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Remediation capabilities of pilot-scale wetlands planted with *Typha aungstifolia* and *Acorus calamus* to treat landfill leachate

Rohit V. Bhagwat*, Dilip B. Boralkar and Ram D. Chavhan

Abstract

Improper management and unsanitary approaches are implemented in disposal of leachate, which has resulted in groundwater pollution at village Uruli Devachi, Pune, India. Various physico-chemical treatment methods are commercially available for leachate treatment. However, the application of biological methods viz. phytoremediation to the municipal solid waste landfill leachate has been limited. We report the remediation ability of *Typha aungstifolia* and *Acrorus calamus* that is capable of reducing hazardous constituents from the landfill leachate. After 96 h of hydraulic retention time (HRT), it was observed that *T. aungstifolia*-treated sample showed high reduction potential in reducing biochemical oxygen demand, chemical oxygen demand, hardness, total dissolved solids, Na, Mg, Ca and Ni whereas *A. calamus* showed greater reduction capacity for alkalinity, Cl, Cu, Zn and Cr. Furthermore, it was also observed that *T. aungstifolia* withstood longer HRT than *A. calamus*. In situ application of *T. aungstifolia* and *A. calamus* for remediation of landfill leachate carries a tremendous potential that needs to be further explored.

Keywords: Landfill, Leachate, Open dumping, Remediation, Treatment

Introduction

Nature of the problem

Municipal solid waste (MSW) and its management have become a major concern throughout the world. Asian countries including China (Asian Development Bank (ADB) 2007), Nepal (Asian Development Bank (ADB) 2013), India, Bangladesh, Sri Lanka, Indonesia, Malaysia and the Philippines are facing severe difficulties due to unplanned and rapid urbanisation (Agamuthu and Tanaka 2014). For many decades, landfilling has been the most preferred waste management options in these countries. Most of the times, these landfills are open and unscientific and are located either in urban fringe or in the rural settings. MSW disposal in a landfill generates active biochemical substances in the form of leachates over a period of many years (Jones et al. 2006 and Erdogan and Zaimoglu 2015). Pollution caused by unscientific designs of the landfills poses a serious threat to biodiversity, soil, subsurface and surface waters and human well-being.

Factors such as waste composition, decomposition rates, stability and meteorological conditions affect the composition of leachate; therefore, its quality is site specific, and variations are frequent (Jones et al. 2006). The downward movement and outward flow of the leachate transfer the contaminants to the groundwater and peripheral areas of the dump site respectively, thereby also affecting surface water (Papadopoulou et al. 2007). Furthermore, human health risks such as infections, skin irritation, nausea, vomiting and headache, while chronic exposure can led to anaemia, kidney damage and cancer, have been reported by various groups (Klinck and Stuart (1999); Raman and Narayanan (2008)) due to use of leachate-contaminated groundwater.

Phytoremediation

There are many biological, physical, chemical and physico-chemical techniques to treat the leachate, which

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carries its own merits and demerits (Kamaruddin et al. 2015). Remediation using plants is one of the cost-effective and low maintenance techniques where the dynamics of organic and inorganic interactions are used to decompose and degrade potentially harmful elements in the leachate (Jones et al. 2006). Many species from the plant kingdom are known for their remediation abilities (Table 1); however, it is observed that the application of plant species for treatment of landfill leachate has been limited.

Application of remediation method

Most of the available literature cites ex situ application of plants to treat the landfill leachate in constructed wetlands. Batool and Baig (2015) report the hyperaccumulation capacity of *Typha* sp. for Cu whereas *Thlaspi caerulescens*, *Ipomea alpine*, *Psychotria douarrei*, *Thlaspi rotundifolium*, *Astragalus racemosus* and *Pteris vitatta* show hyper accumulation capacities for Zn and Cd, Cu, Ni, Pb, Se and As respectively. (Oh et al. 2014); Baskar et al. (2014) have used *Typha latifolia* for treating domestic sewage at pilot scale. Bose et al. (2008) in a field study at Delhi applied *Tyaha angustata L.* to assess the uptake and transport mechanism of heavy metals in waste-amended soils in water logged condition. A phytoremediation study was performed at Pariej reservoir, Gujarat, where aquatic macrophytes viz. *Ipomoea aquatica*, *Eichhornia crassipes*, *Typha angustata*, *Echinochloa colonum*, *Hydrilla verticillata*, *Nelumbo nucifera* and *Vallisneria spiralis* were analysed for heavy metal accumulation (Sharma and Pandey 2014).

