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Municipal Solid Waste Landfill Leachate Treatment by *Phragmites australis*, *Typha latifolia* and *Scirpus validus* through Constructed Wetlands

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ABSTRACT

A sustainable performance evaluation of pilot-scale was carried through horizontal sub-surface Constructed Wetlands system for treating the leachate from constructed Municipal Solid Waste Landfill at Institute of Environmental Engineering and Management, Mehran University of Engineering and Technology Jamshoro. The CWs were planted with *Phragmites australis, Typha latifolia* and *Scirpus validus* with sand and gravel. The leachate had been treated with two different cycles, first cycle was performed in the winter season whereas second cycle in summer, to differentiate the performance with seasonal variation. Chemical parameters of leachate pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids TSS, Ammonia-nitrogen (NH_3-N), Nitrate-nitrogen (NO_3-N), Total Phosphate PO_4^{3-} (TP) and heavy metals, Lead (Pb) and Copper (Cu) were tested with intervals of certain weeks. The tests result showed that all parameters experienced a considerable reduction in their concentrations. Significant reduction efficiencies were recorded for parameters, BOD with 53–82%, COD with 32–46%, TSS with 59–75%, NH_3-N with 90–92%, NO_3-N with 85–87%, and TP with 48–64%, and heavy metals Pb and Cu with 28–48% respectively in four weeks of the first cycle by all three plants. Whereas, in the second cycle, the removal efficiencies of BOD 78–93%, COD 63–76%, TSS 52–83%, NH_3-N 90–91% and NO_3-N 91–92% and heavy metals Pb and Cu with 21–58% respectively in five weeks were observed by all three plants. Along with the experimentation, United Nations Sustainable Development Goals UN SDGs are also highlighted. This study helps achieving tremendous SDGs accompanying treatment of leachate.

Keywords: MSW landfill leachate, contamination, CWs, phytoremediation, macrophytes, sustainability.

INTRODUCTION

From the last decade, the attention to environmental awareness has been increased, and the concern of governmental bodies around the world towards the treatment of environmental degradation and contamination has become the prior agenda. Mostly the suitable environmental remediation technique for particular type of waste is taken into the account on the basis of effectiveness of cost of the method and degradation process (Santos et al., 2021; Omandi et al., 2020).

With the economical and urbanization development, the increasing order of municipal solid waste (MSW) has also developed globally. A decade ago, urban residential population were 2.9 billion who were generating 0.64 kg of municipal solid waste MSW per capita (person) per day i.e., 0.68 billion tons per year. The report estimates that population has been increased to about 3 billion urban residents these days and waste generated is 1.2 kg per capita per day that is 1.3 billion tons per year. By 2025 this will likely increase 4.3 billion urban residents' population which will generate about 1.42 kg/capita/day of municipal solid waste that is 2.2 billion ton per year (World Bank 2022), which puts enormous pressure on global ecological system (Chabhadiya et al., 2021). Sanitary landfill and incineration are common techniques to obtain the harmless, recycling, and reduced disposal of MSW (Vyas et al., 2022). A considerable quantity of leachate is unavoidably generated, reaching 4–50% and 5–28.0% of the MSW volume during landfilling and incineration processes, respectively (Mirghorayshi et al., 2021; Lai et al., 2019; Grugnaletti et al., 2016). Some landfill leachate pollutants, largely XOCs (Xenobiotic Organic Compounds) (Wijekoon et al., 2022) and heavy metals pose adverse effects on food chain system and ecosystems causing acute and geno-toxicity and carcinogenic effects in human being (Gajski et al., 2012). The treatment of MSW leachate is challenging due to the complex pollutants like high-level ammonia (85–3000 mg/L), Biological Oxygen Demand (BOD) (500-10000 mg/L), Chemical Oxygen Demand (COD) (1000–60000 mg/L), excessive amount of sulphates, phosphates, DOC, and heavy metals increasing the risk of groundwater, surface water and soil contamination (Ma et al., 2022). The leachate is treated by different methods worldwide, like (i) biological methods (Aerobic Lagoon, Anaerobic Lagoon, Active Sludge etc), (ii) chemical and physical methods (Coagulation-flocculation, Reverse Osmosis etc.). These methods from the different studies are proved to be less effective because they are very much costly in terms of initial installation of plant equipment, energy requirements and use of expensive chemicals (Vymazal et al., 2021; Mojiri et al., 2013; Wan et al., 2016). Mainly, the environmental impact of these methods is adverse because in some remedial techniques the by-products of the treatment are more harmful than the actual contaminant (Santos et al., 2021; Teewno, A M, 2021). Also, these methods relay upon requirement of expensive chemicals and labor intensive (Younas et al., 2022). Thus, it is necessary to engage lower-cost, more efficient, and sustainable technologies.

