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# Seasonal applicability of horizontal sub-surface flow constructed wetland for trace elements and nutrient removal from urban wastes to conserve Ganga River water quality at Haridwar, India

U.N. Rai [a,*], A.K. Upadhyay [a], N.K. Singh [b], S. Dwivedi [a], R.D. Tripathi [a]

[a] *Plant Ecology and Environmental Science Division, CSIR- National Botanical Research Institute, Lucknow 226 001, India*
[b] *Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi 221 005, India*

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ABSTRACT

A horizontal sub-surface flow constructed wetland (HSSF) has been designed to study the seasonal removal of nutrients and trace elements by treating urban sewage through selected aquatic plants at Shantikunj, Haridwar, India. Three aquatic macrophytes i.e., *Typha latifolia, Phragmites australis* and *Colocasia esculenta* were planted in constructed wetland (CW). Samples collected from inlet and outlet of the CW were analyzed for trace elements and physico-chemical characteristics in contrasting seasons (winter and summer). Plant species and season-wise variations were observed in the removal of trace elements and nutrients in CW. Results indicated that trace element removal efficacy of plants were more in summer than in winter in order of Pb (86%) > Cu (84.01%) > Zn (83.48%) > As (82.23%) > Cr (81.63%) > Co (76.86%) > Ni (68.14%) > Mn (62.22%) during summer. While in winter, it was in the order of Pb (78.59%) > Cu (72.50%) > Zn (68.40%) > Co (65.12%) > Cr (64.5%) > As (63.18%) > Mn (53.34%) > Ni (51.39%). Indeed, the removal of Pb was higher in both the seasons. In general, the selected aquatic macrophytes used in this study showed higher bioconcentration factor (BCF) and translocation factor (TF) in summer than in winter, which was highest for *T. latifolia*. The average removal efficiency of physico-chemical characteristics, i.e., conductivity, TDS, BOD, TSS, $NO_3$-N, $NH_4$-N and $PO_4$-P in winter and summer season were observed from 55.3–91.61% to 64.8–94.1%, respectively. The study demonstrated that CW seems suitable eco-technology for remediation of urban wastes containing trace elements and high nutrients, before entering into Ganga River.



## 1. Introduction

Technogenic activities are the primary sources of pollution that contaminate the different components of environment in addition to geogenic sources (Ma et al., 2011) in which trace elements contamination in water is one of the serious concern that threatens not just the aquatic ecosystems but also intimidating the human health (Rashed, 2010; Kumar et al., 2013). Intake of trace elements through food-chain by human population has been widely reported throughout the world (Muchuweti et al., 2006). Approximately, 74% of the total water withdrawn from rivers, lakes and aquifers, get contaminated with organic pollutant and trace elements that also lead to threat the phytoplankton and aquatic macrophytes (Rai et al., 2011). Plants have evolved efficient mechanisms for uptake of trace elements from the environment. Plant rhizospheric secretion of various organic acids, aided by plant-producing chelating agents, pH changes and redox reactions are able to solubilize and accumulate trace element at low levels, even from nearly insoluble precipitates (Headley et al., 2005; Tangahu et al., 2011).

Since, trace elements cannot be transferred from water through degradation by biological processes; using vegetation to remove, detoxify or re-stabilize polluted sites have been widely accepted tool in developed countries for cleaning such polluted water as it regenerates the original water permanently (Ali et al., 2013). However, recently, green alga *Chlorella* sp. has been reported to remove and transfer trace elements from biogas fluid (Yan et al., 2014; Yan and Zheng, 2014). In India, use of plant based affordable technology for the reduction of toxic elements in sewage and municipal waste during dumping condition in different season remains unexplored. Therefore, trace elements contamination in river water needs to be addressed urgently.

Ganga is the largest river basin in India in terms of catchment area and supporting about 43% of its population located in the

* Corresponding author. Tel.: +91 522 2297829; fax: +91 522 2205836/39.
*E-mail address:* rai_un@rediffmail.com (U.N. Rai).

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watershed. In recent decades, Ganga became one of the most critically polluted river in the world (Wong et al., 2007) due to the extensive discharge of untreated sewage from different cities containing high concentration of toxic elements viz., Cu, Cr, Pb, As, Hg, Mn, Zn and Fe etc. (Purushothaman and Chakrapani, 2007; Rai et al., 2012). Report of the CPCB (2009) indicated that out of total 38,255 million liters per day (MLD) generated sewage, only 17,787 MLD get treated through sewage treatment plants (STPs) and the rest is directly released into the river. Although initiatives have been acquired by the Government of India to install STPs in different urban areas for the treatment of sewage, yet, it does not fit the required measures, particularly in the removal of trace element present in sewage as these are not designed for trace element removal (Pantsar-Kallio et al., 1999). Such low quality effluent imposed aesthetic, health, odor problem and also the survival of flora and fauna in the river. Besides, India being a developing country cannot afford the high cost to treat such sewage due to various investment priorities and energy crisis, it is necessary to provide an integrative approach for the prevention and control of trace element pollution, to limit its impact on water resources, biodiversity, trophic network and human wellness. For this purpose, introduction of CWs between natural aquatic ecosystems and industrialized zones or catchments is a promising strategy for eco-remediation and tackle the energy crisis (Liu et al., 2012; Guittonny-Philippe et al., 2014). Yan et al. (2012) also reported that cost effective vertical sub-surface flow CWs under different influent C/N ratios could enhance nutrient removal and reduce greenhouse gas production from the wetland.

