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Efficiency of *Pistia stratiotes* in treatment of municipal solid waste leachate in an upwards flow constructed wetland system

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ABSTRACT

Constructed wetlands are one of the effective treatment technologies that have been used to treat various kinds of wastewater and leachate and are very economical and cost-effective, simple and easy to operate, without any complex technology. The BOD5/COD ratio of raw leachate was observed as low (0.27), indicating it as biodegradable leachate. That's why for the treatment of this leachate, CW's methods are used. The main objective of the present study is to assess the efficiency of CW's for the treatment of landfill leachate. To fulfill the objectives of the present study an upwards flow engineered wetland was constructed using gravel, sand and plant (*Pistia stratiotes*). The efficiency of CW's was assessed for 21 parameters such as TDS, COD, BOD, NH_4-N, Fluoride, TKN, and Heavy metals, etc. The maximum removal efficiency was observed in the case of BOD (97.58%) followed by COD (97.03%), Turbidity (87.09%) and Sulphate (85.89%) while minimum efficiency was observed in case of pH (8.24%). Due to the large removal efficiency observed in the present study and based on literature, it can be said that CW's methods would play a major role in the sustainable management of wastewater.

Key words: *Constructed wetlands, Leachate, Municipal solid waste (MSW), Upward flow.*

Introduction

Increasing urbanization, industrialization, and growing population and affluent lifestyle are the main causes of the increasing rate of solid waste generation (Chen *et al.,* 2013). Various methods adopted for solid waste management are incineration, pyrolysis, landfilling, etc. Leachate is the liquid that seeps through solid waste or another medium has extracts of dissolved or suspended material from it (Moravia *et al.*, 2013). Leachate quality depends upon the type of waste (Schiopu and Gavrilescu, 2010). Both old leachate (methanogenic type) and fresh leachate (acidogenic type) possess different characteristics (Lak *et al.*, 2013; Hermosilla *et al.,* 2009; Abood *et al.*, 2014; Zazouli *et al.,* 2012). In rainy season leachate formation increasedas the leachate formation occurs from moisture leaded waste and rainwater percolation from degraded waste (Lak *et al.*,2013; Singh and Tang, 2013;Venu *et al.*,2014).

Leachate has high pH, TDS, TSS, Chlorides, Total

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nitrogen, Ammonical nitrogen, Cyanide, Fluoride, Ca^{+2}, Mg^{+2}, Nitrites, Fe^{+2}, Phenols, Arsenic, Nickel, lead, zinc, copper, Chromium, Cadmium, Mercury, BOD and COD (Paxeus, 2008; Klimiuk *et al.,*2007) and toxic organic matters, which distribute among different particles with various sizes. Leachate formation occurs in three phases and these are- Aerobic phases, anaerobic phase, and methane phase. To confirm the potential dangers of leachates before discharging, its toxicity tests were performed on various test organisms as *Vibrio fisheri, Daphnia similes* and *Artemiasalin*a (Silva *et al*., 2004) and organic matter removal were assessed in the form of COD, BOD, and Ammonia.Biological methods were described as effective (Kang and Hwang, 2000; Ding *et al.,* 2001) for the treatment of young leachates (low ratio of BOD5/COD and low biodegradability), while for the treatment of old or partially stabilized leachates (high ratio of BOD5/COD and high biodegradability) physicochemical processes were described as effective (Ntampou *et al.,*2005). Biological methods investigated and used are: UASB, activated sludge, stabilization ponds, bio discs, trickling filters and SBR (Agdag and Sponza, 2005), while physicochemical technologies used are coagulation, flocculation, sedimentation, reverse osmosis, micro and ultrafiltration, ammonia stripping and advanced oxidation processes (Zouboulis *et al.,* 2004; Zhang *et al.,* 2005).

Implementationof the above discussed biological and physicochemical process of leachate treatments requires high operation costs and skilled labor but the economy of developing countries such as India is not so good to support these expensive treatments (Chiemchaisri *et al.,*2009). Taking the above discussion into account and the serious consequences of the groundwater pollution problem from leachate, the landfill leachate treatment problems are urgent to solve. There is an urgent need to work with systems more flexible and low cost both in investment, operation, and maintenance. Leachate treatment with constructive wetland is the system applicable to the entire situation discussed above.