Wetlands are considered one of the most effective among the pollutant's removal technologies that now attract the environmentalist for the treatment of leachate and contamination of wastewater (Omondi et al., 2020). CWs perform treatment of wastewater by employing a amalgamated action of microorganisms and plants in the physico-chemical environment of the wetland. The substrates are provided by the inlet of leachate required for the growth of microorganisms, shown in Figure 1. The principle in CWs for remediation of pollutants from leachate relay upon the usage of gravel, sand, wetland plants and microbial action (Dotro et al., 2012). The processes in the CWs are biodegradation, sorption, phyto stabilization, phytoextraction, and rhizofiltration (Donde et al., 2017; Van et al., 2018). Landfill leachates is treated through CWs using natural processes in degrading contamination; thus, it is an environmentally friendly remediation method with minimum detrimental environmental impact (Dan et al., 2011).

The CWs is one of MSW Leachate treatment processes. The types of CW are namely, free surface and sub surface, flow type wetlands. The subsurface flow wetlands are further divided into horizontal and vertical depending upon their flow pattern. These types depend on many mechanisms for pollutant removal like microbial breakdown of pollutants, plant uptake, retention, settling, filtrations, and adsorption. Pollutants removed include solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrates, phosphorous, microbes etc. The new research proves that the wetlands are biologically productive and support ecosystem (Ayesha et al., 2017).

MATERIAL AND METHODS

Experimental site

Three wetlands have been constructed and connected by the MSW Landfill system constructed by (Arif et al., 2014), besides the Institute of Environmental Engineering and Management, MUET Jamshoro. The system constructed was Sub-surface Flow Horizontal CW System due to its greater efficiency in the removal of leachate contamination (Picard et al., 2005; Pendleton et al., 2005). Figure 1 shows the design and dimensions of CWs. Each wetland is 6 feet long, 3 feet wide and 3 feet high. The leachate generated in the MSW landfill, coursed to CW through pipes. Percolated pipes were installed for leachate flow within the wetlands. The landfill leachate then stored into CWs for the further treatment.

Plant installation

Three types of plants, *Phragmites australis* (common reed), *Typha latifolia* (common cattail), *Scirpus validus* (soft stem bulrush) were used for this experiment due to their availability, sustainability and quality of removing the leachate contamination (Kaviat et al., 2013; Hazra et al., 2015;

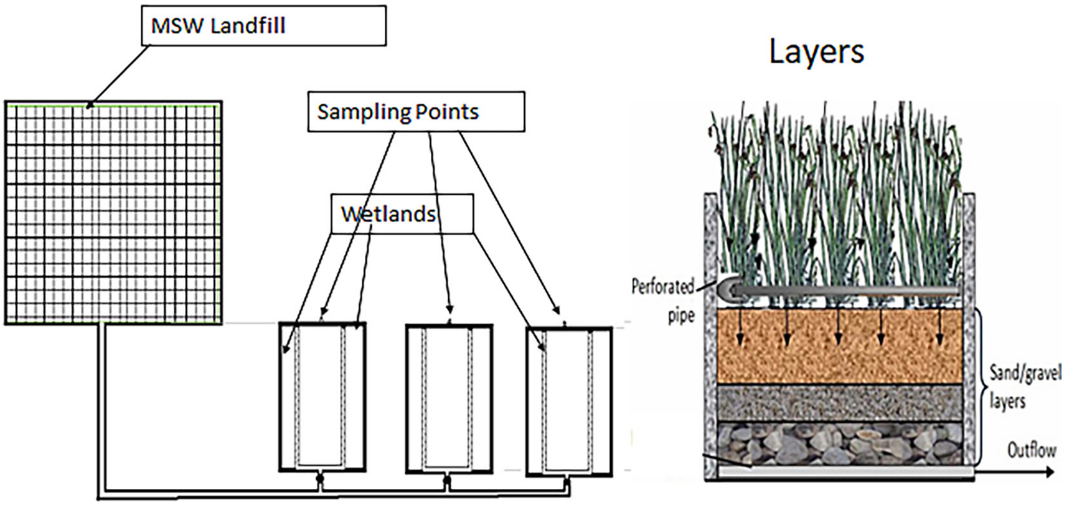

Figure 1. Design of MSW and CWs

Figure 2. CWs and installed plants respectively

Aweng et al., 2018). All three plants have been taken from different locations from the vicinity of Hyderabad Sindh Pakistan. Each of the plant installed to each wetland as shown in Figure 2.