Even though it is a promising technology, their full-scale applications for landfill leachate treatment are yet to be explored mainly due to their low remediation rate, longer treatment time and higher space requirement as compared with the other commercially available physico-chemical methods. However, its eco-friendly approach is gaining more attention as well as its efficiency in removing pollutants from waste waters (Oh et al. 2014). Therefore, identification and application of plants with higher remediation potential and faster rates is essential. Biological remediation of contaminated sites has been practiced for many decades, but the application of *Typha aungstifolia* and *Acorus calamus* to treat landfill leachate has not been reported in India. Therefore, this pilot-scale study was undertaken to examine the abilities of these plant species treating leachate from unsanitary MSW dumpsite. It also offers an important conservationist perspective by using native and easily available plant species instead of exotic varieties such as *Eichhornia* spp., causing ecological imbalance.

Table 1 Plant species known for remediation applications

Name of the species	Type of remediation	Reference
Alternanthera sessilis, *Commelina nudiflora*, *Paspalum conjugatum*, *Typha angustifolia*	Turbidity, TDS, BOD, nitrate, orthophosphate in landfill leachate	Laily et al. 2017
Canna indica, *Acorus calamus* and *Iris tectorum* Maxim.	Pentachlorophenol contamination	Zhao et al. 2017
Scirpus validus, *Phragmites australis* and *Acorus calamus*	Nitrate contamination in Water	Li et al. 2016
Saccharum spontaneum	Bare fly ash (FA) dumps	Pandey et al. 2015
Typha latifolia, *Phragmites australis*	Removal of heavy metals in landfill leachate	Grisey et al. 2012

Materials and methods

Study area

The study area involves an unsanitary MSW landfill site at the village Uruli Devachi (UD), located approximately 20 km to the South East of Pune city, India (Fig. 1) (Lat. 18° 27′ 55.6″ N and Long. 73° 57′10.3″ E; elevation at 600 m above mean sea level.) The site is an open dump and being used for more than 20 years. The dump site receives untreated mixed MSW from the city of Pune (Fig. 2). It was estimated that the landfill site receives about 1050 tonnes per day of untreated mixed solid waste, whereas precise estimation of daily leachate generation is unavailable (Pune Municipal Corporation 2017). No scientific leachate collection was observed during the site visit undertaken 7 years after reporting of ground water contamination by Kale et al. (2010). The leachate is being collected in an unscientifically designed collection pond on the edge of the dump (Fig. 3). This is suggestive of possible leaching of harmful chemicals into the ground water.

Leachate collection

The sample was collected in pre-cleaned polyethylene containers of 20 L capacity. The pH and electrical conductivity (EC) were recorded onsite at the time of sampling using digital pH and EC meters, respectively. For the analysis of biochemical oxygen demand (BOD), a 300-mL capacity BOD bottle was used and dissolved oxygen (DO) was fixed onsite. For heavy metal analyses, the sample was separately collected in pre-washed polyethylene containers of 100 mL capacity. Spatial data was recorded using a Garmin (eTREX- 30X) global positioning system.

Selection of plant species

T. angustifolia and *A. calamus* are both native to India. *T. angustifolia* is a marshy plant found on the margins

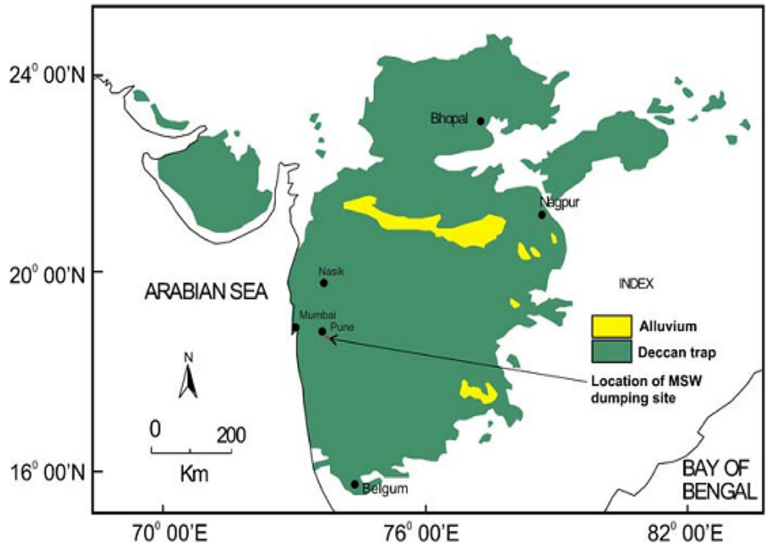

Fig. 1 Location of MSW dumping site at Uruli Devachi (UD), Pune, India (source: Kale et al. 2010)

