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Efficiency of *Canna Indica*, *Phragmites Australis* and *Eichhornia Crassipes* in Remediation of Leachate Through a Vertical Flow Constructed Wetland

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Abstract

Leachate treatment and disposal from landfills is one of major environment concern. Leachate contains various pollutants which may cause various environmental and health problem to terrestrial and aquatic living bodies. In the Present study, Landfill leachate was collected from Okhla landfill, New Delhi and treatment of leachate was done by using laboratory scale vertical flow treatment grown with *Canna indica*, *Phragmites australis* and *Eichhornia crassipes*, respectively. The experimental plots were obtained by set up of four different flow rates by balancing the inflow manipulations to obtain detention times of 1,7,14 for 21 days. The reduction of COD, BOD, NH4-N, TSS and heavy metals (Cd, Cu, Co, Cr, As, Pb, Ni, Fe, Zn and V) were investigated for 21 days. Average removal efficiency (%) for VCW (W1) planted with *Canna indica* showed 77.7%, 78.7%, 63.6%, and 76.7% for COD, BOD, NH4-N and TSS, respectively. Heavy metal removal (%) efficiencies of W1 planted with *Canna indica* was 60%, 82.5%, 100%, 29.37%, 27.9%, 62.67%, 13.33%, 44.5%, 75.2% and 78.85% for As, Cr, Cd, Cu, Co, Fe, Mn, Pb, Zn and V, in given order. VCW(W2) planted with Eicchornia crassipes species has shown reduction efficiency (%) of COD (68.5%), BOD (52%), NH4-N (45.4%), TSS (92.75%), respectively and in case of heavy metal 89.9% Cr, 100% Cd, 53.49% Cu, 62.7% Co, 85.2% Fe, 67.9% Ni, 76.2% Pb, 83.08% Zn, 65% As and 61.15% V, respectively. VCW (W3) planted with *Phragmites australis* exhibited removal efficiency (%) of COD (68.5%), BOD (52%), NH4-N (45.4%) and TSS (92.7%), respectively. *Phragmites australis* was able to remove As (100%), Cd (100%), Cr (89.9%),

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Cu (53.49%), Co (62.7%), Fe (85.82%), Ni (67.9%), Pb (76.2%), V (61.15%) and Zn (83.08%), respectively. All the three species were able to remove Cd (100 %). However, *Canna indica* (W1) has highest removal efficiencies (%) of COD (77.7%), BOD (78.7%) and NH4-N (63.6 %), respectively. Eicchornia crassipes has highest reduction efficiency (%) of TSS (92.75%), Cr (89.9%), Cd (100%), Cu (53.49%), Co (62.7%), Fe (85.2%), Ni (67.9%), Pb (76.2%) and Zn (83.08%), respectively. *Phragmites australis* was found good for removal of As (100 %) and Cd (100%). The result highlighted that these plant species can be used as single in lab scale Constructed wetland for the treatment Organic pollutants and heavy metals from landfill leachate.

Introduction

Generation of leachate from municipal solid waste landfill is unavoidable, therefore, treatment of landfill leachate is required to minimize the strength of pollutants in leachate. Presently one of major environmental concern of landfill site is leachate as it contains various pollutants which may cause various environmental and health problem to terrestrial and aquatic living bodies. Municipal solid waste landfill leachate contain substantial amount of organic and inorganic pollutants, heavy metal, chlorinated organic compound, highly salinity and other pollutants, which can deteriorate the land, surface water and ground water.[1,2,3] Due to variation in leachate specific characteristic both quality and quantity which create treatment of leachate an environmental issue and disposal of leachate after treatment should meet the set standard with make it cost effective.[47] However, only well scientific design sanitary landfills can give a solution to these adverse impacts.[2]

Various treatment method such as physical, chemical and biological are available, but biological treatment methods are preferred in most of the cases. Constructed wetlands are considered as the most in demand cost-effective scientific technology giving in-situ treatment to landfill leachate.[4] There are different biological methods and the constructed wetlands (CWs) as an engineered systems that uses natural processes to remove contaminants from wastewater.[12] Constructed wetlands (CWs) are successfully eliminates contaminants through three processes that is biological, physical and synergistic relationship between chemical, microorganisms, plant growth, and substrate properties at the end organic matter is transformed into carbon dioxide and methane.[5,6]

Constructed wetlands are one of the biological method, in which phytoremediation of polluted liquid treatment takes place, which is a bioengineering method that uses natural medium to remove pollutants from wastewater in CWs such as phyto-desalination, phyto-volatilization phyto-filtration, phyto-extraction, phyto-stabilization, and phyto-degradation.[7]

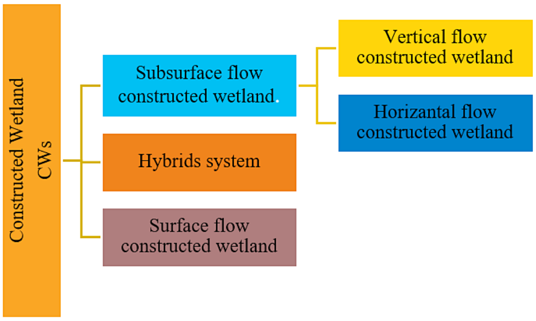

Fig. 1: Classification of Constructed Wetlands (CWs)

Constructed wetlands may be categorized into three main types of constructed wetlands are as shown in Fig 1.[8] Remediation of leachate was done by [9] using constructed horizontal, vertical and integrated *Typha lantifolia* as vegetation based on pot culture experiment with varying dilution levels. Vertical flow wetlands are mostly used as the primary stage for removal of NH_4-N and other toxic metals from leachate[10, 11, 12] had used mesocosm scale vertical flow wetland studied that most efficient species for removal of NH_4-N and COD, Cr, Ni, Zn with vegetation such as Typha domingensis and *Canna indica*. Outcome of *Typha lantifolia* and *Canna indica* on reduction of NH_4-N, orthophosphate and COD occurred in leachate was studied by.[13]

Tables: 1 Single and mixed plant species used for studies by various researcher. Source (References)