Natural wetland is an area consisting of soil, plant, and water where the soil is covered by water or saturated with moisture such as marsh, swamp or bog while constructed wetland is defined as engineer-made equivalent to natural wetlands and designed to reduce and mitigate the pollution level from wastewater as occurred in natural wetlands (Kumar and Choudhary, 2018). Constructed wetland consists of gravel, water or shallow pond, soil, aquatic plant or macrophyte and microorganism (Saeed and Sun, 2012). For developing countries and remote sites with a small community, constructed wetlands are very useful for leachate treatment and possess higher efficiency (Bakhshoodeh *et al.,* 2017; Gajewska *et al.,* 2015).

In comparison to conventional treatment processes, constructed wetlands are easy in operation and low cost in maintenance and offer an alternative way of leachate treatment (Kumar and Choudhary, 2018; Akinbile *et al.,* 2012; Choudhary *et al.,* 2011). These are a combination of physical, chemical and biological processes and act as a biological filter. Vertical flow constructed wetlands (VF CWs) are more efficient than other wetlands. VF CWs requires a very small space for its operation. They depend upon various processes like filtration, sedimentation, volatilization, precipitation, adsorption, etc. Constructed wetlands system is widely applied for the purification of domestic waste, stormwater runoff, and industrial effluent. In the present study, we worked on the upward flow constructed.

The leachate was collected from Bawana Dumping Yard, Delhi, operated since 2011. Narela-Bawanais the first scientific landfill site of city Delhi. Approximately 1300 metric tonnes of solid waste are continuously processed to obtain refused derived fuel (RDF), manure and other recyclable items. Delhi spread over 1483 square Km area and is situated in North India at an altitude of 293 m above mean sea level. Delhi (2nd rank occupier in population among all Indian metropolitan cities), is estimated to generate about 10500 metric tons of MSW daily. Per capita generation of solid waste in Delhi ranged from 550 to 600 gm/d. The waste processing capacity of Delhi is 6,100 tonnes per day (TPD), with the help of three incineration plants and two centralized composting units. Approximately 4,600 TPD of waste from commercial, industrial and residential areas is disposed of in three dumping sites of Delhi, i.e. Okhla, Bhalswa and Ghazipur. The Narela-Bawana MSW site is constructed in different phases. Currently, it is processing 2000 tonnes/day of waste for processing, disposal, and waste to energy conversion. The site is producing 24MW electricity from waste. It has an area of approximately 100ha, including ballistic separators, including Refuse Derived Fuel (RDF) trammels, Compost Plant and waste to the energy power plant.

Materials and Methods

The leachate sample was collected from the solar evaporation pond (SEP) in the center of the MSW landfill of Bawana. Leachate sample was collected in 20 liters plastic containers (previously acidified with HCL). Some parameters were analyzed at the site while for the analysis of the rest of the parameters and experiment, the sample was transported to the laboratory immediately. All the samples were analyzed following the standards methods (APHA, 2012; Khanna and Bhutiani, 2008; Trivedy and Goel, 1986).

Plant species and experimental setup

For the experiment, the macrophyte (water lettuce also called pistia) was selected. Pistia is one of the genera of aquatic plants in the arum family, *Araceae*. The other name of *Pistia stratiotes,*arewater cabbage, water lettuce, Nile cabbage, or shellflower. The selected plant was collected from the nearby village ponds and then their root was washed after that, the plant was cultivated in the artificial pond. In artificial ponds, the plants grow and stabilize their population. The experiment was conducted in three phases as phase 1, phase 2 and phase 3. Phase 1 is associated with the collection and stabilization of the plant population. Phase 2 is associated with the optimization of experimental factors (HRT, SRT, the width of sand and gravel bed and diameter of gravel) while phase 3 is the actual experiment phase. Before phases 1, 2 and 3, the leachate was diluted with groundwater and then aeration was performed to reduce the concentration of ammonia and to improve the C/N ratio (Smaoui *et al.,* 2019). The wetland was constructed in horizontal design. The layers consisted of 15 cm of 0.3–2 mm diameters of sand and, 20 cm of 5–15 mm diameter semi-coarse gravel and 30 cm of 15–25 mm diameter coarse gravel. The uniformity coefficient for the sand is 3.55, for semi-coarse gravel 1.67 and coarse gravel layers were 1.37.