of shallow lotic systems (Halder et al. 2014), whereas *A. calamus* grows on the margins of standing or slow-flowing water, typically in river backwaters, canal margins and the margins of ponds and lakes (Lansdown 2014). Both of these plants are readily available and easy to grow in marshy areas and have been used for remediation of various pollutants. Therefore, in order to explore their efficiency to treat landfill leachate, these plant species were selected.

Leachate treatment

In order to deduce the best concentration level for leachate treatment, untreated samples were treated with the *T. angustifolia* and *A. calamus* in three different modes viz. control (raw leachate), 1:1 dilution of leachate to tap water and 1:2 dilution of leachate to tap water along with the control using only tap water. Statistical analysis was performed using Student's *t* test (Microsoft Excel, 2010) between each of the treatment mode using standard settings in the software to check for the significance of the treatment for 48 h and 96 h of HRT respectively.

Wetland mesocosm

The experimental setup was polyethylene containers with dimensions of 49.5 cm × 32.5 cm × 22 cm ($L \times B \times H$). These containers were filled with river sand (5 cm depth) at the bottom and the top layer of garden soil (12 cm depth). The sample was introduced from the top of the container, and water logged conditions were maintained for the period of hydraulic residence time (HRT). The bottom part of

Fig. 2 Open dumping of MSW, UD, Pune, India

Fig. 3 Unscientific leachate pond at UD landfill, Pune, India

these containers had a control tap (outlet) to extract the samples as per requirement. The experiment was performed in triplicates using *T. angustifolia* and *A. calamus* in an open air laboratory (Figs. 4 and 5) resembling the landfill site. Every container contained pre-grown and acclimatised plants (six nos.), where *T. angustifolia* had an average shoot height and root length of 45.5 ± 6 cm and 20.1 ± 2.5 cm respectively. *A. calamus* had an average shoot height and root length of 21.1 ± 2.5 cm and 7.5 ± 1.2 cm respectively before they were subjected to the experiment.

Generally, the commercial waste water or leachate treatment units are operated on a shorter residence time with large influx of effluent. Similarly, at the landfill sites, the leachate is generated continuously. Hence, in order to simulate the field conditions, the HRT was maintained for 48 and 96 h, respectively.

Analytical methods

Immediately after sampling, the collected leachate was brought to the laboratory and refrigerated at temperature below 4 °C. BOD was estimated using the azide modification of Winkler method, while chemical oxygen demand (COD) was determined by open reflux digestion method. Hardness, alkalinity, Ca, and Cl^- were analysed by titrimetry methods (American Public Health Association (APHA) 2012). Na was determined by a flame photometer (Systronic - model no. 128). Total dissolved solids (TDS) and total suspended solids (TSS) were analysed as described previously (American Public Health Association (APHA) (2012)). Mg and trace element viz. Zn, Cu, Ni, Pb and Cr concentrations were determined by multispectral inductive coupled plasma–optical emission spectroscopy (ICP–OES) (model: SPECTRO ARCOS- config. FHM22).

Results

Leachate characterisation

The leachate sample was analysed for 18 physico-chemical parameters including the analysis of five heavy metals. The average leachate composition is shown in Table 2 along with the comparison with available literature and standards prescribed by the Government of

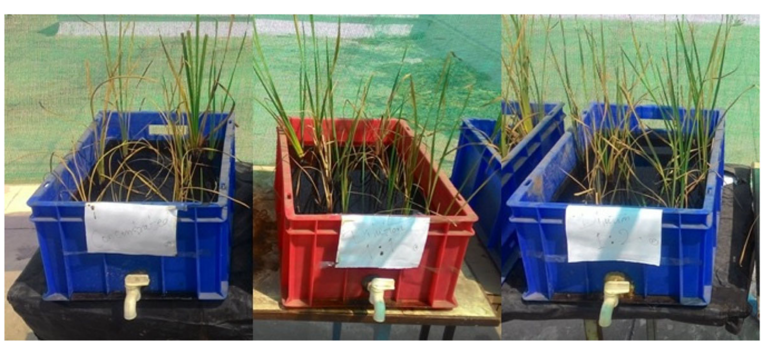

Fig. 4 Experiment setup for *T. angustifolia* [treated control, 1:1 dilution and 1:2 dilutions (left to right)]