Plant species used	% Pollutant removed	References
Canna indica	COD (83.6%), PO4 (48.66%), NH4-N (62.84%),TSS (87.77%)	Yalcuk and Ugurlu 2020
Typha lantifolia	COD (65%), NH4-N (94%)	Silvestrini *et al*. 2019
Phragmites australis	Fe (99%), Zn (99%), Ni (98%), Cr (97%), Cd (87%), Mn (49–99%), Pb (92%).	Dan *et al*., 2017
Phragmites australis, Canna indica, Typha lantifolia	Ni (57.14%), BOD (57%), COD (56%) Cu (40%), Cr (32.14%)	Ali *et al*., 2018
Eichhornia crassipes	TSS (97.43%),	Kamarudzaman *et al*. 2013
Eichhornia crassipes	Zn (85.5%), Pb (52.5%), Ni (26.30%), Cu (47.59%), Cr (56.39%), Cd (48.52%).	Odjegba and Fasidi (2007)

Removal of toxic pollutants like Cr, Cd, Mn, Fe, Pb, Ni, Pb, and Zn from artificial leachate[14] reported that three day hydraulic residence time was utilized in the sequencing batch VFWs. Concentrations of metals in leachates of matured landfills are usually less than those of young landfills.[15]Vertical flow constructed wetlands planted with *Canna indica* in which metals were successfully kept by macrophytes in its roots and were significantly higher than in shoots.[16]

The current analysis was performed to analyze the potential of the laboratory scale vertical constructed wetland to remediate high organic pollutants such as (COD, BOD, NH_4-N, TSS) and heavy metals like (As, Cr, Co, Fe, Cd, Mn, Ni, Pd, Zn, V) and to investigate the performance of the systems grown with *Canna indica*, *Phragmites australis* and *Echhornia crassipes* in vertical constructed wetland (VCW) W1, W2, W3 systems. Furthermore, also investigated pollutant removal efficiency of three different macrophyte species of plants. These three plants species such as *Canna indica*, *Phragmites australis* and Echhornia crass *Echhornia crassipes* ipes were easily available and have good records of removal of contamination from waste water.

Material and Methodology

Experimental Design

The samples of leachate were collected from the Okhla Landfill located at South east Delhi, India. Around 2000 metric tons of municipal waste and construction and demolition waste are dumped into this landfill. The site is located at 28°30'40.05"N, 77°17'4.47"E of latitude and longitude which is located at Tughlagabad just close to ESIC hospital, Delhi, India. This site was commissioned in 1994 and operationalized in year of 1996 and had completed its commission date in 2018 but still receiving unsegregated solid waste along with construction and demolition waste from four zones (South, West, Central and Najafgarh) of South Delhi without any attention on segregation.[17] Around 2000 tonnes of wastes on an average are dumped into Okhla landfill every day. Various types of wastes dumped at Okhla landfill includes plastic wastes, domestic wastes, vegetable market wastes construction wastes, and unauthorized industrial wastes. A huge density of 1200 kg/m^3 wastes is contributed to the high volumes of construction cum demolition wastes and from the inert wastes18. Details are lacking for the estimated leachates that are generated at this landfill due to unscientific landfilling (without outliner, leachate collection and gas trapping facilities).

Sampling was done in the year 2021-22 and collected leachate samples were promptly transferred to the laboratory and were preserved in ice boxes till the analysis started. The leachate used in the study was made less concentrated with tap water in the dilution ratio of 1:2 because raw leachate could not be tolerated by plants as leachates are highly toxic. The experimental plots are set up in three (3) Polyvinyl Chloride (PVC) containers having a part inlet, outlet and the vegetation. These are filled up with porous media dominated by gravel 4 cm with diameter 12-20 mm and then Sand 3 cm of 2 mm. The uppermost layer of wetland was filled with garden soil 2cm to support the macrophytes to properly grown, in which macrophytes plant collected from Yamuna Biodiversity Park, Bank of Yamuna River and local area such as *Canna indica*, *Phragmites australis* and *Eichhornia crassipes* are planted in each vertical constructed wetland name as W1, W2 and W3. In each VCW seven (7) fresh seedling of above mentioned species were planted and let them to adapt for two months before treatment of the leachate. Plants are main component in the designing of constructed wetland.Vegetation have various attributes linked to the activity in constructed wetland.[19]

The length, breadth and depth of wetland unit was 55cm × 35cm × 25 cm. The experimental unit was constructed with slight slope of 1% between influent and effluent zones. A mild inclination was given to the system to ensure free flow of leachate from inlet to outlet and to avoid the backflow. Four different flow rates through the experimental plots were noted to obtain with a detention times of 1,7,14 for 21 days. At single detention time from the samples were taken from the input and output unit in accordance with this time so as to capture the same volume of leachate in and out flow. The samples taken out from outlets were analyzed in a laboratory according to APHA 2017 Standards. At each detention time various Parameters such as COD, BOD, NH4-N, TSS and heavy metal Cu, Cr, Co, Mn, Fe, Pb, Ni, As, Cd, V, Zn were tested. Besides some other metals like Se and Sb were also analyzed in this study.