Calculation of pollutant removal efficiency

The mechanism of pollutant removal in constructed wetlands (CWs) involve physical treatment i.e. filtration through soil layer, adsorption on the surface of media used, sedimentation, and chemical treatment, i.e. precipitation and oxidation-reduction, and bio-treatment, i.e. uptake of pollutant by plant and bio-degradation with the help of micro-organism (Choudhary *et al.,* 2011; Sauba, 2015) (Table 1). The water is treated primarily before the experiment to suspended matter which can clog the experimental system (Pedescoll *et al.,* 2013). Large gravels create a film for producing bacterial growth. The mode of feeding (i.e. continuous, batch or intermittent) wastewater may affect the treatment efficiency by influencing oxygen transfer, redox conditions, and diffusion of pollutants in the wetland system.

The removal efficiency was obtained using the following equation:-

$$\textbf{Percentage removal} = \frac{Xi - Xf}{Xi} \times 100$$

Where *Xi* and *Xf* refer to the initial and final concentration of the particular parameters.

Results

The samples (Raw leachate, Diluted leachate and treated leachate) collected during the study period was analyzed for the following parameters as pH, TSS, TDS, TS, Chloride, Total Kjeldahl Nitrogen (TKN), Ammonical nitrogen (NH_4-N), Fluoride, Nitrites, Total Phosphorous (T-Phosphorous), Sulphate, DO, BOD, COD and heavy metals (Nickel, Lead, Copper, Iron, and Cadmium) and the results of all the parameters were presented in the Table from 1 to 3.

The average turbidity of the raw leachate was

Table 1. Treatment Processes in Constructed Wetlands (Kumar and Choudhary, 2018).

Parameter	Removal mechanism
Suspended solids	Sedimentation and filtration
Dissolved Organics	Aerobic and anaerobic microbial degradation. phyto-degradation, phyto-volatilization, and plant uptake
Phosphorus	Plant uptake and matrix sorption
Nitrogen	Ammonification, microbial nitrification, plant uptake, denitrification, matrix adsorption
Metals	Sedimentation, filtration, adsorption, precipitation, and plant uptake

found 116.80±13.68 (Ranged from 96 NTU to 136 NTU) while after dilution the turbidity of the leachate was found 57.30±5.54 (Ranged from 48 NTU to 67 NTU). After treatment with the constructed wetlands, the turbidity of the leachate was found 7.40±1.8 (Ranged from 5 NTU to 10 NTU). The average conductivity of the raw leachate was found 12270.10±413.77 (Ranged from 11920.9 µS/Cm to 13113.4 µS/Cm) while after dilution the conductivity of the leachate was found 9000.6±336.5 (Ranged from 8425.4 µS/Cm to 9771.6 µS/Cm). After treatment with the constructed wetlands, the conductivity of the leachate was found 1803.1±88.5 (Ranged from 1712.4 µS/Cm to 2015.4 µS/Cm).

The average total dissolved solids (TDS) of the raw leachate was found 8221.10±272.22 (Ranged from 7987mg/ L to 8786 mg/L) while after dilution the TDS of the leachate was found 6030.40±225.47 (Ranged from 5645mg/L to 6547 mg/L). After treatment with the constructed wetlands, the TDS of the leachate was found 1192.40±48.7 (Ranged from 1120 mg/L to 1278 mg/L). The average total suspended solids (TSS) of the raw leachate was found 205.90±20.01 (Ranged from 180 mg/L to 245 mg/L) while after dilution the TSS of the leachate was found 147.00±22.7 (Ranged from 121 mg/ L to 183 mg/L). A more or less similar characterization of leachate was also found by Gusman *et al.*, 2015. After treatment with the constructed wetlands, the TSS of the leachate was found 43.30±6.6 (Ranged from 35 mg/L to 56 mg/L). The average total solids (TS) of the raw leachate was found 8427.00±271.97 (Ranged from 8208 mg/L to 8975 mg/L) while after dilution the TS of the leachate was found 6177.40±230.52 (Ranged from 5767 mg/L to 6990mg/L). After treatment with the constructed wetlands, the TS of the leachate were found 1344.00±35.9 (Ranged from 1300 mg/L to 1410 mg/ L).