Experimental procedure

The performance of the plants for pollutant removal was evaluated in two cycles in terms of leachate age. In the first cycle, the age of leachate was 8 months, is classified as young age leachate (El-Fadel et al., 2002) i.e.; from July 2020 to February 2021. Whereas the age of leachate was 22 months, is classified as young age leachate (El-Fadel et al., 2002), in the second cycle, i.e.; from July 2020 to May 2022. Purpose for running the different cycles is to observe the effect of climate and retention time for removal performance. The treatment performance of wetland was evaluated by determining the leachate treatment performance of selected plants.

Samples of untreated leachate from inlet and treated effluent from the outlet of each wetland were collected at the interval of 7 days and were analyzed in the laboratory. In the laboratory, physico-chemical parameters of sample were determined by different equipment according to the nature of contaminants. The performance of wetlands was determined through removal percentage of pollutant present in leachate by following equation.

$$Removal\ Percentage = \frac{Influent - Effluent}{Influent} \times 100 \quad (1)$$

Table 1. Parameters of leachate studied, their methods and equipment used

Parameters	Unit	Method	Equipment
pH		Electrode method	Digital pH meter
Chemical oxygen demand (COD)	mg/L	Closed reflux calorimetric method	COD Spectrophotometer
Biological oxygen demand (BOD)	mg/L	Winkler titration method	Titration
Total suspended solids (TSS)	mg/L	Spectrophotometer	DR2000 Spectrophotometer
Ammonia-nitrogen (NH_3-N)	mg/L	Kjeldahl Method	Distillation, Titration
Nitrate-nitrogen (NO_3-N)	mg/L	Spectrophotometer	DR2000 Spectrophotometer
Total phosphate (TP)	mg/L	Vanadomolybdate spectrophotometric method (APHA)	Spectrophotometer
Heavy metals (Lead Pb. Copper Cu)	mg/L	Direct Flame Absorption method	Atomic Absorption Spectrometer

Tested parameters

The chemical characterization of each sample has been tested in the laboratory. Table 1 enlists chemical parameters studied, their method and equipment used. The samples were taken from the site in plastic bottles and then analyzed in the laboratory.

RESULTS AND DISCUSSION

Chemical characteristics BOD_5, COD, Ammonia-nitrogen, TSS, Nitrate-nitrogen, TP, Pb and Cu of leachate have been treated through CWs. The overall performance of CWs was found satisfactory. Result of each of the parameter is discussed in detail.

Biological oxygen demand (BOD_5) and chemical oxygen demand (COD)

The literature states that in CWs, the primary ways of removing organic matter are through the settling of particles and filtration of colloidal organics, as well as the breakdown of organic matter by microorganisms in various aerobic, facultative, and anaerobic environment (Vymazal and Kröpfelová, 2009). The rhizosphere of plants contains many aerobic microorganisms which consume oxygen to decompose the organic matter (Chaturvedi et al., 2018). BOD and COD tend to be decreased due to photosynthesis process in plants. This process increases Dissolved Oxygen (DO) in water which creates the anaerobic condition that is favorable for aerobic bacterial activity and reduce the demand of oxygen (Singh et al., 2012). The mean removal percentage of BOD_5 examined in this study for the first cycle i.e., in the winter season shown in Table 3 and Figure 3 was 61–82%, 57–78% and 39–53% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. Whereas for the second cycle i.e., in summer season the mean removal percentage shown in Table 4 and Figure 4 was 67–93%, 60–90% and 52–78% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. The average mean values of influent and effluent of *Phragmites australis*, *Typha latifolia* and *Scirpus validus* respectively are shown in Table 2.