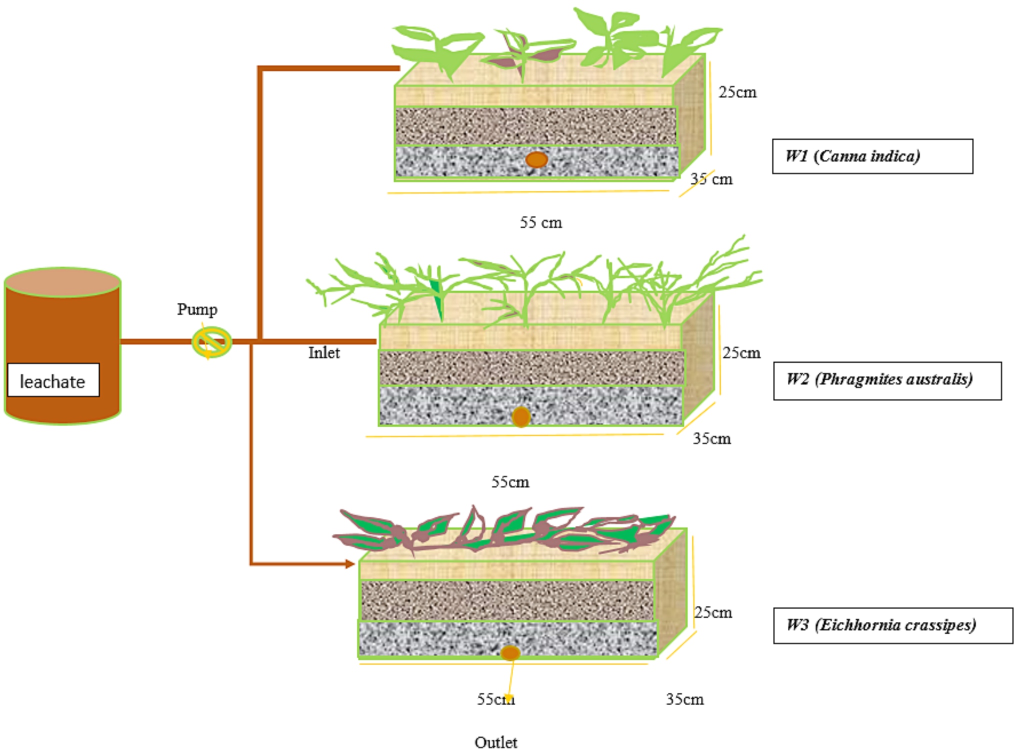

Fig. 2: Diagrammatic representation of Vertical constructed wetland (W1, W2 and W3)

The investigation was carried out in an external environment with the temperature 25º Celsius. It is noted as intense solar radiation, and no wet season. The samples used for treatment was 20 litres in cans and weather condition at that time was dry. Five different plant species were selected to investigate their efficiencies in the treatment of leachate in the vertical constructed wetland and also compared for their efficiencies among the three species of plants. These artificial experimental setups with three different plants were experimented along with a control set up established for comparison purpose with Macrophytes in place of plants in pollution reduction. These artificial experimental setups with three different plants were experimented along with a control set up established for comparison purpose with macrophyte in place of plants in pollution. The experiment was continued till the plants species showed some kind of Senescence, aging, chlorosis, pest attract.

Analytical Methods

Samples of leachates for physiochemical parameter including heavy metals such as pH, TDS, COD, BOD and NH4-N analysis were performed by adopting the standard methods, APHA (2017).

Heavy Metal

Heavy metals such as As, Cd, Cu, Cr, Ni, Co, Zn, Fe, Mn and V in leachate samples were determined by using Induced Coupled Plasma-Atomic Emission Spectrophotometer (CCP-AES) (Make- Perkin Elmer) as per Standard Methods, APHA (2017).

Calculation

Removal Efficiency (%) = (Pollutants removed / Initial pollutants ×100%

Data Analysis

The results of analyses of selected physicochemical parameters and heavy metal of leachates characterized by the Mean, Standard Deviation and one way Anova using MS excel 2016. Statistical significance were tested at P <0.05.

Result and Discussions

In the present research, the efficiency of different plants used in vertical constructed wetland for remediate of leachate samples collected from Okhla dumpsite, Delhi was studied in detail. The influent and effluent was analyzed and result along with removal efficiency were presented in Table 2, 3, 4, and 5. The observations of the study related to physical and chemical properties including heavy metals were given in Figs. 3, 4, 5, 6,7,8,9.

COD Removal

In the current analysis, the initial concentration of COD in the vertical constructed wetland sample was 54000 mg/L and after 21 days of treatment, COD value was reduced to 12187.8mg/L in the sample of Vertical constructed wetland (W1) grown with *Canna indica*, 30418.2 mg/L in Vertical constructed wetland vegetation with *Phragmites australis* (W2), 16999 mg/L concentration in constructed wetland planted with *Eichhornia crassipes* (W3). The reduction in average concentration of COD from (VFCW) vertical flow constructed wetland such as W1, W2, W3 were 77.43%, 43.67%, 68.52%, respectively (Table 2 and Fig. 3).

In the study, it was observed that (VFCW) planted with *Canna indica* has high removal COD efficiencies followed by, *Eichhornia crassipes*, *Phragmites australis* and significance difference was found in concentration reduction. As studied by 20 it was observed that average COD removal efficiencies (%) *Canna indica* 84% flow rate of 5l/day of 22days, respectively. From the observations it was reflected that maximum reduction in COD was done by *Canna indica* (77.4%) and minimum reduction was found by *Phragmites australis* (43.67 %,). Likewise[21] found Vertical constructed wetland planted with plants having high COD removal potential than unplanted.[13] was also found that oxygen necessary for aerobic decomposition could enter the wetlands through the system, and the primary mechanism for removing COD was physical, such as substrate filtration, rather than biological processes related to plants activity. Some other studies observed that plant don't affect COD reduction.[22, 23] According to[24] Vertical constructed wetland grown with *Phragmites australis* achieved 94.69%. COD reduction efficiency.

In the present studies Vertical flow constructed wetland (W3) planted with *Phragmites australis* achieved 43.67% of removal efficiencies. Insignificant removal efficiencies as compared to studied by 24. 3.2. Removal of BOD: - In the present study the initial concentration of BOD in vertical flow constructed wetland (VFCW) samples was 24000 mg/L and after 21 days, concentration was reduced to 5232 mg/L from vertical flow Constructed Wetland (W1) planted with *Canna indica*, 8292 mg/L in Vertical constructed wetland (W2) nurtured with *Phragmites australis*, 11520 mg/L in Vertical constructed wetland (W3) planted with *Eichhornia crassipes*. The reduction in average concentration of BOD from vertical constructed wetland such as W1, W2, W3 were 78.4%, 65.45%, and 54.32 % respectively as shown in table 2 and fig 4.

In the study it was observed that vertical flow constructed wetland planted with *Canna indica* has highest removal efficiencies followed by *Phragmites australis* and *Eichhornia crassipes*. Significance difference was found in concentration reduction as shown in table 2 and in fig. 3 respectively. As reported by [10] reduction of BOD will occur when bacteria decompose the organic matter occured in leachate and removal of BOD will be achieved, which was also evaluated that high temperature contributed in high BOD of leachate sample than cold. *Canna indica* plant have both proliferation and biomass, which can boost microbial activity by expanding the surface area for biofilm growth and increasing oxygen availability [25, 24] Lavrova reported that *Phragmites australis* having well developed rhizomes and has significant removal efficiency of BOD (95.96 %) in vertical constructed wetland. However in the present study 65.45% of BOD was removed in VCW planted with *Phragmites australis*.