Constructed wetlands are an engineered eco-technological system, designed with ecological principals to exploit the natural processes involving wetland vegetation, soils and associated microbial assemblages for treating wastewaters for the removal of nitrogen, phosphorus, total solids, and trace elements (Soda et al., 2012; Madera-Parra et al., 2013; Rai et al., 2013; Nivala et al., 2013; Guittonny-Philippe et al., 2014). Constructed wetlands are especially effective in warmer climate and in the area with sufficiently long day length in winters to support plant growth (Kyambadde et al., 2004). Aquatic macrophytes as the main biological component of CW play an important role in trace element removal through filtration, adsorption, cation exchange, root induced chemical changes in the rhizosphere as well as carbon sources for bacterial metabolism, thus promoting long-term functioning of CW (Mishra and Tripathi, 2009; Marchand et al., 2010; Korboulewsky et al., 2012). In addition, plants used in CW should have a fast growth rate, clonal propagation, large biomass, better tolerance and well developed root system (Brisson and Chazarenc, 2008). Therefore, choice of plant species is an important issue for performance of CWs because they should survive under the potential toxic effects of the influent and its variability (Madera-Parra et al., 2013).

Use of CW for treatment of waste water to allow for safe river discharge is presently being investigated in the Ganga River basin at Haridwar (India) and has been recommended for conservation of river water quality (Rai et al., 2013). The present work was undertaken to evaluate suitability of three aquatic macrophytes viz., *Typha latifolia*,*Colocasia esculenta* and *Phragmites australis* for wastewater treatment and to study their nutrient and trace element removal potential in contrasting season under horizontal sub-surface flow constructed wetland (HSSF) to conserve Gang River ecosystem.

## 2. Materials and methods

### 2.1. Experimental setup and designing

A horizontal sub-surface flow constructed wetland (HSSF) has been developed with the gravel as media at Shantikunj, Haridwar, India, located at 29.93′N latitude and 78.19′E longitude. The basin characteristics of CW designed to treat municipal sewage has been shown in Table 1. The effective treatment area of wetland was 79.17 $m^2$ and with two chambers; rectangular planted zone ($L$ = 7.8 m; $W$ = 6.65 m; $D$ = 1.8 m) and the settling tank ($L$ = 7.8 m; $W$ = 3.5 m; $D$ = 1.8 m). Gravel beds in planted zone were 0.75 m thickness with the gravel ranging from 6 to 25 mm diameter in equal proportion. The treating capacity of the designed CW was 0.065 MLD. For treatment wastewater was allowed to flow 15 cm beneath the gravel surface through perforated pipes from settling tank. Sequencing fills and draw-batch mode was applied to influent. Flow rate was controlled using a 12 mm diameter gate valve by regulating the inlet and outlet flow, using beaker (500 ml) and a stopwatch.

**Table 1**
Major design parameters of constructed wetland.

| Parameters | Settling tank | Planted area |
|---|---|---|
| Water depth (m) | 2 | 0.941 |
| Area ($m^2$) | 27.3 | 51.87 |
| Effective volume ($m^3$) | 54.6 | 48.81 |
| Amount of water (MLD) | 0.065 | 0.065 |
| Retention time (h) | 12-36 | 12-36 |

The aquatic macrophytes i.e., *T. latifolia, P. australis* and *C. esculenta* were collected from catchment area of Ganga River nearby Haridwar, India. To treat sewage, aquatic macrophytes were first grown in the nursery and then sapling of approximately same size and weight were transplanted in planted area of CW in alternate row keeping a distance of 30 cm from each course and each plant. Planted area of CW was irrigated continuously for 2 months with tap water for stabilization and development of plant species and colonization by microorganisms.

The experiment was started in the month of October, 2012 (winter) in which first two months were given for plant growth and establishment. After 2 months, CW was fed with sewage and continuously monitored for a period of two months. After harvesting, new nursery plants were grown in same CW. For the summer another two months (February–March, 2013) were given for the growth and stabilization of plant in CW and sewage was applied as in the case of winter. Time-proportional composite samples of water and plants were collected manually at 12, 24 and 36 h retention time twice in winter and summer season from inflow and outflow water with the help of inlet and outlet pipe, respectively, for physico-chemical and trace element analysis. For the winter season, sampling was carried out during December, 2012–January, 2013, and in the summer season sampling was done during April–May 2013.

### 2.2. Physico-chemical and trace element analysis

Physico-chemical parameters viz., temperature, pH, conductivity, dissolved oxygen (DO), biological oxygen demand (BOD), total dissolved solids (TDS) and total suspended solids (TSS) along with nitrate-nitrogen ($NO_3$-N), ammonical-nitrogen ($NH_4$-N) and phosphate-phosphorus ($PO_4$-P) in wastewater and trace elements in plants and wastewater were determined following the standard methods of APHA (2012). Harvested plant samples were rinsed thoroughly with distilled water, separated into above and below ground parts and dried at 80 °C till a constant weight. 50 ml of wastewater and plants (100 mg) samples were digested with $HNO_3$/$HClO_4$ (3:1, v/v) at 80 °C. After digestion, samples were allowed to cool, dissolved in 0.6% $HNO_3$ and filtered through Whatman filter paper No. 42. Volume of each sample was maintained up to 15 ml with 0.6% $HNO_3$ and trace element