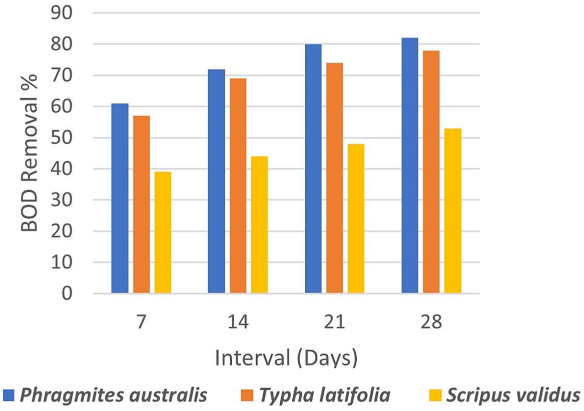

Figure 3. Graph of BOD_5 – first cycle between percentage removal and HRT

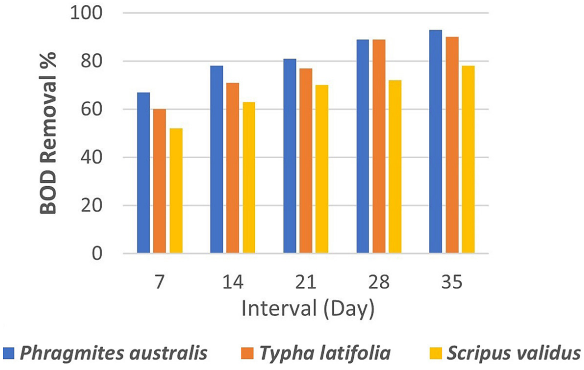

Figure 4. Graph of BOD_5 – second cycle between percentage removal and HRT

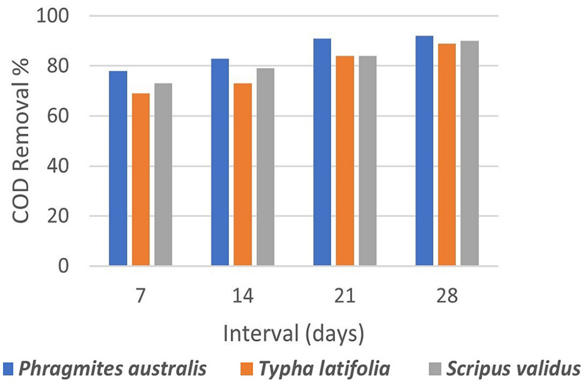

Figure 5. Graph of COD – first cycle between percentage removal and HRT

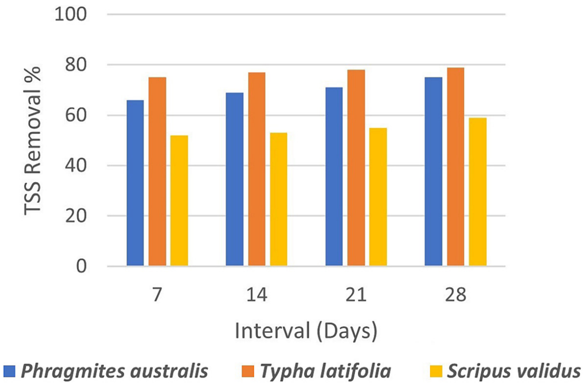

Figure 7. Graph of TSS – first cycle between percentage removal and HRT

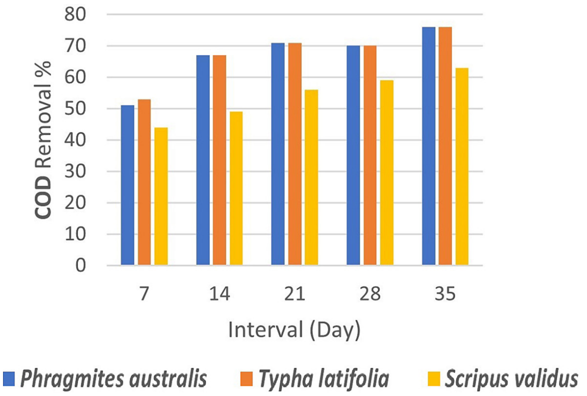

Figure 6. Graph of COD – second cycle between percentage removal and HRT

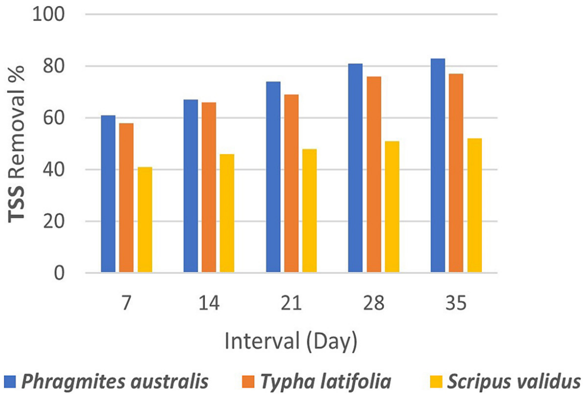

Figure 8. Graph of TSS – second cycle between percentage removal and HRT

The mean removal percentages of Chemical Oxygen Demand examined in this study for the first cycle i.e., in winter season shown in Table 3 and Figure 5 were 32–46%, 30–45% and 24–32% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. And for the second cycle i.e., in summer season the mean percentage shown in Table 4 and Figure 6 was 51–76%, 53–76% and 44–63% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. The mean values of influent and effluent of *Phragmites australis*, *Typha latifolia* and *Scirpus validus* respectively are shown in Table 2.

Results of this study compliance with a comparative study by (Bakhshoodeh et al., 2020) obtained the removal percentage of 60.1±17% for Horizontal Flow (HF) CWs. Another study by (Nivala et al., 2007) determined the removal efficiency of BOD_5 i.e., 88% and of COD is 35–60% with additional aeration system in the Horizontal Sub-Surface Flow CWs.