Removal of NH4-N

In the present study, the initial amount of NH4-N in vertical flow constructed wetland samples was recorded as 440 mg/ land after 21 days of treatment and the concentration was reduced to160.82 mg/L in constructed wetland (W1) planted with *Canna indica*. In vertical constructed wetland (W2) planted with *Phragmites australis* 200.37 mg/L, in vertical constructed wetland W3 planted with *Eichhornia crassipes* 240.02 mg/L shown in table 1 fig 4. The reduction in NH4-N average concentration of from vertical constructed wetland such as W1, W2, W3 were 63.5%, 54.46%, and 45.45 % respectively as shown in table 2 and fig. 5.

n the study it was observed that vertical constructed wetland planted with *Canna indica* has high NH4-N removal efficiencies followed by, *Phragmites australis*, and *Eichhornia crassipes* respectively. There was in significant difference in percent reduction efficiencies among the vertical constructed wetland W1, W2, W3. As studied by 13 removal of NH4-N (Ammonical nitrogen) from landfill leachate is very significant as it is found in high concentration in leachate and in Vertical constructed wetland (VCW) removal of nitrogen take place as plant absorb nitrification ammonia volatilization denitrification and cation exchange. As[26] stated that most widely nitrogen removal by bacterial nitrification and denitrification.

In the present study *Canna indica* has high removal efficiencies than other plant species. As per [27] *Canna indica* have a microbial activity by supplying more aerobic condition because of its rapid growing nature with well grown roots which are suitable for the nitrification.54.46% in concentration of NH_4-N was removed in VCW planted with *Phragmites australis* but as studied by[28] planted with *Phragmites australis* NH_4-N 96%-99% with different filling. 13 observed that average % NH_4-N removal efficiencies of *Canna indica* 56.0% flow rate of 5l/day of 22 days respectively, however in present study 63.5% of NH_4-N was reduced in VCW planted with *Canna indica*.[29] reported that root of the plant help in reduction of NH_4-N in VCW nitrification and root of the plant help in reduction of NH_4-N in vertical constructed wetland.

Low Ammonical nitrogen (NH_4-N) removal reason may be the presence K^+, Na^+, Ca^{2+} and Mg^{2+} which inhibit Ammonical nitrogen adsorption. As per [30,31] reduction Ammonical nitrogen of (NH_4-N) from landfill leachate the plant play important act in transformation of nitrogen when constructed wetland function for more than zero day hydraulic retention day also found that as Ammonical nitrogen (NH_4-N) Ammonical nitrogen) reduction took place then plant speed up the process in plant cell. As reported by [32] constructed wetland method for removal of Ammonical nitrogen (NH_4-N) giving double facilities in one cell to process both the denitrification and nitrification in same area. Nitrification and root of the plant help in reduction of NH_4-N in VCW.[33, 34] Comparison between different plant such as *Canna indica* and *Phragmites australis* by [35] the occurrence of *Canna indica* in wetland beds can boost NH4–N removal, leading to increased aerobic condition, whereas *Phragmites australis* may have lesser effect on enhancing aerobicity during NH_4-N removal. The prominent presence of *Canna indica* was observed by [35] in vertical flow constructed wetland.

TSS Removal

In the present study The initial TSS concentration in the vertical constructed wetland was reached 2700 mg/L and after 21 days of remediation phase the TSS concentration was reduced to 628.02 mg/L in vertical constructed wetland planted with *Canna indica*, 216 mg/L in vertical flow constructed wetland cultivated with *Phragmites australis*, 196.02 mg/L in samples of vertical constructed planted with *Eichhornia crassipes*, respectively also as depicted in table 1 and figure 5. The reduction in mean concentration of TSS from (VFCW) vertical flow constructed wetland such as W1, W2, W3, were 76.74%, 92%, and 92.74% as shown in fig 6. respectively.

In the study it was observed that the Vertical flow constructed wetland planted with *Eichhornia crassipes* has high removal efficiencies than those followed by *Phragmites australis* and *Canna indica*. In vertical constructed wetland processes such as sedimentation and filtration support in reduction of TSS[20] and root section of aquatic plants play a primary role and contribute in the degradation of organic matter reduction in Vertical constructed wetland.[36]

Table 2: Percent leachate pollutants removal efficiency of plant species in a Vertical constructed wetland. (Mean ± SD)

Plants & Selected Pollutants	Initial conc. (mg/L)	Post treatment Final concentration after 21 days (Three weeks)							
		24hr		7day		14 day		21day	
1.Canna indica									
	Mean±SD	mg/L	% Reduction	mg/L	% Reduction	mg/L	% Reduction	mg/L	% Reduction
COD	54000±300	17998.2	66.67	14029.2	74.02	12776.4	76.34	12187.8	77.43
BOD	24000±100	8640	64	7200	70	5839.2	75.67	5232	78.4
NH4-N	440±20	264	40	176	60	174.02	60.45	160.82	63.45
TSS	2700±10	793.26	70.62	744.12	72.44	702	74	628.02	76.74
2.Phragmites australis									
COD	54000±300	35996.4	33.34	32275.8	40.23	31001.4	42.59	30418.2	43.67
BOD	24000±100	15705.6	34.56	12960	46	10430.4	56.54	8292	65.45
NH4-N	440±20	203.98	46.36	226.33	48.56	209	52.5	200.37	54.46
TSS	2700±10	931.5	65.5	648.54	75.98	464.13	82.81	216	92
3.Eichhornia crassipes									
COD	54000±300	27999	48.154	26816.4	50.34	24175	55.23	16999	68.52
BOD	24000±100	21600	10	14400	40	12720	47	11520	52
NH4-N	440±20	300.08	31.8	253.704	42.34	250.8	43	240,02	45.45
TSS	700±10	740.07	72.59	405	85	244.08	90.96	196.02	92.74

Statistical significance $P<0.05$ there is statistical significance among the plants used for leachate treatment.