Fig. 5 Experiment setup *A. calamus* [treated control, 1:1 dilution and 1:2 dilutions (left to right)]

India (GoI) under various rules and guidelines. The leachate composition shows variations since 2006 until now due to dumping of untreated mixed waste at the UD dumping site. Various leachate parameters viz. pH, Cl, TDS, hardness, Cu, Pb and Cr concentrations exceed the drinking water standards IS 10500:2012 (Bureau of Indian Standards (BIS) 2012) and parameters such as BOD, TDS, Ni, Pb and Cr against the standards for disposal of treated leachate (Ministry of Environment, Forest and Climate Change (MoEF& CC) 2016).

Treatment of landfill leachate using *T. angustifolia* and *A. calamus*

Both species showed potential to reduce various leachate constituents after 48 h and 96 h of residence time respectively (Tables 3, 4, 5 and 6 and Figs. 6 and 7). Statistical analysis (t test, p = 0.049–0.01) shows that the experiment results are significantly correlated suggesting effective leachate treatment using two plant species. *T. aungstifolia* showed higher potential for BOD (up to 56%), COD (up to 59%), hardness (up to 28%), TDS (up

Table 2 Leachate composition at the UD landfill site

Sr. no	Sample constituent	2016[a]	2008*[a]	2006#[a]	Standards mode of disposal—land disposal[b]	Drinking water specifications—acceptable limit[c]
1	pH	8.9	7.8	8.33	5.5–9.0	6.5–8.5
2	BOD	499	4.6	4122	100	AB
3	COD	897	36	6834	AB	AB
4	EC	3179	10,700	99,510	AB	AB
5	Hardness	10,000	2440	2200	AB	200
6	Alkalinity	1378	NA	2170	AB	200
7	Cl	213	4558	4485	600	250
8	TDS	2130	6848	11,800	2100	500
9	TSS	8929	NA	NA	200	AB
10	TS	11,059	NA	NA	AB	AB
11	Na	4439	3150	2550	AB	AB
12	Mg	2430	348	110.5	AB	30
13	Ca	4000	512	340.5	AB	75
14	Cu	2.66	NA	0.9	AB	0.05
15	Ni	3.31	NA	2.05	AB	0.02
16	Pb	1.44	NA	0.84	AB	0.01
17	Zn	4.66	NA	1.63	AB	5
18	Cr	2.65	NA	2.87	AB	0.05

NA data not available, *AB* range not provided
[a, b, c]All values are in milligrammes per litre, except pH and EC (in µS/cm). *Groundwater Surveys and Development Agency (GSDA) (2008); #Kale et al. (2010); [b]Ministry of Environment, Forest and Climate Change (MoEF& CC) (2016); [c]Bureau of Indian Standards (BIS) (2012)

Table 3 Pollution reduction potential of *T. angustifolia* (after 48 h of HRT)

Sr. no	Sample constituent	Mean value[a]			
		Raw leachate (pre-treatment)	Treated control	1:1 dilution	1:2 dilution
1	pH	8.9	7.4	7.2	7.1
2	BOD	499	373	153	111
3	COD	897	638	262	190
4	EC	3179	2654	2564	2546
5	Hardness	10,000	6956	5333	4304
6	Alkalinity	1378	599	403	363
7	Cl	213	172	157	134
8	TDS	2130	1752	1695	1588
9	TSS	8929	6225	3019	2179
10	TS	11,059	8136	4865	4012
11	Na	4439	4128	3985	3266
12	Mg	2430	1690	1296	1046
13	Ca	4000	2782	2133	1722

[a]All values are in milligrammes per litre, except pH and EC (in μS/cm)

to 9%), Na (up to 22%), Mg (up to 28%), Ca (up to 28%) and trace elements such as Ni (up to 18%) and Pb (up to 6%) whereas *A. calamus* showed higher reduction potential for alkalinity (up to 17%), chlorides (up to 3%) and trace elements viz. Cu (up to 15%), Zn (up to 8%) and Cr (up to 11%). Additionally, out of the two plants, *T. angustifolia* was found more robust and showed more resilience towards harmful components of the leachate.

