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ORIGINAL ARTICLE

The purification of wastewater on a small scale by using plants and sand filter

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Abstract

The canteen and laboratory of every academic organization need a lot of clean water, and it generates equivalent amount of wastewater every hour which is neither purified nor reused. Due to water scarcity, the recycling and reusing of wastewater become very essential. The present study describes the simple and cost-effective method for the design of a small-scale wastewater treatment plant for the purification of wastewater generated by household, canteen and laboratory of an academic institute. The current study explored the process of phytoremediation by *Typha latifolia* L. and *Canna indica* L. for removal of metal ions and phosphate ions from the wastewater. The partially treated water after phytoremediation was further purified by sand filtration. The various water quality parameters (pH, hardness, dissolved oxygen, chemical oxygen demand, turbidity, total dissolved solids and metal ions) of the treated and untreated water were analyzed. It was observed that there are significant reduction in hardness, turbidity and chemical oxygen demand and increase in dissolved oxygen value. The treated water can be reused for various household works and agriculture.

Keywords Wastewater · Phytoremediation · *C. indica* · *T. latifolia* · Sand filtration · Water quality parameters

Introduction

Water is a transparent liquid, covers approximately 75% of earth surface and is vital for all living forms of life. For survival every living being should have access to sufficient amount of clean water. The word "water scarcity" describes the relationship between demand for water and its availability. Water scarcity is rapidly becoming a major problem for many developing countries which means shortage of enough water (quantity) and lack of access of safe water (quality) (Alcamo et al. 2003; Alcamo et al. 2007). With growing demand for water and depletion of the available water, assured supply of good quality water is becoming a major concern (Alonso-Castro et al. 2009; Anning et al. 2013). The population growth coupled with industrialization and urbanization has resulted in an ever-increasing demand for water (Belinda et al. 2007). There exist numerous high-technology systems to purify wastewater. But for a huge proportion of population in the developing world that lives in the rural areas, such systems would be inappropriate or too expensive (Biswas 2004; Bose et al. 2008; Carranza-Álvarez et al. 2008). The current study describes the process of phytoremediation coupled with sand filter for the purification of wastewater generated from kitchen, canteen and chemistry laboratory of an academic institution. Phytoremediation is the process of purification of wastewater by the use of green plants which include grasses, herbs and woody species (Clark et al. 2012; Demirezen and Aksoy 2004). In the past few decades, phytoremediation has become an important and eco-friendly technique for the removal of various environmental contaminants from soil and water. Plants are known to play very important role in removal of toxic heavy metal ions from wastewater (Dimaano 2015; Dushenkov et al. 1995). They accumulate heavy metal ions in roots, rhizomes and old leaves (Fediuc and Erdei 2002). Various processes (phytoextraction, rhizofiltration, phytodegradation and phytovolatilization) have been described in literature by which plants remove the toxic substances and metal ions from wastewater (Gleick 2000; Gottinger et al.

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2011). Among these, phytoextraction and rhizofiltration are the most accepted mechanisms for the removal of heavy metal ions form wastewater. In phytoextraction, impurities are accumulated in shoots and leaves (Gratão et al. 2005; Gupta and Sinha 2007), while in rhizofiltration impurities are accumulated in the massive root system of the plant (Hale and Melia 1913).

The purification of wastewater by sand filtration is very well-known and cost-effective method. Sand filter can be easily fabricated by using sand which is supported by gravels of various sizes. The height of the filter, water flow rate, size of gravels and thickness of sand are very important parameters for designing the sand filtration unit (Hollender et al. 2009). The purification of water by sand filter is largely based on biological process. Microorganisms accumulate and multiply on the filter media and degrade the waste material present in the water. As the water percolated downwards, impurities are strained out by the filter media resulted in the purification of wastewater (Kamal et al. 2004). The aim of the present work is to purify the wastewater generated by the from kitchen, canteen and chemistry laboratory of an academic institution by combining the process of phytoremediation and sand filtration.

Experimental methods

Standard methods have been used for the determination of various water quality parameters; a brief outline of the methods has been given here. Turbidity, pH and total dissolved solids (TDS) were measured by turbidity meter, pH meter and TDS meter, respectively. Total hardness of water was estimated by titrating it with EDTA salt (disodium salt of ethylene diamine tetraacetic acid) solution using Eriochrome Black T as an indicator. Dissolved oxygen and chemical oxygen demand were determined by modified Winkler's method and open refluxed method, respectively (Kumar et al. 2003). The detailed procedure for estimation of total hardness, dissolved oxygen and chemical oxygen demand has been given in supporting information.