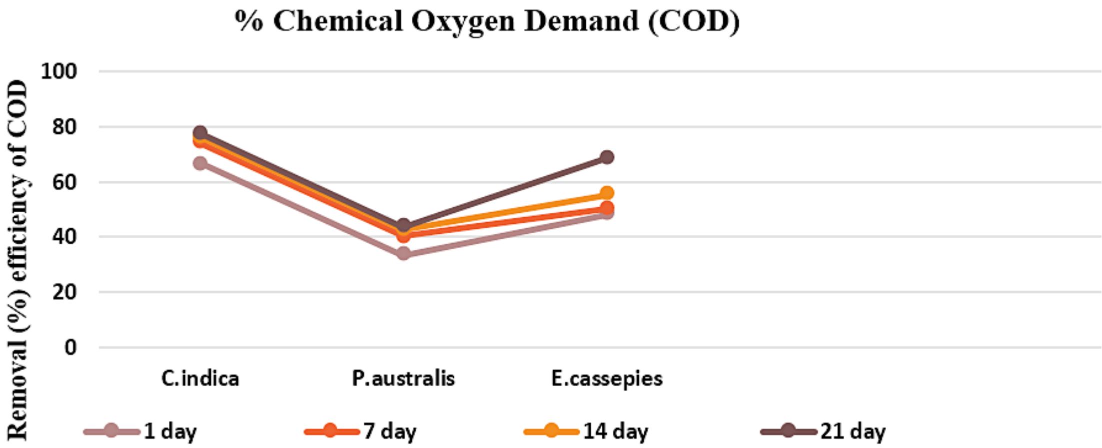

Fig. 3: COD removal (%) efficiency of *Canna indica, Phragmites australis* and *Eichhornia crassipes*

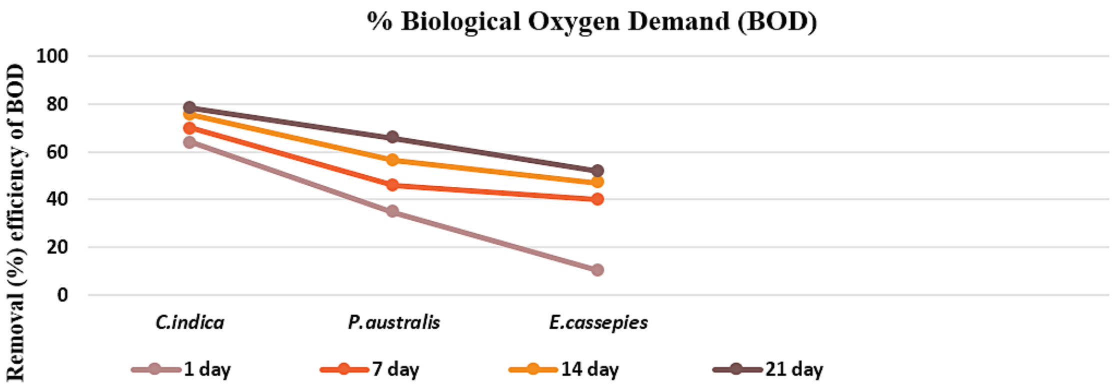

Fig. 4: BOD removal (%) efficiency of *Canna indica, Phragmites australis* and *Eichhornia crassipes*

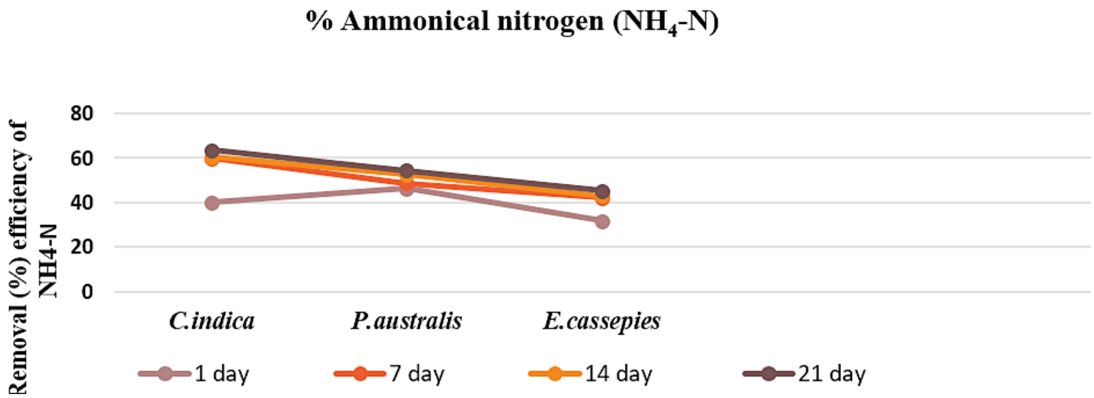

Fig. 5: (%) NH4-N removal efficiency of *Canna indica, Phragmites australis* and *Eichhornia crassipes*

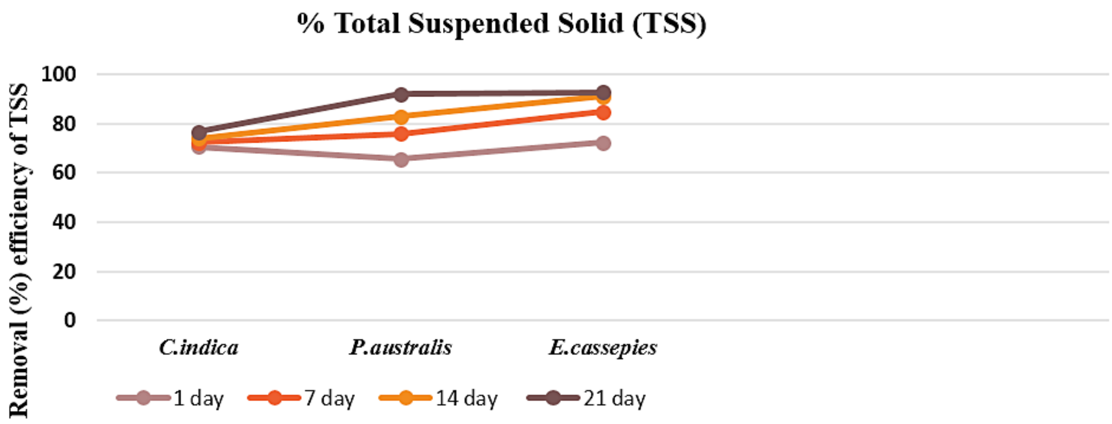

Fig. 6: (%) TSS removal efficiency of *Canna indica, Phragmites australis* and *Eichhornia crassipes*