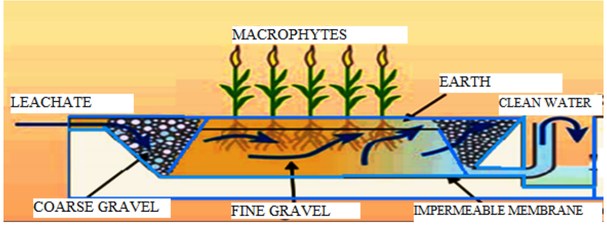

Fig. 1. Showing the Adapted design for the present study (Adapted from UNEP, 2003)

The average pH of the raw leachate was found 7.98±0.14 (Ranged from 7.8 to 8.2) while after dilution the pH of the leachate was found 7.82±0.12 (Ranged from 7.56 to 7.96). A more or less similar trend in pH was observed by Gotvajn *et al.*,2009. After treatment with the constructed wetlands, the pH of the leachate was found 7.18±0.09 (Ranged from 7.07 to 7.32). The average biochemical oxygen demand (BOD) of the raw leachate was found 3421.50±433.58 (Ranged from 2818 mg/L to 4103 mg/L) while after dilution the BOD of the leachate

Fig. 2. Leachate collection site (Solar Evaporation Pond)

Table 1. Showing Physical characteristics of Raw diluted leachate and Treated leachate.

SPL/PMS	Turbidity (NTU)		Conductivity (µs/cm)		TDS (mg/L)		TSS (mg/L)		TS (mg/L)	
	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW
SN-1	67	9	8425.4	1813.5	5645	1220	122	35	5767	1300
SN-2	56	8	8804.5	1765.8	5899	1180	158	45	6057	1345
SN-3	61	9	8956.7	1876.9	6001	1278	142	43	6143	1365
SN-4	61	10	9138.8	2015.4	6123	1250	183	56	6306	1360
SN-5	60	5	8934.3	1723.8	5986	1170	133	41	6119	1350
SN-6	57	5	9771.6	1745.4	6547	1120	143	47	6690	1410
SN-7	59	6	8935.8	1800	5987	1206	177	51	6164	1370
SN-8	52	8	8922.4	1797.8	5978	1200	121	36	6099	1300
SN-9	52	8	8977.6	1712.4	6015	1160	165	40	6180	1300
SN-10	48	6	9138.8	1780	6123	1140	126	39	6249	1340
AV	57.3	7.4	9000.6	1803.1	6030.4	1192.4	147	43.3	6177.4	1344
SD	5.5	1.8	336.5	88.5	225.5	48.7	22.7	6.6	230.5	35.9

was found 1615.10±77.46 (Ranged from 1467mg/ L to 1725 mg/L). After treatment with the constructed wetlands, the BOD of the leachate was found 39.10±11.97 (Ranged from 25 mg/L to 56 mg/L). The average chemical oxygen demand (COD) of the raw leachate was found 12580.10±635.40 (Ranged from 11899 mg/L to 1410 mg/L). A more or less similar COD in Raw leachate was also observed by several researchers (Ohwoghere Asumaand Aweto, 2013), while after dilution the COD of the leachate was found 6274.50±556.15 (Ranged from 5654mg/ L to 7324 mg/L). A more or less similar observation was obtained by Singh *et al.,* 2016. After treatment with the constructed wetlands, the COD of the leachate was found 186.30±24.18 (Ranged from 160 mg/L to 223 mg/L).