Collection of experimental plant

Two plants, namely *Typha latifolia* L. (cattail) and *Canna indica* L. (keli), were collected from the main drainage water channel at Yamuna river bank, India.

Fabrication and working of filtration plant

The tank used for phytoremediation is made by a plastic container with a diameter of 40 cm and height of 46 cm. The plant was grown to the depth of 35 cm using garden soil. The sand filtration unit is very simple in design and operation (Lasat 2002). It consists of a plastic bucket of height 35 cm and diameter 32 cm. The water-carrying capacity of the bucket is 25 L. The retention time in sand filter varies from 5 to 48 h. The flow rate of the water is 15 L/h. It is filled with various layers of gravel (different diameter) and thick sand. The topmost layer of the sand filter consists of thick sand, and the second layer consists of small-sized gravel having diameter 2–4 mm. The third and fourth layer is composed of medium- and large-sized gravel having diameter 6–8 mm and 12–14 mm, respectively. Figure 1 depicts the (a) experimental setup for phytoremediation, (b) design of water purification plant, (c) various gravel layers used for fabrication of sand filter and (d) sand filtration unit. For the removal of metal ions and phosphate ion from the wastewater, the process of phytoremediation using *T. latifolia* and *C. indica* has been demonstrated. The partially purified water is further purified by passing it through sand filter prepared by arranging various layers of gravels and sand one over the other (Li Fangyue and Wichmann 2009; Logsdon et al. 2002; Manios et al. 2003). The water is allowed to pass through the filter at a very slow rate, and as water slowly percolates through a bed of carefully arranged sand medium, almost all the suspended and colloidal material is trapped by the top layers of sand. (Marchiol et al. 2004) Clear, filtered water is collected at the bottom of the filter medium. The water quality parameters were checked before and after purification of water. The water quality parameters (color, pH, hardness, total dissolved solid (TDS), dissolved oxygen (DO) and chemical oxygen demand (COD) and turbidity) of the treated and untreated water have been estimated by literature known procedures (Maurer et al. 2005; Muthusaravanan et al. 2018).

Results and discussion

The wastewater generated from academic laboratory is generally composed of organic matter, wide range of chemicals and heavy metals and is most difficult to purify. On the other hand, wastewater produced from canteen or house is highly turbid and contains phosphate ion from dish washing soap and detergent as the major impurity. *T. latifolia* and *C. indica* plant has been used for the removal of heavy metal contaminant from the wastewater generated from laboratory and canteen/house respectively (Peter et al. 2012; Prasad et al. 2006). *T. latifolia* can grow in water contaminated by heavy metals, and it gathers metal ions in its tissue (Sasmaz et al. 2008; Seckler et al. 1999). The wastewater was kept in well-grown plants species, and effluent water was checked for removal of zinc (Zn), cadmium (Cd) and lead (Pb) metal. The reduction in phosphate ions is due to process of mineralization in which soil microorganisms convert organic phosphorous into orthophosphates which can be easily taken up