In the present studies vertical flow constructed wetland (VFCW) W3 planted with *Eichhornia crassipes* achieved 92.74% of removal efficiencies. *Eichhornia crassipes* has highest removal performance and recorded enhanced growth which helps to utilize the solar energy and nutrient mixtures in water and support in an aerobic condition in day time. Reduction in pollutants was due to lowered microbial processes and increase in carbon dioxide levels from plant metabolism, which minimized the pH levels in wastewater.[19] Macrophyte root provided large surface area to remove TSS and also enhanced physical, chemical and microbial activities optimized nutrient uptake and nitrification reaction. Removal of TSS (Total suspended solids) in Vertical constructed wetland was high as HRT (Hydraulic retention time) low as compared to high HRT (Hydraulic retention time) as studied by.[37] Role of plant become limited for TSS (Total suspended solids) reduction and reduction of TSS (Total suspended solids) are take place by filter from substrate when remobilization effect the performance of Constructed wetland with high HRT.[38]

Table: 3 Heavy metal concentration (mg/L) in initial and final treated leachates (values were given as Mean±SD)

		Final leachate(mg/l) Treatment after 21 days		
Parameters	**Initial leachate Concentration (mg/L)**	***Canna indica***	***Phragmites australis***	***Eichhornia crassipes***
As	0.08±0.009	0.032±0.002	0	0.028±0.002
Cd	0.0126±0.002	0	0	0
Co	0.086±±0.004	0.062±0.001	0.076±0.002	0.032±0.002
Cr	0.526±0.018	0.092±0.022	0.146±0.001	0.053±0.005
Cu	0.286±0.009	0.202±0.022	0.212±0.002	0.133±0.05
Fe	25.96±1.469	9.698±0.001	Neg.	3.686±0.013
Mn	0.6±0.02	0.524±0.002	1.155±0.003	0.806±0.0005
Ni	0.262±0.014	0.529±0.001	0.143±0.003	0.0846±0.0015
Pb	0.101±0.002	0.056±0.002	0.038±0.004	0.0246±0.003
V	0.363±0.102	0.09±0.017	0.104±0.002	0.141±0.001
Zn	0.473±0.027	0.1±0.1	0.252±0.002	0.08±0.02

Statistical significance $p<0.05$, Neg-Negative values

Removal of Heavy Metals Using Vertical Constructed Wetland (VCW)

Heavy Metal Removal

Constructed wetland not only removed organic matter but also reduction of heavy metals in good concentrations. However reduction is dependent on current environment in addition to pH, metal characteristics, Oxidation and Potential.[14] Around eleven (11) heavy metals were analyzed from influent and effluent leachate samples in Vertical constructed wetland and mean concentration reduction of these toxic metals were As, Co, Cu, Cd, Pb, Cr, Ni, Fe, Mn, Zn, and V, after 1 day, 7day, 14 day and 21 days of treatment as shown in table and figure below % removal efficiencies of each heavy metal were presented in table 3 and fig. 7, 8, 9, respectively.

Table: 3 Percent heavy metals removal efficiency of plants in a Vertical constructed wetland. (Mean ± SD)

Heavy Metals	*Initial leachate*	*Phragmites australis*	*Eichhornia crassipes*	*Canna indica*
As	0.08±0.009	100±0	65±5	60±1.73
Cd	0.0126±0.002	100±0	100±0	100±0
Co	0.086±±0.004	11.62±0.8	62.7±0.85	27.9±1.06
Cr	0.526±0.018	72.24±1.57	89.92±1.32	82.5±2
Cu	0.286±0.009	25.87±1.29	53.49±0.26	29.37±1.02
Fe	25.96±1.469	Neg.	85.82±0.71	62.67±0.62
Mn	0.6±0.02	Neg.	Neg.	13.33±2.22
Ni	0.262±0.014	45.41±4.9	67.93±1.9	Neg.
Pb	0.101±0.002	62.37±1.78	76.23±1.82	44.55±0.78
V	0.363±0.102	71.34±1.33	61.15±0.87	75.2±2.6
Zn	0.473±0.027	46.3±0.85	83.08±0.04	78.85±0.45

Statistical significance $p<0.05$, Neg-Negative values

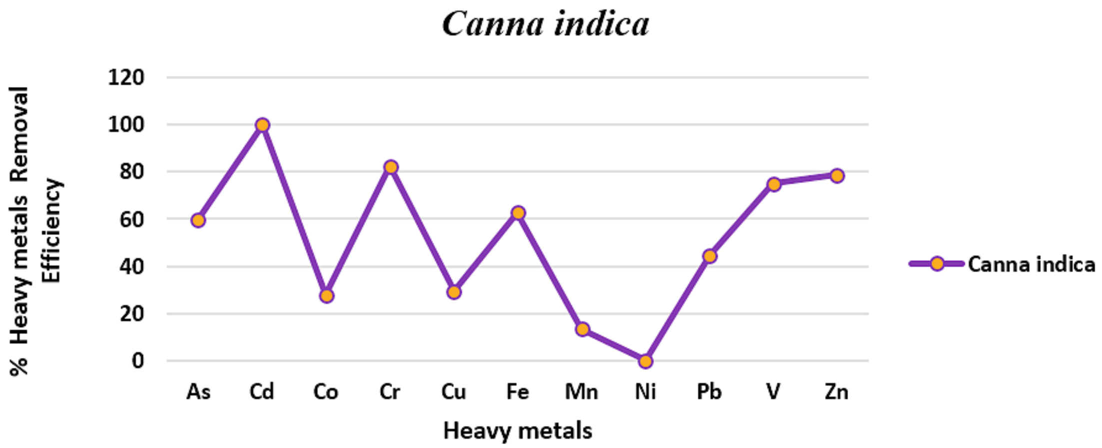

Fig. 7: Heavy metals (%) removal efficiency of Canna indica in VCW

In the current investigation, the amount of heavy metals in the samples obtained after 21 days from each of three Vertical Constructed Wetland (W1, W2, and W3) planted with three different Macrophyte *Canna indica* in *(W1), Phragmites australis in (W2), Eichhornia crassipes in (W3)* was measured and detected by inductively coupled plasma spectrometer. Removal of heavy metal from constructed wetland are mostly by filtrations of suspended by plant root and biological way, binding to organic matter, chemical precipitation and sorption on surface of soil.[39]