Total suspended solids

Total suspended solids (TSS) are the solid particles that are not dissolved. TSS is the dry weight of suspended particles. As all three plants have long hairy extensive roots and greater amount of dark brownish particulates were observed to be attached with them. The decrease in total suspended solids is due to the sedimentation, filtration and degradation or bacterial decomposition of organic matter (Yang et al., 2021). Results of this study found resemblance with the reduction values of (Bakhshoodeh et al., 2020). The mean removal percentages of TSS examined in this study for the first cycle i.e., in winter season shown in Table 3 and Figure 7 were 66–75%, 75–79% and 52–59% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. Whereas for the second cycle i.e., in summer season the mean percentage shown in Table 4 and Figure 8 was 61–83%, 58–77% and 41–52% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. The mean values of influent and effluent of *Phragmites australis*, *Typha latifolia* and *Scirpus validus* respectively are shown in Table 2.

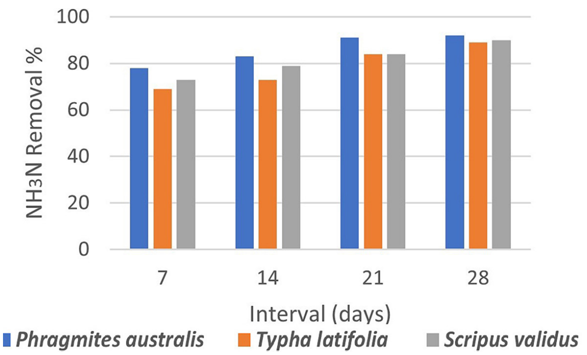

Figure 9. Graph of NH_3-N – first cycle between percentage removal and HRT

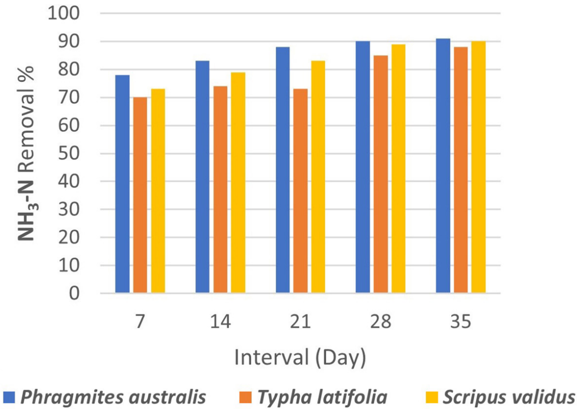

Figure 10. Graph of NH_3-N – second cycle between percentage removal and HRT

Ammonia nitrogen NH_3-N

Various processes are involved in eliminating ammonia from constructed wetlands. These include volatilization, nitrification (in the presence of oxygen), adsorption (which is not very effective), absorption by living organisms and plants, as well as anammox (in the absence of oxygen) (Dong and Sun, 2007). The decrease in ammonia nitrogen was due to the reason that ammonium ions and nitrogen were absorbed by plants through the root system (Yang et al., 2021). The decrease in quantity of ammonia nitrogen is due to nitrification-denitrification process (Harne et al., 2022).

Overall, the CW system removed sufficient amount of Ammonia Nitrogen, the mean removal percentages of Ammonia Nitrogen examined in this study for the first cycle i.e., in winter season shown in Table 3 and Figure 9 were 78–92%, 69–89% and 73–90% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. And observed removal performance for the second cycle i.e., in summer season shown in Table 4 and Figure 10 was 78–91%, 70–88% and 73–90% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively and exceeds the removal amount examined by the authors (Silvestrini et al., 2019; Cano et al., 2019; Yalcuk and Ugurlu, 2009). The mean values of influent and effluent of *Phragmites australis*, *Typha latifolia* and *Scirpus validus* respectively are shown in Table 2.

Nitrate nitrogen NO_3-N

The decreased NO_3-N value is due to denitrification by the micro-organisms (Wdowczyk et al., 2022). The NO_3-N is also absorbed by plants through the root system. The mean removal percentages of Nitrate Nitrogen examined in this study for the first cycle i.e, in winter season shown in Table 3 and Figure 11 were 71–87%, 63–79% and 58–85% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. Whereas for the second cycle i.e., in summer season the mean percentage shown in Table 4 and Figure 12 was 73–92%, 70–90% and 50–91% for

