Leachate Characterization and Leachate Pollution Index from Landfill Dump Sites in Warri Metropolis, Nigeria

Asibor Godwin[1]* and Edjere Oghenekohwiroro[1]

[1]Department of Environmental Management and Toxicology, College of Science,
Federal University of Petroleum Resources, P.M.B. 1221, Effurun, Delta State, Nigeria.

*Corresponding Author, email: asibor.godwin@fupre.edu.ng

ABSTRACT. The paucity of standard engineered landfills in Nigeria has given rise to the proliferation of open waste dumpsites. The environment can be impacted by leachates from these dumpsites if not properly managed. This study assessed the characteristics of leachates from three open dumpsites in Warri Metropolis and its contamination potential using leachate pollution index (LPI). The dump sites had low pH with acidic level lower than the recommended limit. The calculated LPI values of the three sites ranges from 6.377 to 7.438. These values are low when compared to open dumpsites in other metropolitan areas of similar climatic conditions. The low value of LPI for leachate indicates relatively lower contaminant potential due to low concentrations of heavy metals, relatively young age of the landfill as well as low population and organic origin of the wastes. The calculated low LPI value does not in any way preclude the continuous monitoring of the dumpsites as the values recorded are just slightly below the threshold level. It is recommended that there should be an upgrade of all open dumpsites to a standard engineered landfill with a robust and effective monitoring put to curtail future release of deleterious materials from these dumpsites

INTRODUCTION

Solid waste management is a serious problem in Nigeria, as most cities lack standard engineered landfills. Open landfills are the primary means of municipal solid waste (MSW) disposal in many countries worldwide including Nigeria because they offer low economic costs and have capacity to accumulate large amounts of solid waste compared to other methods such as incineration [1, 2]. The absence of proper engineered landfills for disposal of wastes by the local and state governments has given rise to the proliferations of open dumps that are scattered in every nook and cranny of the country.

Leachate formation occurs when the percolating water dissolves the soluble components out of the solid material. This is generally heavily contaminated and consists of complex waste water that is very difficult to deal with [3, 4, 1, 5]. Further contaminants are added depending on the type of solid waste and biodegradation stage [6]. Many factors influence the leachate composition including the types of wastes deposited in the landfill, composition of wastes, moisture content, the particle size, the degree of compaction, the hydrology of the site, the climate, and age of the fill and other site specific conditions such as landfill design and type of liner used if any [6, 7]. As a result, surface water, groundwater reservoirs and soil layers become vulnerable to pollution from the dumpsite. A number of incidences have been reported in the past where leachates have been implicated in the contamination of surrounding soil and groundwater aquifer or nearby surface water [8, 9, 10]. It is therefore expedient that a comprehensive study be carried out on the assessment of pollution levels from these dumpsites, taking into account related parameters, which provide an overall perspective of the pollution of the dumpsites.

The estimation of quality of leachate generated is important for evaluating surface and ground water contamination and it is an indicator for the landfill degradation stage [11]. Biodegradable landfill produces leachate that contains significant ammonical nitrogen concentrations. Runoff water from landfill leachate containing suspended solids and ammonical nitrogen can be potential

toxins to the aquatic organisms [12]. Leachate is still a significant environmental threat even if the landfill contains non-hazardous waste. The potential of leachate contamination from landfill site can be estimated through Leachate Pollution Index (LPI) [13].

The Leachate Pollution Index value can be beneficial in many ways as it is used to report the variation in the leachate pollution over time at a particular landfill site. The trend of the leachate pollution at a specific site in an area can also facilitate the designing of leachate treatment facility for another site in the same area [14]. The LPI can be used to report pollution changes in specific landfill overtime. Other applications include ranking of landfill sites based on their leachate pollution potential, allocation of the resources for the remediation of leachate pollution, scientific research and leachate standards enforcement. A high Leachate Pollution Index value expresses a poor condition of surrounding environment.

LPI was formulated using Rand Corporation Delphi Technique [15]. The LPI represents the level of contamination potential of a given landfill. It is a single number ranging from 5 to 100, which expresses the overall contamination potential of a landfill based on severe pollution parameters at a given time. It is an increasing scale index, where a higher value indicates a poor environmental condition. The standard value of LPI is 7.378 [15].

This study was carried out to assess and characterise leachate from different open dump sites around Warri Metropolis, determined the pollution potential index, with a view of advising relevant authorities on appropriate monitoring plan to adopt.