Table 4 Pollution reduction potential of *A. calamus* (after 48 h of HRT)

Sr. no	Sample constituent	Mean value[a]			
		Raw leachate (pre-treatment)	Treated control	1:1 dilution	1:2 dilution
1	pH	8.9	7.3	7.1	7.1
2	BOD	499	409	360	304
3	COD	897	736	647	548
4	EC	3179	2614	2557	2550
5	Hardness	10,000	7246	6323	5365
6	Alkalinity	1378	584	394	356
7	Cl	213	158	140	128
8	TDS	2130	1911	1846	1765
9	TSS	8929	7218	4020	2390
10	TS	11,059	8970	5733	4098
11	Na	4439	4224	4014	3890
12	Mg	2430	1761	1536	1304
13	Ca	4000	2898	2529	2146

[a]All values are in milligrammes per litre, except pH and EC (in μS/cm)

Table 5 Pollution reduction potential of *T. angustifolia* (after 96 h of HRT)

Sr. no	Sample constituent	Mean value[a]			
		Raw leachate (pre-treatment)	Treated control	1:1 dilution	1:2 dilution
1	pH	8.9	7.3	7.1	7.1
2	BOD	499	310	101	77
3	COD	897	530	173	132
4	EC	3179	2596	2550	2543
5	Hardness	10,000	5247	4429	2886
6	Alkalinity	1378	466	246	187
7	Cl	213	158	145	128
8	TDS	2130	1685	1635	1533
9	TSS	8929	4666	2459	1859
10	TS	11,059	6405	4168	3562
11	Na	4439	3556	1860	1628
12	Mg	2430	1275	1076	701
13	Ca	4000	2099	1771	1154

[a]All values are in milligrammes per litre, except pH and EC (in μS/cm)

Discussion

The landfill site at village UD is being operated for more than 20 years. The leachate generated at the dump site is disposed without any scientific intervention, where it percolates to the local aquifer and contaminates the groundwater. The characterisation of leachate undertaken herein demonstrates its potential of impacting the soil quality and groundwater in the surrounding areas.

Table 6 Pollution reduction potential of *A. calamus* (after 96 h of HRT)

Sr. no	Sample constituent	Mean value[a]			
		Raw leachate (pre-treatment)	Treated control	1:1 dilution	1:2 dilution
1	pH	8.9	7.2	7.1	7.1
2	BOD	499	367	196	176
3	COD	897	661	353	316
4	EC	3179	2564	2543	2536
5	Hardness	10,000	6219	5788	3985
6	Alkalinity	1378	430	204	184
7	Cl	213	157	141	126
8	TDS	2130	1740	1704	1680
9	TSS	8929	5812	3970	3160
10	TS	11,059	7530	5673	4859
11	Na	4439	3789	2370	1762
12	Mg	2430	1511	1407	968
13	Ca	4000	2488	2315	1594

[a]All values are in milligrammes per litre, except pH and EC (in μS/cm)

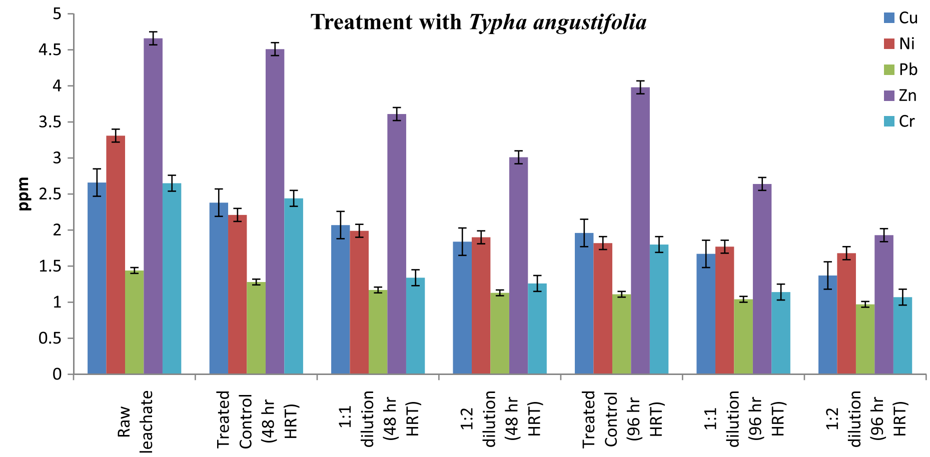

Fig. 6 Reduction of trace elements after treatment using *T. angustifolia* (48 h of HRT; error bars represent standard deviation; Student's *t* test, p = 0.049–0.01 and 96 h of HRT; error bars represent standard deviation; Student's *t* test, p = 0.049–0.01)