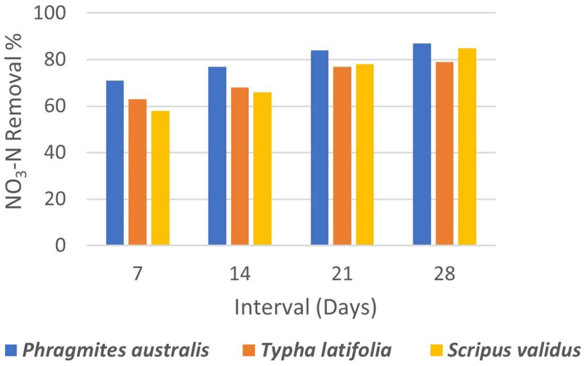

Figure 11. Graph of NO_3-N – first cycle between percentage removal and HRT

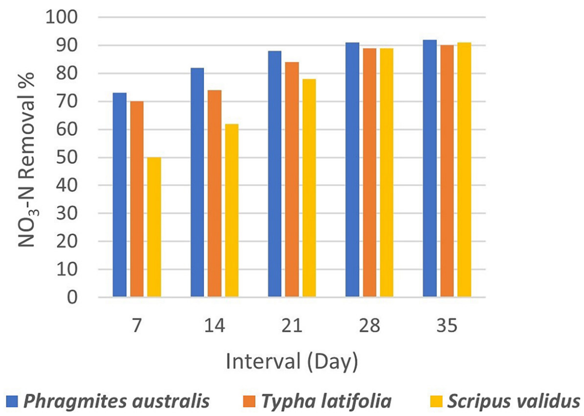

Figure 12. Graph of NO_3-N – second cycle between percentage removal and HRT

Phragmites australis, *Typha latifolia* and *Scirpus validus*, respectively. The mean values of influent and effluent of *Phragmites australis*, *Typha latifolia* and *Scirpus validus* respectively are shown in Table 2.

Total phosphate PO_4^{3-}

Studies have indicated that phosphorus elimination in CWs occurs mainly through chemical and physical-chemical processes involving sorption and precipitation, where Al, Fe, Ca, and Mg are the primary agents (Reddy et al., 1999; Drizo et al., 2000). Microbial removal is minimal as the uptake of phosphorus by microbiota is only transitory, and the uptake of phosphorus by macrophytes can be viewed as a "removal" mechanism only if the plants are harvested. If the macrophytes are not harvested, phosphorus is released back into the water when the biomass decomposes, and only a small amount of phosphorus is retained and becomes resistant to decomposition (Vymazal and Kröpfelová, 2008). During high growth of plants for building up their biomass, they need a high amount of phosphorus. Phosphorus is particularly required to protect the metabolism process (Tara et al., 2019).

The mean removal percentages of Phosphate examined in this study for the first cycle i.e., in winter season shown in Table 3 and Figure 13 were 42–64%, 44–59% and 33–48% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. The removal performance for the second cycle i.e., in summer season shown in Table 4 and Figure 14 was 38–50%, 32–48% and 40–48% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. Results of this study shows similarity with (Wdowczyk et al., 2022). The mean values of influent and effluent of *Phragmites australis*, *Typha latifolia* and *Scirpus validus* respectively are shown in Table 2.

Heavy metals lead (Pb) and copper (Cu)

The presence of consumer products such as batteries, plastics, ceramics and electronics

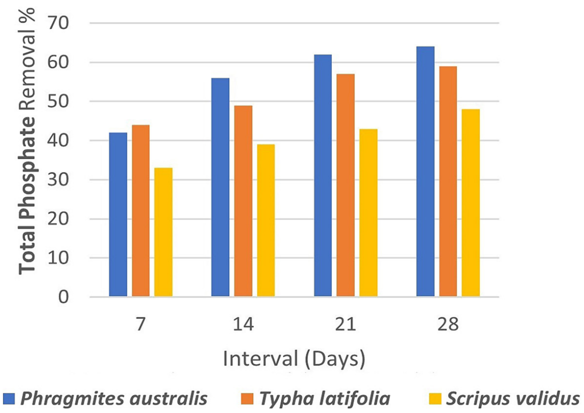

Figure 13. Graph of total phosphate – first cycle between percentage removal and HRT

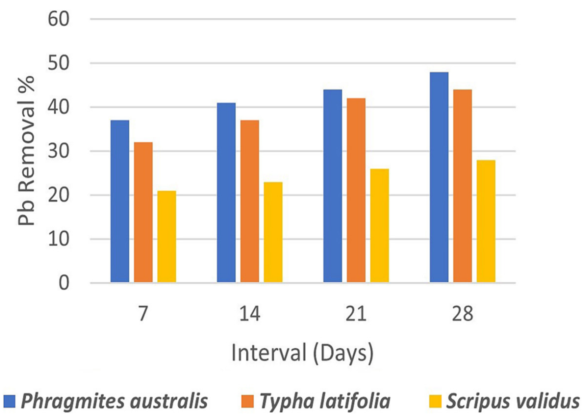

Figure 15. Graph of Pb – first cycle between percentage removal and HRT

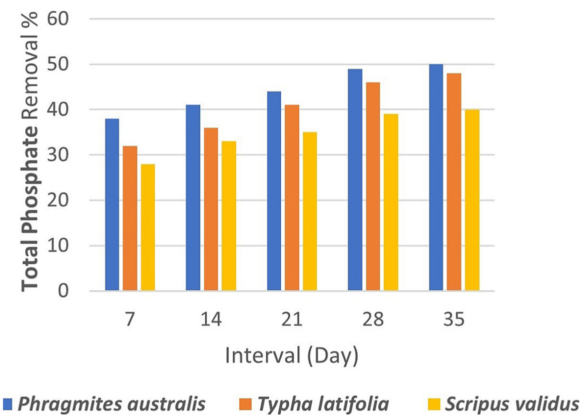

Figure 14. Graph of total phosphate – second cycle between percentage removal and HRT