MATERIALS AND METHODS

Area of Study

Warri is one of the towns geographically located within the western Niger Delta of Nigeria. It is situated some few kilometres away from the Atlantic Ocean. The Warri Refinery and Petrochemical Company (WRPC) and other oil and gas companies are jointly located in the Metropolis, thus making it one of the two major oil cities in Nigeria. It is the most populated town in Delta State. Warri Metropolis comprises Warri South, Uvwie, Okpe and Udu Local Government Areas (Figure 1) with a population of about 800,000 [16]. Figure 1 shows map of the three open waste dumpsites investigated within the metropolis, while details of the dumpsites are given in Table 1. The waste type from each of the dumpsites consists of organic, non-organic, hazardous and non-hazardous. These wastes may have originated from domestic, agricultures, industrial and electronic wastes.

Table 1: Details of the investigated open dumpsites

S/N	Landfill Area	LGA	Designation	Dimension	Year established	Waste Types
1	Okuvo	Okpe	Leachate 1 (LC1)	12 Acres	2010	General Waste
2	NPA Expresway	Uvwie	Leachate 2 (LC2)	10 acres	2004	General Waste
3	Osubi Abattoir	Okpe	Leachate 3 (LC3)	8 acres	2008	Abattoir & general wastes
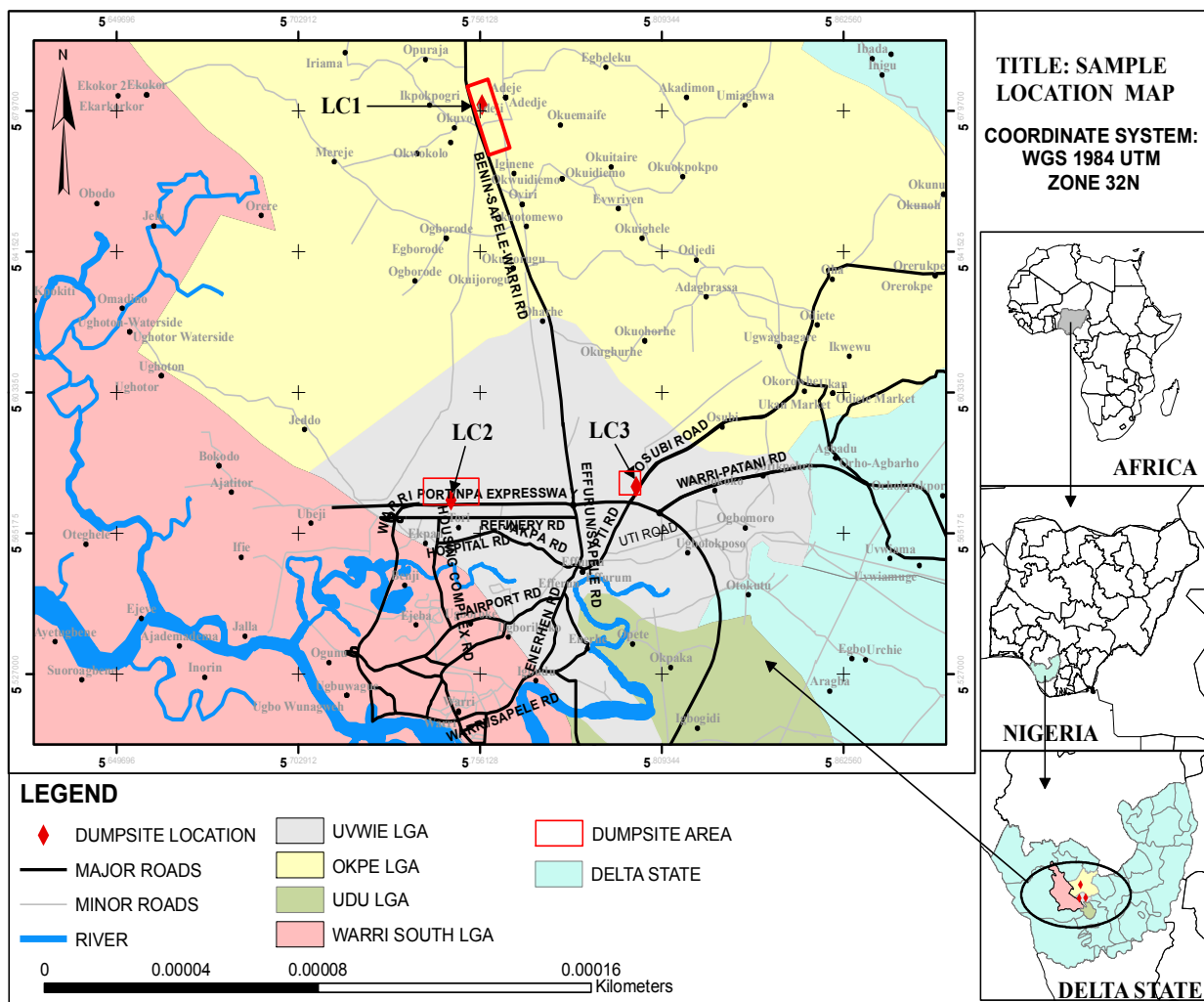
Figure 1: Map of Warri Metropolis Showing Study Area