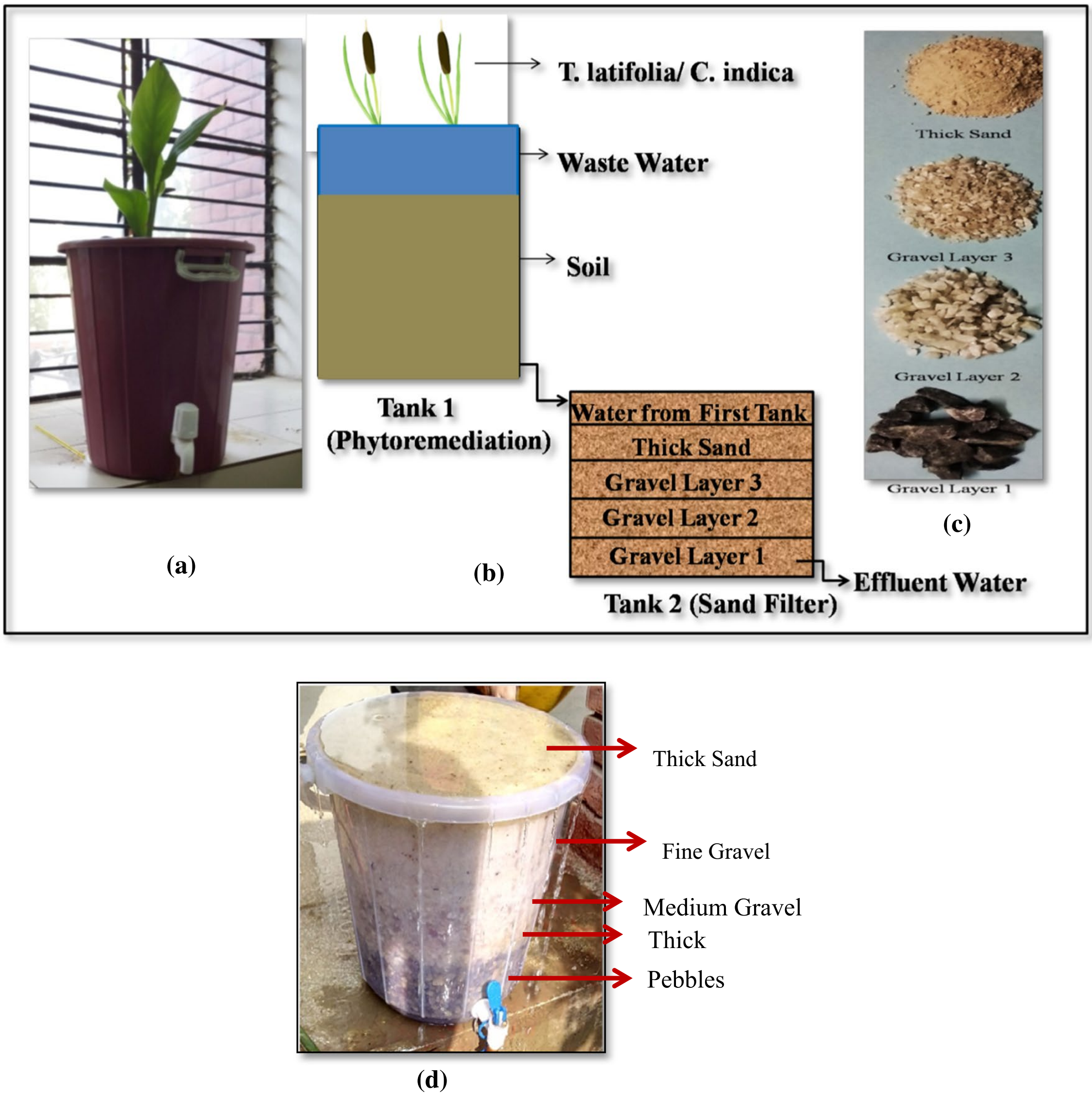

Fig. 1 **a** Setup for phytoremediation, **b** design for water purification plant, **c** digital photographs of various gravel layers used in sand filter and **d** sand filter (showing various layers of pebbles and sand)

by plants for their growth (Silva et al. 2015; Smakhtin et al. 2004). The procedure for the qualitative detection of metal ions, phosphate ion and various water quality parameters has been given in supporting information. After phytoremediation, the treated water was admitted to sand filter. Slow sand filters are known to substantially remove suspended solids, turbidity and microorganism from wastewater (Suresh and Ravishankar 2004; Taghizadeh et al. 2007).

The partially treated water was allowed to enter into sand filter from where it flowed downwards under the action of gravity. As water drains downward, purification occurs by sedimentation where particles settled down by gravitational forces (Vardanyan and Ingole 2006). Sand bed (composed of sand and gravel of different diameter) acts as effective strainer that retained suspended particles and other impurities; those are larger than the interstices between the sand filter (Vogel 1987). Contaminants are physically and chemically adsorbed on sand bed by various electrostatic, van der Waals and chemical interactions (Vogel 1989; Wang et al., 2002). Table 1 shows the value of various water quality parameters for untreated and treated water. Qualitative test for detection of Zn, Cd, Pb and phosphate ion has been done, and it was found that treated water does not have any of these metals. The reduction in metal ions is due to uptake by plants to meet growth requirement (Smakhtin et al. 2004). The percentage reduction in TDS and turbidity of canteen water and laboratory water is 77, 91 and 47, 99.8, respectively. The decrease in TDS and turbidity is due to a decrease

Table 1 Various water quality parameters checked before and after treatment (values are mean ± SD of three observations)