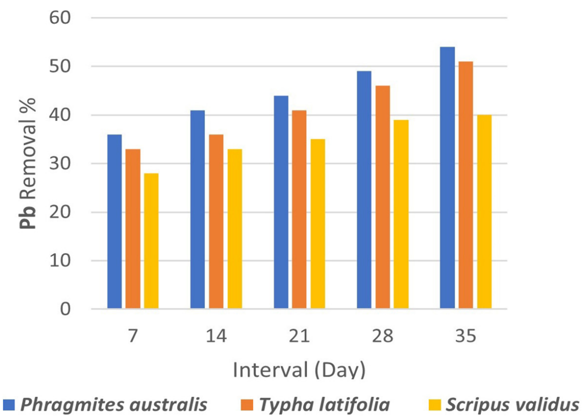

Figure 16. Graph of Pb – second cycle between percentage removal and HRT

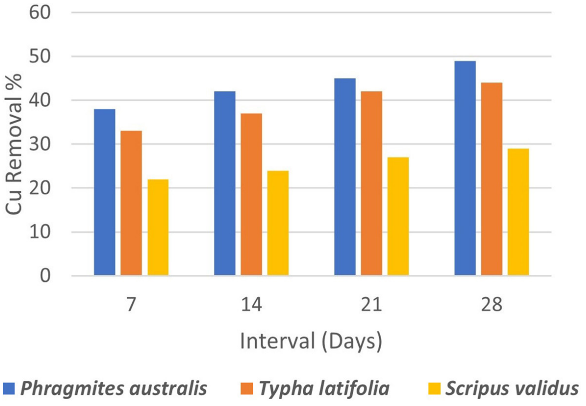

Figure 17. Graph of Cu – first cycle between percentage removal and HRT

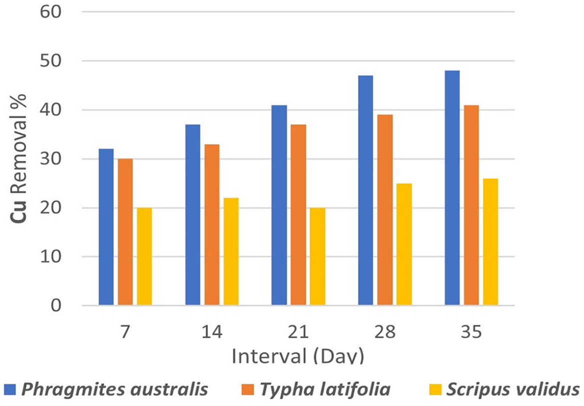

Figure 18. Graph of Cu – second cycle between percentage removal and HRT

in landfills leads to the entry of heavy metals into the landfill leachate. Various mechanisms are involved in the removal of heavy metals, including biological processes, chemical precipitation and co-precipitation, binding to organic matter, sorption onto soil and plant roots and filtration of suspended solids by root and soil systems (Kadlec and Wallace, 2009; Bakhshoodeh et al., 2016). Heavy metals are needed for the upkeep and growth of aquatic plants. The roots accumulate heavy metals and then translocate them to the shoots (Chan et al., 2022). The mean removal percentages of Pb and Cu examined in this study for the first cycle i.e., in winter season shown in Table 3, Figure 15 and 17 were 37–48%, 32–44% and 21–28% and 38–49%, 33–44% and 22–29% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. And that for the second cycle i.e.; in summer season the mean percentage shown in Table 4, Figure 16 and 18 was 36–54%, 33–51% and 28–40% and 32–48%, 30–41% and 20–26% for *Phragmites australis*, *Typha latifolia* and *Scirpus validus*, respectively. The mean values of influent and effluent of *Phragmites australis*, *Typha latifolia* and *Scirpus validus* respectively are shown in Table 2.

pH

In this experimentation of phytoremediation process of leachate, no such significant impact on the pH was observed except the slight change of values. The change observed in the effluent could possibly be due to the change in leachate characteristics shown in Table 2.