Leachate sampling and analysis

Leachate samples were collected from trenches dug into the dumpsites and designated LC1, LC2 and LC3 for the three dumpsites as shown in Table 1. Sample containers were washed with detergent and rinsed with de-ionized water, thereafter rinsed with sample fluids prior to collection. *In-situ* analysis was carried out for pH, temperature, dissolved oxygen, total dissolved solids and conductivity. The measurement of leachate pH was carried out by pH meter, while temperature, conductivity and total dissolved solids was measured using thermometer and HANNA instrument meter. Leachate samples for other parameters were collected along the leachate surface flow path in clean 5Lpolyethylene bottles following the standard operating procedures according to [17] and transported to laboratory. Biological oxygen demand (BOD_5), chemical oxygen demand (COD), phosphate (PO_4^{-3}), nitrate (NO_3^{-1}) and sulphates (SO_4^{-2}) were estimated within 6 hours of sampling according to methods described in [17].

Metal analysis

Leachate samples were preserved by acidifying the samples with concentrated HNO_3 at pH less than 2. Samples were acid digested and filtered through 0.045µm membrane filter and analysed by atomic absorption spectrophotometer (AAS) Shimadzu AA-2000F.The chemical analysis was initiated immediately as soon as the samples arrived the laboratory in accordance with the [17] methods. The heavy metals analyzed include nickel, iron, lead, chromium, manganese, cadmium, arsenic and mercury.

Calculation of Leachate Pollution Index (LPI)

The data from the analysis of samples were used. The 'P' values or sub-index values for all the parameters analysed were computed from the sub-index curves based on the concentration of the leachate pollutions obtained during the analysis. The 'P' values were obtained by locating the concentration of the leachate pollutant on the horizontal axis of the sub index value where it intersected the curve was noted. The 'P' values obtained for the parameters analysed were multiplied with the respective weights assigned to each parameter. The LPI for each of the dumpsite leachate was calculated using the equation of [18] as shown in the equations below.

$$LPI = \sum_{I=1}^{n} wi.pi \qquad \text{(equation 1)}$$

Where,
LPI = the weighted additive leachate pollution index, *wi*= the weight for the *Ith*pollutant variable, *pi* = the sub index value of the *I* th leachate pollutant variable, *n = 18 and Σ wi =1*. However, when the data for all the pollutant variables included in *LPI* is not available, the *LPI* can be calculated using data set of the available pollutants by the equation

Where
$$LPI = \sum_{I=1}^{n} wi.pi / \sum_{I=1}^{n} wi \qquad \text{(equation 2)}$$

Where pollutant parameter for which data is available in this study as, m < 18 and Σ wi <1

RESULTS

The results obtained from the physico-chemical analysis of leachates at the three dumpsites are summarized in Table 2. The pH values for the three leachate samples examined ranged from 5.48 to 6.38, with mean values of 5.78±0.54, 5.74±0.64 and 6.02±0.34 for LC1, LC2 and LC3. The electrical conductivity (EC) values for the three leachate samples depict different values, in which LC1 has the highest value of 4194±68.6μS/cm, followed by LC2 with value of 2556±54.8μS/cm, while the lowest value of 1880±58.8μS/cm was recorded for the LC3 leachate sample. Total dissolved solids (mg L-1) of the leachates range from 1080 to 2870 to 2680.The oxygen demanding parameters of $BOD_5$and COD, nutrients and heavy metals concentrations are also depicted in the Table 2.