The average Total Kjeldahl Nitrogen (TKN) of the raw leachate was found 246.50±21.20 (Ranged from 225 mg/L to 297mg/L) while after dilution the TKN of the leachate was found 141.60±14.12 (Ranged from 125 mg/L to 165 mg/L). After treatment with the constructed wetlands, the TKN of the leachate was found 33.40±4.43 (Ranged from 26mg/ L to 38 mg/L). The average Ammonical nitrogen (NH_4^+-N) of the raw leachate was found 116.40±18.90 (Ranged from 93 mg/L to 156 mg/L) while after dilution the NH4+-N of the leachate was found 55.40±11.47 (Ranged from 40 mg/L to 76 mg/L). After treatment with the constructed wetlands, the NH_4^+-N of the leachate was found 23.60±3.63 (Ranged from 18 mg/L to 30 mg/L).

The average chloride of the raw leachate was found 2787.30±131.90 (Ranged from 2650mg L/to 3017 mg/L) while after dilution the chloride of the leachate was found 1295.50±79.02 (Ranged from 145 mg/L to 1678 mg/L). After treatment with the constructed wetlands, the chloride of the raw leachate was found 504.30±21.68 (Ranged from 485 mg/L to 543 mg/L). The average nitrates of the raw leachate were found 41.05±3.18 (Ranged from 35.67 mg/L to 45.8mg/L) while after dilution the nitrates of the leachate were found 23.25±0.82 (Ranged from 21.98 mg/ L to 24.67 mg/ L). Our results are in agreement with Boumechhour *et al.,*2016. After the treatment with constructed wetlands, the nitrate of the leachate was found 8.09±0.56 (Ranged from 7.45 mg/L to 9.12 mg/L). The average fluoride of the raw leachate was found 1.48±0.16 (Ranged from 1.27 mg/v to 1.76 mg/L) while after dilution the fluorides of the leachate were found 0.68±0.07 (Ranged from 0.78 mg/L to 0.97 mg/L). After the

Table 2. Showing Chemical characteristics of Raw diluted leachateand Treated leachate.

SPL/PMS	pH		BOD (mg/L)		COD (mg/L)		TKN (mg/L)		NH_4-N (mg/L)		Chloride (mg/L)		Nitrates (mg/L)		Fluorides (mg/L)		TP (mg/L)		Sulphate (mg/L)	
	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW
SN-1	7.8	7.3	1545	27	6134	189	134	34	45	20	1543	512	23.67	8.97	0.89	0.28	12.5	4.6	22.3	3.5
SN-2	7.8	7.3	1634	51	6578	213	156	38	40	18	1456	489	22.34	7.89	0.86	0.25	14.1	5.1	24.5	2.9
SN-3	7.9	7.1	1600	38	5767	167	128	26	55	23	1450	490	23.5	8.09	0.93	0.32	13.6	4.8	25.1	4.6
SN-4	7.9	7.1	1614	49	5987	170	165	38	40	20	1678	543	24.67	9.12	0.78	0.24	13.9	3.5	22.1	4.1
SN-5	7.6	7.2	1725	56	7234	223	160	37	56	24	1545	510	23.7	8.12	0.87	0.26	13.2	3.6	24.1	3.2
SN-6	7.8	7.2	1467	25	5654	160	143	35	67	26	1500	496	21.98	7.45	0.97	0.38	14.8	4.1	22.3	3.8
SN-7	7.7	7.1	1598	28	5878	165	125	28	55	25	1480	485	23.89	8.24	0.78	0.25	15.7	4.7	21.9	2.5
SN-8	7.9	7.1	1580	26	5934	168	130	28	60	27	1500	492	22.78	7.85	0.81	0.25	13.9	3.9	22.7	3.4
SN-9	7.9	7.1	1678	41	6456	189	140	35	76	30	1656	540	23.45	7.56	0.95	0.36	13.7	3.9	21.9	2.3
SN-10	7.9	7.2	1710	50	7123	219	135	35	60	23	1487	486	22.54	7.65	0.79	0.25	14.9	4.5	22.8	2.1
AV	7.8	7.2	1615.1	39.1	6274.5	186.3	141.6	33.4	55.4	23.6	1529.5	504.3	23.3	8.1	0.9	0.3	14.0	4.3	22.9	3.2
SD	0.1	0.1	77.5	11.9	556.2	24.2	14.1	4.4	11.5	3.6	79.0	21.7	0.8	0.6	0.1	0.1	0.91	0.5	1.	0.81