Table 2. Average mean value of each parameter in first and second cycle with respect to each plant i.e., *Phragmites australis, Typha latifolia, Scirpus validus*

Parameter	Unit	Before treatment		Average mean value after treatment					
		Average mean value of MSW landfill leachate		*Phragmites australis*		*Typha latifolia*		*Scripus validus*	
		Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2
pH		7.81	7.13	7.26	7.34	7.23	7.14	7.2	7.13
BOD_5	mg/L	530.8	1250.5	136	185.29	158	232.3	283	368.29
COD	mg/L	1940.2	4131	1126.5	1343	1168.2	1211	1328.7	1805.7
Total suspended solids	mg/L	890.5	1391.7	259	339.2	198	400.8	394.7	728.4
Ammonia nitrogen	mg/L	387.5	1189	52.5	139.1	79.7	231.4	69.4	170.7
Nitrate-nitrogen	mg/L	218	336.6	43.9	39.04	55.9	52.2	40.1	66.2
Total phosphate	mg/L	15.7	37.475	6.75	19.536	7.26	20.6975	9.12	22.9085
Lead	mg/L	1.24	2.375	0.69	1.24	0.73	1.32	0.91	1.48
Copper	mg/L	0.33	0.78	0.18	0.42	0.19	0.46	0.24	0.57

Table 3. Removal percentage of each parameter in first cycle time with respect to each plant i.e., *Phragmites australis, Typha latifolia, Scirpus validus*

Parameter	Time (week)											
	1	2	3	4	1	2	3	4	1	2	3	4
	Phragmites australis removal %				*Typha latifolia* removal %				*Scripus validus* removal %			
BOD$_5$%	61	72	80	82	57	69	74	78	39	44	48	53
COD %	32	38	44	46	30	35	41	45	24	29	31	32
Total suspended solids %	66	69	71	75	75	77	78	79	52	53	55	59
Ammonia nitrogen %	78	83	91	92	69	73	84	89	73	79	84	90
Nitrate-nitrogen %	71	77	84	87	63	68	77	79	58	66	78	85
Total phosphate %	42	56	62	64	44	49	57	59	33	39	43	48
Lead %	37	41	44	48	32	37	42	44	21	23	26	28
Copper %	38	42	45	49	33	37	42	43	22	24	27	29

Table 4. Removal percentage of each parameter in second cycle time with respect to each plant i.e., *Phragmites australis, Typha latifolia, Scirpus validus*

Parameter	Time (week)														
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Phragmites australis Removal %					*Typha latifolia Removal %*					*Scripus validus Removal %*				
BOD$_5$ %	67	78	81	89	93	60	71	77	89	90	52	63	70	72	78
COD %	51	67	71	70	76	53	67	71	70	76	44	49	56	59	63
Total suspended solids %	61	67	74	81	83	58	66	69	76	77	41	46	48	51	52
Ammonia nitrogen %	78	83	88	90	91	70	74	73	85	88	73	79	83	89	90
Nitrate-nitrogen %	73	82	88	91	92	70	74	84	89	90	50	62	78	89	91
Total phosphate %	38	41	44	49	50	32	36	41	46	48	28	33	35	39	40
Lead %	36	41	44	49	54	33	36	41	46	51	28	33	35	39	40
Copper %	32	37	41	47	48	30	33	37	39	41	20	22	20	25	26

CONCLUSIONS

An attempt was made to evaluate the performance efficiency of constructed wetland with *Phragmites australis*, *Typha latifolia*, *Scirpus validus* in MSW landfill leachate. The tests result showed that all parameters experienced a considerable reduction in their concentrations. Sufficient reduction efficiencies were recorded for parameters, BOD with 53–82%, COD with 32–46%, TSS with 59–75%, Ammonia Nitrogen with 90–92%, Nitrate with 85–87%, and Total Phosphate with 48–64%, respectively in four weeks of the first cycle by all three plants. Whereas, in the second cycle, the removal efficiencies of BOD 78–93%, COD 63–76%, TSS 52–83%, Ammonia Nitrogen 90–91% and Nitrate 91–92%, respectively in five weeks were observed by all three plants. The removal efficiency of *Typha latifolia* and *Phragmites australis* was correlatively equal whereas the *Scripus validus* was proved to be less efficient in BOD, COD, TSS, and TP. The removal efficiencies by plants were greater in percentage in the second cycle than in the first cycle, the possible factor responsible for this is temperature. The second cycle observation was conducted in May 2022 in a recorded temperature of 35–40 °C. High temperature active plant growth and increase transpiration losses during active plant growth. It was also observed that for a longer hydraulic retention time HRT, there was a higher percentage reduction.

Phytoremediation of the landfill leachate found to be most environmentally friendly treatment as this study achieves 7 Sustainable Development Goals out of 17 SDGs. Also, from the overall performance of the Sub-surface Flow Horizontal Constructed Wetland System, it was established that the method was efficient in removing a significant percentage of the parameters tested from the leachate sample.

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