The Initial concentration As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn and V in influent samples were 0.08mg/L, 0.012mg/L,0.086mg/L, 0.526mg/L, 0.286mg/L, 25.96mg/L, 0.6mg/L, 0.262mg/L, 0.10mg/L, 0.473mg/L, 0.363mg/L as shown in table 3. After 21 days of treatment in vertical constructed wetland (W1) planted with *Canna indica* the final concentrations reductions of heavy metal from (VFCW) vertical constructed wetland W1 were As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn and V in (0.032 mg/L, 0 mg/L,0.062mg/L,0.092,0.202, 9.69 mg/L, 0.52mg/L, 0.529 mg/L, 0.05mg/L, 0.1 mg/L and 0.09 mg/L). However Vertical constructed wetland (W2) planted with *Phragmites australis* has removed heavy metal after 21 days treatment were As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn and V with value of (0 mg/L,0 mg/L, 0.076 mg/L, 0.146 mg/L, 0.212 mg/L, Neg. mg/L, 1.155 mg/L, 0.143 mg/L, 0.038mg/L, 0.252 mg/L and 0.104 mg/L).Table 3 and fig. After 21 days the Final concentration reduction of heavy metal in vertical constructed wetland (W3) planted with *Eichhornia crassipes* was as shown in fig.9 and table 3was As (0.028 mg/L), Cd (0 mg/L), Co (0.032mg/L), Cr (0.053 mg/L), Cu (0.133 mg/L), Fe (3.68 mg/L), Mn (0.806 mg/L), Ni (0.084 mg/L), Pb (0.024 mg/L) Zn (0.473 to 0.08mg/L), and V (0.141 mg/L).

Removal Efficiency of Heavy Metals

Removal efficiencies of some selected toxic metals such as As, Cd, Cr, Ni, Zn, Fe, Cu, Pb, Co, Mn, V, from Vertical constructed wetland were shown in table 4 and fig.7,6,9.

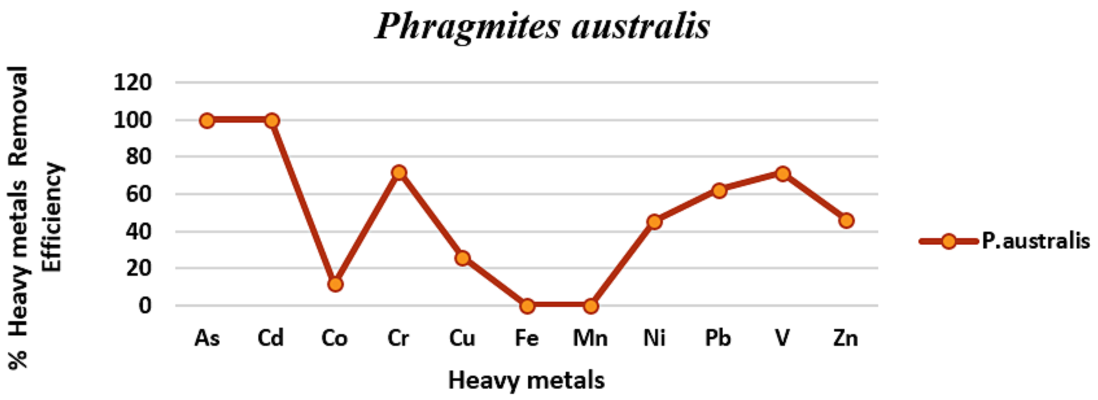

Fig. 8: Heavy metals (%) removal efficiency of *Phragmites australis* in a VCW

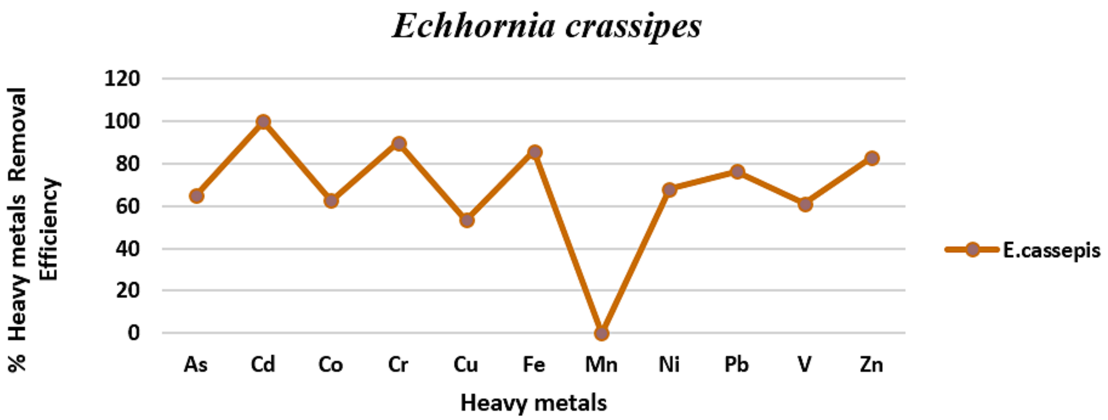

Fig. 9: Heavy metals (%) removal efficiency of *Eichhornia crassipes* in a VCW

In the present investigation it was observed that % removal efficiency of heavy metals in Vertical constructed wetland (W1) planted with *Canna indica* were As(60%), Cd(100%), Co(27.9%), Cr(82.5%), Cu(29.37%), Fe(62.6%), Mn(13.3%), Ni(0), Pb(44.5%), V(75.2), Zn(78%), as shown in fig and removal efficiencies was observed in series of Cd > Cr > Zn > V > Fe > As > Pb > Cu > Mn > Ni respectively as shown table 4 and fig 7.

In the study it was observed that % heavy metal removal efficiency in vertical constructed wetland (W2) cultivated with *Phragmites australis* was As(100%), Cd(100%), Co(11.6%%), Cr(72.2%), Cu(25.8%), Fe (Neg.), Mn (Neg.), Ni(45.4%), Pb(62.37%), V(71.34%), Zn(46.3%), Cu (29.37%) as shown in fig and reduction efficiencies was observed in series of As & Cd >Cr> V >Pb >Zn >Ni > Cu > Co >Fe & Mn respectively fig 8. Likewise % removal efficiency of heavy metal in vertical constructed wetland (W3) planted with *Eichhornia crassipes* was As(65%), Cd(100%), Co(62.7%), Cr(89.9%), Cu(53.49%), Fe(85.8%), Mn (Neg), Ni(67.9%), Pb(76.23%), V(61.15%), Zn(83.08 %) and % removal efficiencies was observed in order of Cd>Cr>Fe>Zn >Pb>Ni>Co>V> Cu>Mn so in fig. 9 and table 4 ,respectively.