Therefore, it is necessary to scientifically design the landfill site to dispose of MSW and collection of hazardous leachate, which can be treated further and disposed without causing any harm to the environment. Remediation can be limited in case of plant application due to retention of chemicals on the soil particles. This may vary depending upon charge on soil and its respective adsorption dynamics. Further, the microbial consortium in leachate and soil may hinder or accentuate remediation in the wetland mesocosm.

Remediation potential of *T. angustifolia* and *A. calamus*

Pilot-scale application of *T. angustifolia* and *A. calamus* to treat landfill leachate demonstrates that both species were capable of reducing various pollutants from the leachate. The method provides a natural, cost-effective, low maintenance method to treat leachate. With appropriate pre-treatment of the leachate, both species would provide an effective alternative to the costly leachate treatment processes such as reverse osmosis. However, the process is slow and requires higher space for treatment as compared to commercial methods. During the experimentation, it was also observed that *T. angustifolia* is more robust and capable of withstanding heavy loads of contaminants even after 96 h of residence time as compared to *A. calamus*.

Conclusion

Direct disposal of untreated MSW landfill leachate on the open sites poses a serious threat to the community health and environment due to its harmful components. An appropriate landfill design would reduce the threat

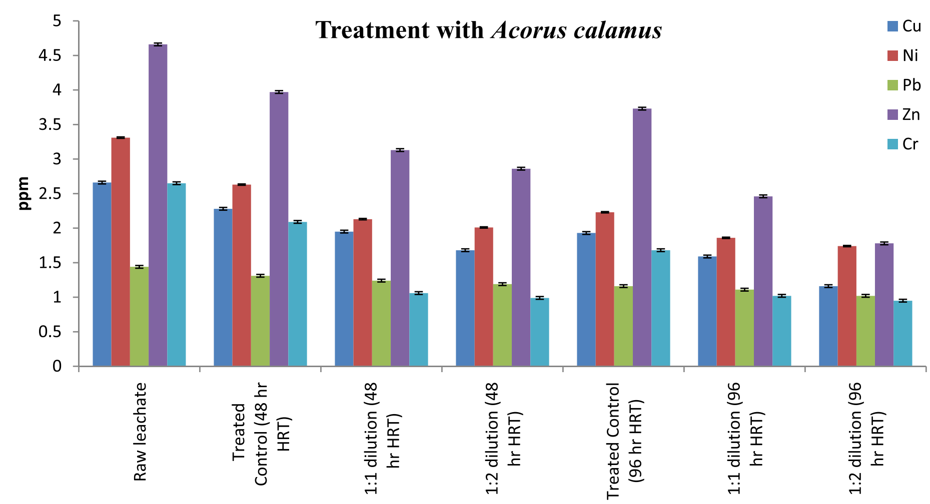

Fig. 7 Reduction of trace elements after treatment using *A. calamus* (48 h of HRT; error bars represent standard deviation; Student's *t* test, p = 0.049–0.01 and 96 h of HRT; error bars represent standard deviation; Student's *t* test p = 0.049–0.01)

of leachate pollution by collecting it scientifically, which is also essential for leachate remediation. Herein, we show that plants have potential and offer an eco-friendly alternative for leachate treatment. Application of *T. angustifolia* and *A. calamus* has shown positive results in reducing hardness, alkalinity and Cl along with trace elements such as Cu, Pb, Ni and Cr in the tested samples. *T. angustifolia* was more robust of the two species and could sustain longer HRT. These results highlight the remediation potential of these two species, and hence, in situ applicability of these plant species needs to be further explored.

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Availability of data and materials
The datasets during the current study are available from the corresponding author on reasonable request.

Authors' contributions
RVB and DBB formulated the idea, drafted the manuscript and wrote the final text. RVB and RDC performed the experiments, and RVB analysed the results. All authors read and approved the final manuscript.

Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable

Competing interests
The authors declare that they have no competing interests.

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