal pollution indicators is preferred to optimize the selection of water reuse. However, this study focuses on the retention kinetics of the target pollutants in the RBS rather than water reuse. Therefore, the aim of this study has been set to evaluate the performance of the installed RBS for observing whether or not the effluent from the RBS would satisfy Bangladesh standards.

STUDY AREA

The study area is in Kutupalong, which is approximately 40 km from Cox's Bazar town. The RBS was designed for 14 community latrines used by nearly 500 refugees. To facilitate the performance of the RBS, the faecal sludge with wastewater was passed through primary- and secondary treatment plants by means of a septic tank (STT), and anaerobic baffle reactor (ABR), respectively, prior to the RBS (see Figure 1). The ABR has two chambers, and the RBS has three 8 mm deep gravel layers (upper layer with fine sand of 2.5 fineness modulus, middle layer with 5 mm downgrade gravel, and bottom layer with 15 mm downgrade gravel). Note that the design capacity of the installed RBS has been set to 5 m^3/day.

The target of the RBS is to treat fecal sludge in three steps: primary (in the septic tank), secondary (in the ABR) and tertiary (in the RBS). Highly concentrated wastewater from the septic tank is pumped to the ABR, where the wastewater is treated by settling the heavier particles at the bottom and floating particles as scum at the top of the first chamber. The liquid portion of this wastewater is then collected in the second chamber.

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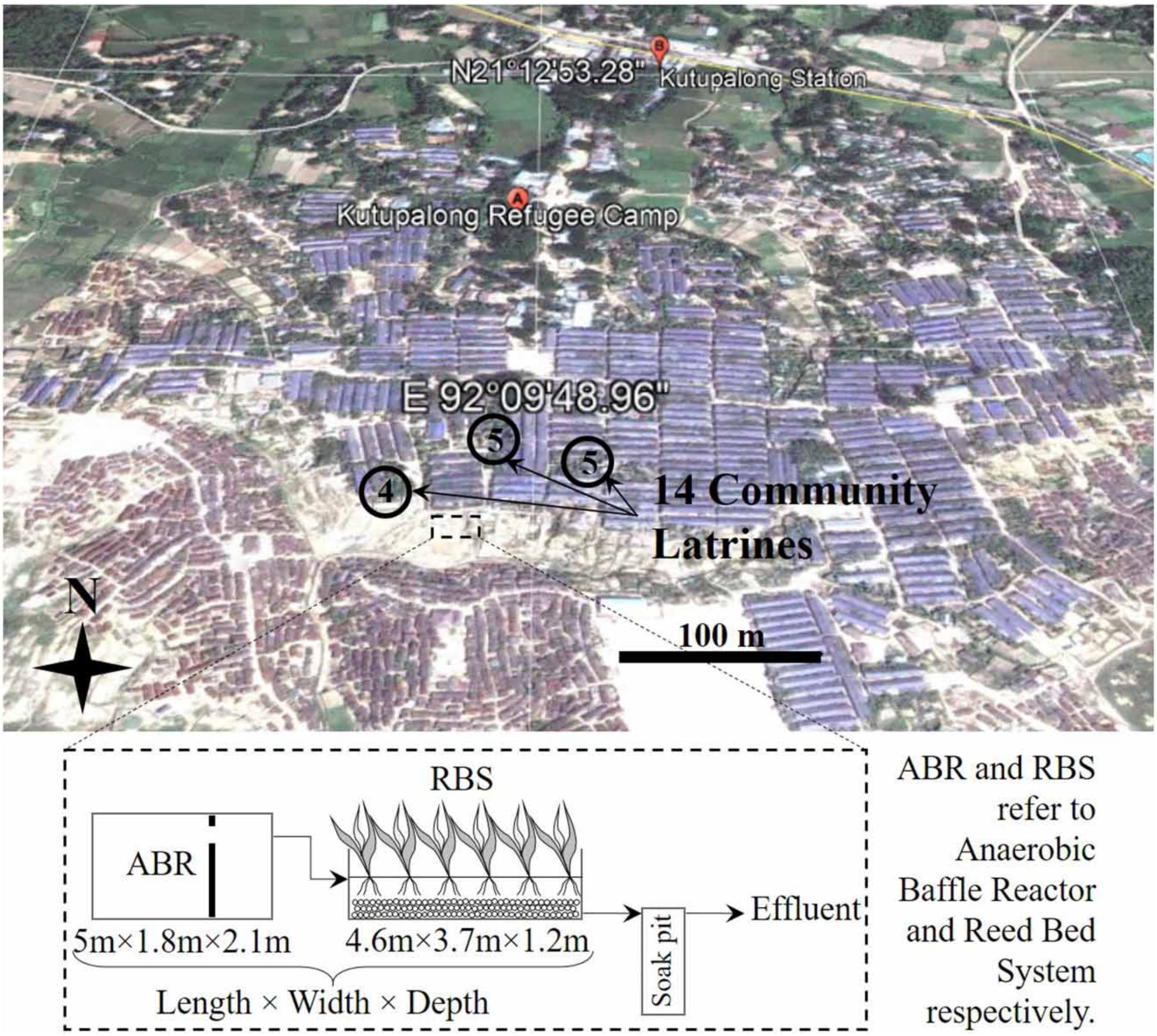