SPL- Sampling
PMS- Parameters
BOD-Biochemical Oxygen Demand
COD-Chemical Oxygen Demand
TKN-Total KjeldahlNirogen
NH_4-N- Ammonical Nitrogen
TP-Total Phosphorous

treatment with constructed wetlands, the fluoride of the raw leachate was found 0.28±0.05 (Ranged from 0.24 mg/ L to 0.38 mg/ L). The average phosphorous (T-Phosphorous) of the raw leachate was found 32.60±1.99 (Ranged from 28.9 mg/ L to 35.7 mg/L) while after dilution the total phosphorous of the leachate was found 14.03±0.91 (Ranged from 12.50 mg/L to 15.70 mg/ L l). After treatment with the constructed wetlands, the total phosphorous of the raw leachate was found 4.27±0.54 (Ranged from 3.50 mg/L to 5.10 mg/L). The average sulfate of the raw leachate was found 39.21±1.50 (Ranged from 36.9 mg/L to 41.2 mg/L) while after dilution the sulfate of the leachate was found 22.97±1.16 (Ranged from 21.9 mg/ L to 25.1 mg/ L). Our results are in agreement with Agbozu *et al.,* 2015. After treatment with the constructed wetlands, the sulfate of the raw leachate was found 3.24±0.81 (Ranged from 2.1 mg/ L to 4.6 mg/ L).

The average nickel (Ni) of the raw leachate was found 0.43±0.03 (Ranged from 0.38 mg/L to 0.49 mg/ L) while after dilution the nickel of the leachate was found 0.14±0.03 (Ranged from 0.11 mg/L to 0.18 mg/ L). After treatment with the constructed wetlands, the nickel of the raw leachate was found 0.04±0.01 (Ranged from 0.02 mg/L to 0.06 mg/L). The average lead (Pb) of the raw leachate was found 0.04±0.01 (Ranged from 0.032 mg/L to 0.055 mg/L) while after dilution the lead of the leachate was found 0.03±0.00 (Ranged from 0.02 mg/L to 0.03 mg/L). After treatment with the constructed wetlands, the lead of the raw leachate was found 0.01±0.01 (Ranged from 0.00 mg/ L to 0.02 mg/L). The average zinc (Zn) of the raw leachate was found 1.85±0.21 (Ranged from 1.54 mg/ L to 2.23 mg/ L) while after dilution the zinc of the leachate was found 1.09±0.13 (Ranged from 0.96 mg/ L to 1.29mg/ L). Our results are in agreement with Agbozu *et al.,*2015 and Gupta and Rani, 2014. After treatment with the constructed wetlands, the zinc of the raw leachate was found 0.31±0.09 (Ranged from 0.20 mg/ L to 0.46 mg/ L). The average copper (Cu) of the raw leachate was found 1.97±0.07 (Ranged from 1.88 mg/ L to 2.12 mg/ L) while after dilution the copper of the leachate was found 0.94±0.07 (Ranged from 0.83 mg/ L to 1.02 mg/ L). After treatment with the constructed wetlands, the copper of the raw leachate was found 0.21±0.04 (Ranged from 0.16 mg/ L to 0.26 mg/ L). The average cadmium (Cd) of the raw leachate was found 0.31±0.10 (Ranged from 0.1 mg/ L to 0.45 mg/ L) while after dilution the cadmium of the leachate was found 0.19±0.07 (Ranged from 0.04 mg/ L to 0.30 mg/v). After treatment with the constructed wetlands, the cadmium of the raw leachate was found 0.07±0.04 (Ranged from 0.00 mg/ L to 0.12 mg/ L). The average iron (Fe) of the raw leachate was found 11.58±1.02 (Ranged from 9.89 mg/l to 12.9 mg/l) while after dilution the iron of the leachate was found 5.40±0.88 (Ranged from 4.24 mg/ L to 6.89 mg/ L). Our results are in agreement with Agbozu*et al.,*2015. After treatment with the constructed wetlands, the iron of the raw leachate was found 1.25±0.24 (Ranged from 0.87 mg/ L to 1.67 mg/ L).

Discussion

The summarized results of raw leachate, diluted and treated leachate were given in Table 4. Table 4 also describes the removal efficiency of *Pistia*

Table 3. Showing Heavy metals concentration in Raw diluted leachate and Treated leachate.