Parameter	Canteen/house waste			Laboratory water		
	Before treatment	After treatment	SD	Before treatment	After treatment	SD
Color	Dirty white color	Colorless	–	Grey	Colorless	–
Temperature (°C)	20	20	±0.0	20	20	±0.0
pH	7.15	7.30	±0.2	1.43	6.81	±0.2
Total hardness (ppm)	1240	160	±8.7	770	130	±6.2
Total dissolved solid (ppm)	646	149	±0.0	232	124	±0.0
Turbidity NTU	30	2.61	±0.0	50	1.77	±0.0
Dissolved oxygen (D.O.)	6.4	9.6	±0.3	0.97	4.5	±1.1
Chemical oxygen demand (C.O.D.)	80	20	±0.4	160	20	±1.4
Phosphate test	Positive	Negative		–	–	
Zn^{2+}, Pb^{2+}, Cd^{2+}	–	–		Positive	Negative	

in suspended and dissolved solids (Weber-Shirk and Dick 1997; Wotton 2002). The percentage reduction in COD for canteen and laboratory water is 75 and 88, respectively. The appreciable decrease in COD value is due to consumption of organic matter by microorganisms. Microorganisms get food from organic matter present in wastewater and in turn release oxygen which increases the dissolved oxygen content of the water. The significant improvement in various water quality parameters is graphically shown in Fig. 2. The treated water can be reused for various purposes like cleaning, gardening, agriculture, etc.

The purification of wastewater has been done by using sand filtration alone. It was observed that without phytoremediation, there is no appreciable removal of metal ions. On the other hand, there is sufficient improvement in TDS, turbidity and COD values. These results show that plants play important role in removal of metal ions from wastewater. Quantitative estimation of metal ions and various disinfection methods are currently underway so that the treated water can be used for drinking purposes as well.

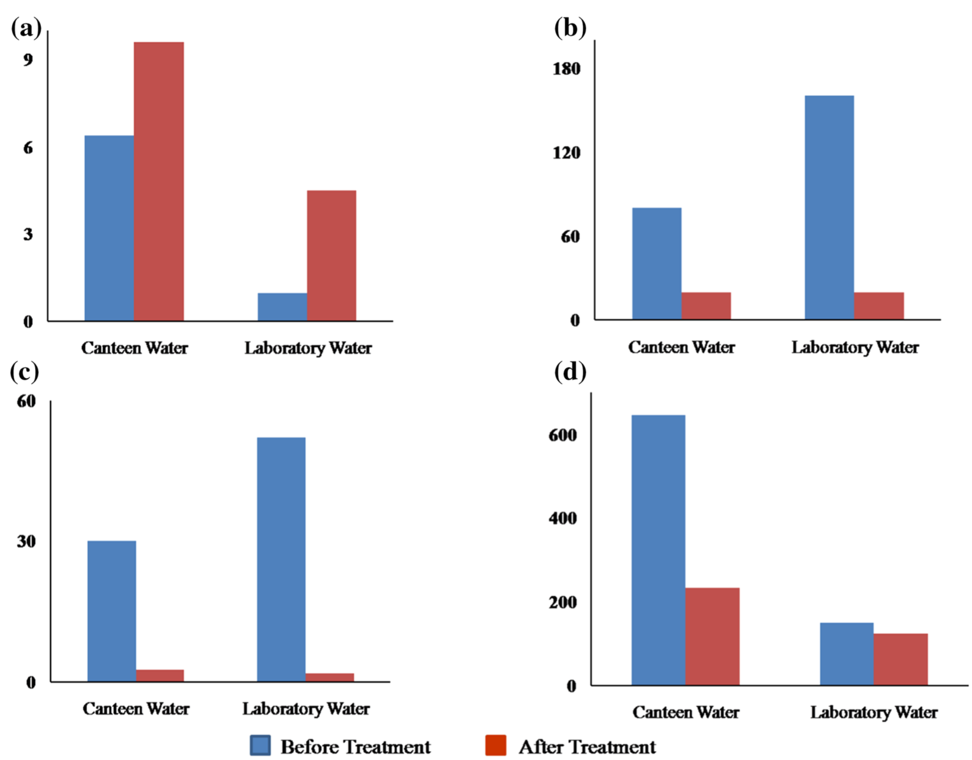

Fig. 2 Graph showings the results water quality parameter before and after treatment. **a** Dissolved oxygen (ppm), **b** chemical oxygen demand (ppm), **c** turbidity (NTU) and **d** total dissolved solid (ppm)

Conclusions

A simple and cost-effective water treatment plant was built whose construction, operation and maintenance are easy. It can be easily implemented in rural areas because it does not need electricity for its operation. In the nut shell, this paper provides an overview of purification of wastewater by combining the technique of phytoremediation and sand filtration. The initial values of the various water quality parameters are quite high which indicate the high impurity level in untreated water generated from chemistry laboratory and canteen. There is substantial improvement in all the water quality parameters after treatment. The present method provides an eco-friendly and cost-effective small-scale water treatment plant.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13201-021-01406-4.

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Declarations

Conflict of interest All authors declare that they have no conflict of interest.

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