Figure 1 | Location map of the study area along with the position of 14 community latrines. The details of the ABR and RBS are shown in the dashed panel.

SAMPLE COLLECTION AND TESTING METHOD

From the STT and ABR, wastewater samples were collected at retention times of 3, 4, 5, 6 and 7 days over a four-month period. Thereafter, the treated wastewater was collected from the effluent of the RBS. Special precautions were taken not to create any turbulence and not to develop any bubbles in the collection bottles. These samples were then tested in the laboratory for BOD_5, COD, NO_3^- and PO_4^{3-} following standard methods (APHA/AWWA/WEF 2005).

RESULTS AND DISCUSSION

Fecal wastewater quality

The maximum values of COD and BOD_5 in the STT have been found to be nearly 3,780 mg/L and 700 mg/L respectively, which are at least 60% more compared to their mean values (see Figure 2 and Appendix in Supplementary Materials) and nearly 18 times higher than the sewage discharge standard of Bangladesh. When the effluent water has been passed to the ABR, the concentration of COD and BOD_5 reduces to nearly 1,366 mg/L and 210 mg/L on average. Finally, after retaining

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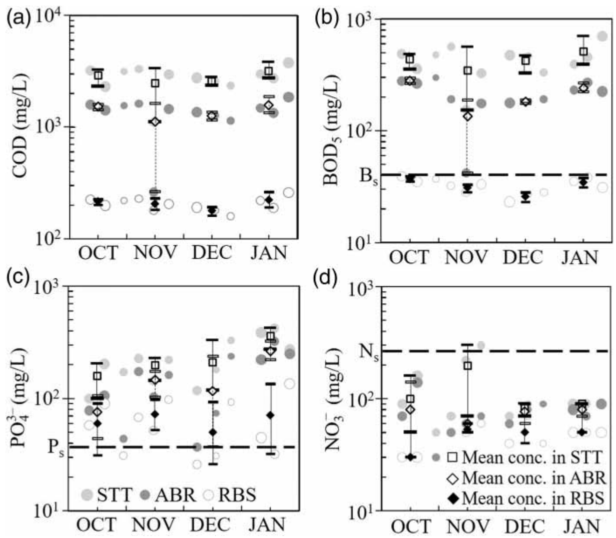

Figure 2 | Concentration of oxygen demand and nutrients in wastewater at various treatment stages. The size of the bubbles used for STT, ABR and RBS varies because of various HRT. The legends used in panel (c) and (d) are applicable to all panels. The top and bottom whiskers represent the maximum and minimum concentration respectively. B_S, N_S and P_S refer to the sewage discharge standards for BOD_5, NO_3^- and PO_4^{3-} respectively in Bangladesh.