SPL/PMS	Nickel (Ni)		Lead (Pb)		Zinc (Zn)		Copper (Cu)		Cadmium (Cd)		Iron (Fe)	
	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW	RW	TW
SN-1	0.16	0.05	0.030	ND	0.99	0.3	0.83	0.23	0.11	0.05	5.45	1.25
SN-2	0.13	0.05	0.029	0.01	1.23	0.39	1.02	0.19	0.21	0.09	6.89	1.67
SN-3	0.11	0.03	0.024	0.02	1.12	0.28	0.92	0.16	0.21	0.12	4.78	1.32
SN-4	0.17	0.05	0.030	0.01	1.26	0.46	0.94	0.19	0.04	ND	5.67	1.29
SN-5	0.12	0.02	0.022	ND	0.98	0.22	1.01	0.26	0.2	0.04	6.51	1.56
SN-6	0.14	0.03	0.022	0.01	0.97	0.27	1.01	0.21	0.25	0.08	5.99	1.13
SN-7	0.16	0.04	0.025	0.001	1.1	0.36	0.94	0.25	0.14	ND	5.34	1.18
SN-8	0.13	0.04	0.031	0.011	1.01	0.2	0.83	0.18	0.23	0.06	4.45	0.98
SN-9	0.11	0.04	0.024	0.013	1.29	0.42	0.93	0.16	0.3	0.12	4.24	0.87
SN-10	0.18	0.06	0.023	ND	0.96	0.21	0.98	0.24	0.21	0.11	4.67	1.23
AV	0.14	0.04	0.03	0.01	1.09	0.31	0.94	0.21	0.19	0.07	5.40	1.25
SD	0.03	0.01	0.00	0.01	0.13	0.09	0.07	0.04	0.07	0.04	0.88	0.24

stratiotes in the treatment of municipal solid waste leachate in the upwards flows constructed wetland system.

In the case of turbidity removal efficiency of 87.09% was calculated. More or less similar efficiency was also observed by Akinbile *et al.,* 2012 and Mathew *et al.,* 2016. In the case of conductivity, 79.97% removal efficiency was observed. More or less similar efficiency was also observed by Boumechhour *et al.,* 2016. In the case of TSS removal efficiency of 70.54% was calculated. More or less similar efficiency was also observed by Akinbile *et al.,* 2012. In the case of total dissolved solids (TDS) 80.23% removal efficiency was observed. In the case of TS, the removal efficiency of 78.24% was calculated. The solids were removed due to different reactions which results in the coagulation process and reduced the solid content simultaneously turbidity and conductivity were reduced. In the case of pH, the removal efficiency of only 8.24% was calculated. The removal efficiency of 97.58% was calculated in the case of BOD. Nivala *et al.* (2007) also observed more or less similar removal efficiency using an artificial aeration system. Similar removal efficiency was also observed using different plants by various researchers (Lavrova, 2016; Dadrasnia *et al.,* 2017; Wojciechowska, 2017). The removal efficiency of 97.03% was calculated in the case of COD. A more or less similar trend was obtained by Prost-Boucle and Molle, 2012; Akinbile *et al.,* 2012; Lavrova, 2016 and Dadrasnia *et al.,* 2017. In case of some parameters (BOD, COD, and TDS) our results are different from that of the study performed by Gupta and Rani (2014) due to the sampling slot difference (they performed in summer, 2014 while we perform sampling in between summer and rainy season). In summers most of the parameters increased due to evaporation.