According to [40] removal of heavy metals from constructed wetland an adsorption play major role. Zinc (Zn) reduction from vertical constructed wetland (W3) planted with *Eichhornia crassipes* was high (82%) followed by vertical constructed wetland (W1) 78% and equal concentrations were reduced by vertical constructed wetland (W2) 43%. As studied by [10] Zinc (Zn) can bound upper ground part of plant however other heavy metal has low only 10%.

Likewise Nickel (Ni) reduction was about (67% and 45%) in vertical constructed wetland (W3) and (W2) and negative in vertical constructed wetland and W1).[34] has observed nickel (Ni) removal in vertical constructed wetland at about (28 to 42.7%). However [39,14] observed (75- 99%) reduction.

Tables 5: Comparative result among Macrophyte on pollutants removal efficiency.

Canna indica (W1) (Canna lily)	***Phragmites australis (W2) (Common reed)***	***Eichhornia crassipes (W3) (Water hyacinth)***
COD (77.4%), BOD (78.4%), NH4-N (63.4%) TSS (76.7%) As (60%), Cr (82.5%), Cd (100%), Cu (29.37%), Co (27.9%), Fe (62.67%), Mn (13.33%), Ni (Neg.), Pb (44.5%), V (75.2%), Zn (78.85%)	COD (43.6%), BOD (65.45%), NH4-N (54.4%), TSS (92%) As (100%), Cr (72.24%), Cd (100%),Cu (25.88%), Co (11.62%), Fe (Neg.), Mn (Neg.), Ni (45.4%), Pb (62.37%),V (71.37%), Zn (46.3%)	COD (68.5%), BOD (52%), NH4-N (45.4%) TSS (92.7%) As(65%),Cr(89.9%),Cd(100%), Cu (53.49%), Co (62.7%), Fe (85.82%), Mn (Neg.), Ni (67.9%), Pb (76.2%), V (61.15%), Zn (83.08%)
Pollutants COD, BOD, NH4-N, Cd, V which was highest removed by VCW planted with *Canna indica*	Heavy metal such as As, Cd, which was highest removed by VCW planted with *Phragmites australis*	Pollutants like TSS, Cr, Cd, Cu, Co, Fe, Ni, Pb, Zn which was highest removed by VCW planted with *Eichhornia crassipes*

Concentration reduction of Iron (Fe) in vertical constructed wetland (W3) was 85% and 62% in vertical constructed wetland (W1) but constructed wetland such as (W2) have shown negative reduction of Iron (Fe). As per [41] Iron (Fe) is needed by plants for their survival, low and very high dose of Fe lead to stress and toxicity and observed chlorosis and low yield in crop.

Heavy metals like Manganese (Mn) reduction concentration after 21 days of treatment in vertical constructed wetland (VCW) was (13.33%) in vertical constructed wetland (W1) but no reduction was done by other vertical constructed wetland (W2, W3).[5] reported that Manganese (Mn) required by plants and its deficiency similar to deficiency of Magnesium (Mg) breakdown of carbohydrate and nitrogen also chlorosis observed on upper surface of leaves rather than beneath of the leaves.

Reduction of Chromium (Cr) was (82.5% and 89.9%) in vertical constructed wetland (W1 and W3). 72.2% in vertical constructed wetland (W2).[14] reported that (80-100%) of reduction of chromium (Cr) in vertical constructed wetland but [39] has reported that Chromium (Cr) reduction was (43-71%). About vertical constructed wetland [14] reported that lab-scale Vertical Flow Wetlands removed Zn , Cr , Ni , Cd , and Pb (92%,80%, 75%,68%,and 54%) from synthetic leachate.

Constructed wetland filled with different substrates and planted with *Phragmites australis* has heavy metal removal efficiency of (41-56%) for Zn, Ni, Cu, and Cr.[28] Likewise substantial decrease in pollutant metals like (Ni, Co, Cu, Mn, Zn, Cd, Pb, Cr, Fe (55.63%,73.92%, 54.81%, 31.44%, 41.48%, 66.78%, 66.92%, 46.32%, 52.47 %) and so on can be due to various constructed wetland processes[40, 20] has well accepted the useful role of plants in removal in heavy metal in constructed wetlands. Heavy metals absorption and accumulation and removal differs from species to species. *Canna indica*, *Eichhornia crassipes* and *Phragmites australis* showed good efficiencies for removal various pollutants could be used for leachate treatment for present study area. Each species of Macrophyte can be used for selected pollutant reduction from landfill leachate based on table 5.

Conclusion

Landfill leachate treatment through Vertical constructed wetland is very easy and a cost effective method which does not require any advance technology. It was observed that out of three plants species *Canna indica* showed better for removal of COD 77.7%, BOD 78.7% and NH4-N 63.6%,V(75.2%).TSS was highest (%) removed by using *Eichhornia crassipes* 92.75%,Cr (89.9%), Cu(53.49), Co(62.7%), Fe(85.2%), Ni(67.9%), Pb(76.2%), Zn (83.08%) and *Phragmites australis* was found good for removal of heavy metal As, Cd. Result showed that *Canna indica* was good for removal of organic pollutant and *Eichhornia crassipes* showed good for removal of TSS and heavy metals. All the three plant species highly removed the Cd (100%). All the three species have removed Cd 100%. Cr (89.9, 82.2%) & Fe (82.8 % & 62.7%) was highly removed by *Eichhornia crassipes* &*Canna indica* that was followed by Phragmites species. Ni, Pb, Zn was highly reduced by *Eichhornia crassipes*. Therefore Different plant species emergent, surface water floating can be used as single or mixed for biological treatment of landfill leachate. Treated landfill leachate in vertical constructed wetland was compared with standard set by MOEFCC 2016 and found that all the 11 heavy metals were come under the standard set by officials for discharge in public sewer, inland water and subsurface also organic pollutant concentration was greatly reduced.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

All the data analyzed during this study are included.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval."

Authors' Contribution

Sonam Angmo: Conceptualization, Sampling, Experiment design, Laboratory experiments, Data analysis and original drafting of paper. Yogita Kharayat: Laboratory experiments and analysis, Review and Editing Shachi Shah: Methodologies and Supervision.

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