the effluent water from the ABR in the RBS for 7 days, the BOD_5 concentration in the final effluent to be discharged has been found to be as low as 23 mg/L. In fact, the concentration of BOD_5 for all tested samples for various HRT has been observed to meet the discharge standard (see Figure 2). Interestingly, the mean concentration of NO_3^- has been found to be very low in the STT, and it has been reduced to 30 mg/L after passing through the RBS. On the contrary, the concentration of PO_4^{3-} in RBS's effluent has been observed to exceed the sewage standard for nearly 67% of samples. Although the minimum concentration of PO_4^{3-} has been found in December as 26 mg/L after 5 days in the RBS, the mean concentration has been observed as more than 4 times higher than the national standard.

Reduction in oxygen demand and nutrients

The removal efficiency of COD and BOD_5 has been observed to be 87–94% in the effluent from the RBS (Figure 3). In fact, it was hypothesized that the efficiency percentage would not be increased much with respect to the increment in HRT, and such result has been observed for COD and BOD_5. On the other hand, linear increasing NO_3^- removal efficiency with increasing HRT has been observed whereas linear decreasing PO_4^{3-} removal efficiency with increasing HRT has been seen, possibly because of acting as a source of PO_4^{3-}. However, the optimum HRT has been selected

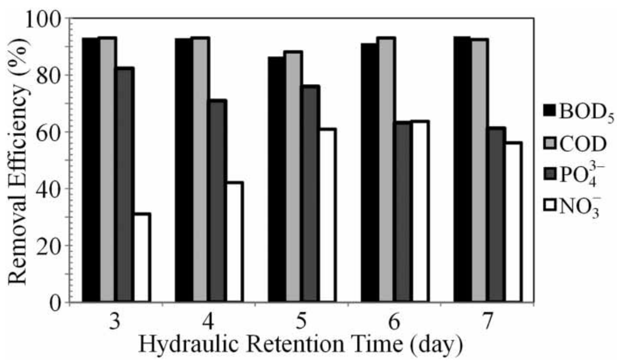

Figure 3 | Efficiency of reed bed system (RBS) with respect to hydraulic retention time (HRT).

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to be 3 days when the PO_4^{3-} has been reduced at maximum rate and the other parameters have met the national standard (see Figure 3).

Correlation analysis

The correlation among the tested parameters has been shown in Table 1, where the correlation between NO_3^- and PO_4^{3-} has been found to be the highest. In fact, this correlation is significant at the 0.01 level (2-tailed).

Table 1 | Correlation among the testing parameters

	BOD_5	COD	NO_3^-	PO_4^{3-}
BOD_5	1			
COD	0.919	1		
NO_3^-	−0.679	− 0.34	1	
PO_4^{3-}	−0.629	− 0.285	0.937	1

CONCLUSION

The purpose of the study was to assess the removal efficiency of different constituents of faecal wastewater to be treated through an RBS in a refugee camp. According to the experimental results and discussion, the RBS has been found to be efficient to retain, on average, nearly 90% BOD_5 and 50% NO_3^-. However, the high concentration of PO_4^{3-} could not be retained much to allow the wastewater to discharge safely to nearby waterbodies without further treatment. In fact, the highest PO_4^{3-} and NO_3^- concentration have been found in the RBS's influent as nearly 320 mg/L (exceeds local sewage discharge standard) and 140 mg/L (meets local sewage discharge standard) respectively. Interestingly, the wastewater seems to be treated in the STT, whose effluent has met the safe discharge criteria for all constituents except PO_4^{3-}. Therefore, the existing RBS requires design modification to enhance PO_4^{3-} removal efficiency, and the co-treatment of faecal sludge and wastewater in an aerobic granular sludge system may be a potential option (Barrios-Hernández *et al.* 2020).

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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