In the case, of TKN efficiency removal of 76.41% was calculated. The approximately similar removal efficiency was observed by Axler *et al.,* 2001. Nitrogen removal was due to adsorption on the surface of the substrate. In the present study, less removal was observed in the case of TKN as compared to other studies due to large gravel size contributing to fewer surfaces for adsorption (Wojciechowska *et al.,* 2017; Araya *et al.,*2016). The removal efficiency of 57.40% was calculated in the case of NH_4^+-N.Our results are in agreement with Dong *et al.,* 2012; Singh *et al.,* 2016; Akinbile *et al.,* 2012; Dadrasnia *et al.,* 2017. ZhengFang *et al.* (2008), observed 99.90% removal of ammonical nitrogen using immobilized bacteria but in our case, we obtained 57.40% removal due to the absence of artificial adding of mi-

Table 4. Showing characteristics of raw and diluted leachate (Physico-chemical and heavy metals)

Parameters/ Sampling	Raw leachate (Untreated)	Diluted Leachate (Untreated)	Treated Leachate	% Removal
Turbidity	116.80±13.68	57.30±5.54	7.40±1.8	87.09
Conductivity	12270.10±413.77	9000.60±336.52	1803.10±88.5	79.97
TDS	8221.10±272.22	6030.40±225.47	1192.40±48.7	80.23
TSS	205.90±20.01	147.00±226.6	43.30±6.6	70.54
TS	8427.00±271.97	6177.40±230.52	1344.00±35.9	78.24
pH	7.98±0.14	7.82±0.12	7.18±0.09	8.24
BOD	3421.50±433.58	1615.10±77.46	39.10±11.97	97.58
COD	12580.10±635.40	6274.50±556.15	186.30±24.18	97.03
TKN	246.50±21.20	141.60±14.12	33.40±4.43	76.41
NH_4-N	116.40±18.90	55.40±11.47	23.60±3.63	57.40
Chloride	2787.30±131.90	1295.50±79.02	504.30±21.68	67.03
Nitrates	41.05±3.18	23.25±0.82	8.09±0.56	65.19
Fluorides	1.48±0.16	0.68±0.07	0.28±0.05	67.09
T-phosphorous	32.60±1.99	14.03±0.91	4.27±0.54	69.57
Sulphate	39.21±1.50	22.97±1.16	3.24±0.81	85.89
Nickel	0.43±0.03	0.14±0.03	0.04±0.01	70.92
Lead	0.04±0.01	0.03±0.00	0.01±0.01	71.15
Zinc	1.85±0.21	1.09±0.13	0.31±0.09	71.49
Copper	1.97±0.07	0.94±0.07	0.21±0.04	78.00
Cadmium	0.31±0.10	0.19±0.07	0.07±0.04	64.74
Iron	11.58±1.02	5.40±0.88	1.25±0.24	76.88

crobes to the experiment and other factors as temperature, DO, pH and alkalinity. For the survival of nitrifying and denitrifying bacteria, an optimum amount of dissolved oxygen is necessary (Zhang *et al.*, 2002). In the case of chloride, nitrates, fluorides, and sulfate removal efficiency were 67.03%, 65.19%, 67.09%, and 85.89% respectively.

The removal efficiency of 69.57% was calculated in the case of total phosphorous. More or less similar efficiency was also observed by Akinbile *et al.*, 2012. In the case of lead, copper and cadmium removal were 71.15%, 78.00%, and 64.74% respectively. In the case of a nickel, a removal of 70.92% was calculated. A more or less similar result was obtained by He *et al.*, 2017. In the case of zinc, a removal of 71.49% was calculated. More or less similar efficiency was also observed by Akinbile *et al.*, 2012. In the case of iron removal of 76.88% was calculated. More or less similar efficiency was also observed by Bulc *et al.*, 2006. In the constructed wetlands on the upper layer, a microbial layer known as the Schmutzdecke layer was developed which acts as a biological barrier for the pollutants. Microbes present in this layer eat up all the organic matter present in the inlet water.

Conclusion

Constructed wetlands provide safe and eco-friendly solutions for the management of landfill leachate. Both upward and downward flow CW's are effective but upward flow constructed wetlands are much more effective as it increases the retention time of water in a different layer of the reactor. An increase in retention time increases the efficiency of the present upward flow constructed wetlands with *Pistia stratiotes.* The maximum removal efficiency was observed in the case of BOD (97.58%) followed by COD (97.03%), Turbidity (87.09%) and Sulphate (85.89%). In the case of all the parameters removal efficiency was found more than 60%, except pH (8.24%) and ammonical nitrogen (57.40%). Based on all the parameters studied we can conclude that upward flow constructed wetlands with *Pistiastratiotes* is a good alternative for landfill leachate treatment or wastewater management.

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