The concentration of heavy metals was fairly low and similar for all the dumpsites except for iron and chromium where slightly elevated concentrations were recorded the dumpsites.

The calculated leachate pollution index (LPI) value of the three dumpsites are presented in Table 3 with values of 7.438, 6.963 and6.377 respectively.

Table 2: Comparison of the mean values of the leachate characteristics with standard

S/N	Parameter	Leachate (LC1)	Leachate (LC2)	Leachate (LC3)	Standard (India)*
1	Odour	Objectionable	Objectionable	Objectionable	NA
2	pH	5.78±0.54	5.74±0.64	6.02±0.34	6.0-9.0
3	Temperature (^{o}C)	31.3±2.28	30.8±1.86	30.5±1.22	35
4	TDS (mg/l)	2,330±40.4	1,420±20.8	1090±28.6	2000
5	Conductivity (μ/cm)	4,194±68.6	2,556±54.8	1880±58.8	125
6	BOD (mg/l)	41.2±6.4	35.3±8.4	55.0±4.2	30
7	COD (mg/l)	103.11±11.6	88.25±12.2	150.8±16.8	75
8	BOD/COD	0.400	0.400	0.365	0.400
9	Phosphate (mg/l)	63.26±6.4	57.34±4.4	56.2±8.6	50

10	Sulphate (mg/l)	110.43±16.8	103.52±12.8	98.8±12.6	100
11	Nitrate (mg/l)	38.11±6.2	27.08±4.8	28.8±6.8	20
12	Nickel (mg/l)	0.215±0.08	0.187±0.04	0.224±0.02	0.01
13	Chromium (mg/l)	3.873±1.02	2.764±0.88	3.04±1.04	0.2
14	Iron (mg/l)	10.217±4.2	9.773±3.6	28.8±4.8	0.05
15	Lead (mg/l)	0.843±0.11	0.642±0.18	0.456±0.20	0.05
16	Cadmium (mg/l)	0.504±0.04	0.431±0.06	0.602±0.08	0.01
17	Manganese (mg/l)	0.144±0.06	0.128±0.04	0.122±0.11	0.05
18	Arsenic (mg/l)	0.043±0.02	0.031±0.02	0.082±0.01	NA
19	Mercury (mg/l)	<0.001±0.00	<0.001±0.00	<0.001±0.00	NA

*Rafizul *et al.* (2011)

Table 3: Calculated leachate pollution index (LPI) in the three dumpsites

Parameter	Variable weights (wi)	Leachate1 (LC1)			Leachate1 (LC2)			Leachate1 (LC3)		
		ci	pi	wipi	ci	pi	wipi	ci	pi	wipi
pH	0.055	5.78	5.5	0.303	5.74	5.5	0.303	6.02	0.55	0.030
TDS	0.050	2,330	5.5	0.275	1,420	5.2	0.26	1090	5	0.250
BOD	0.061	41.2	5.6	0.342	35.3	5.5	0.336	55.0	5.6	0.342
COD	0.062	103.11	5.6	0.347	88.25	5.6	0.347	150.8	5.8	0.360
NO_3^-	0.053	38.11	5	0.265	27.08	5	0.265	28.8	5	0.265
Ni	0.052	0.215	5	0.26	0.187	5	0.26	0.224	5	0.260
Cr	0.064	3.873	24	1.536	2.764	18	1.152	3.04	20	1.280
Fe	0.045	10.217	5	0.225	9.773	5	0.225	28.8	5	0.225
Pb	0.063	0.843	8	0.504	0.642	7	0.441	0.456	6	0.378
As	0.061	0.043	5	0.305	0.031	5	0.305	0.082	5	0.305
Hg	0.062	0.001	5	0.31	0.001	5	0.31	0.001	5	0.310
Total	0.628			4.671			4.203			4.005
LPI Value				7.438			6.963			6.377

DISCUSSION

Average pH for the three leachates was acidic as shown in Table 2. Leachates are generally found to have pH of a range between 4.5 and 6, this was observed in the dumpsites analysed. A similar trend was observed by [19, 20, 21, 9] who postulated that young and active leachates from dumpsite are usually accompanied with low pH. The low value of pH is a strong reflection of an acid producing phase during the decomposition of wastes. According to [22], the low value of pH measured, is an indication of leachate undergoing anaerobic or methanogenic phase. [23] described this phase of decomposition of wastes with the production of volatile fatty acids and carbon dioxide. Tthe initial period of leachate formation is characterized by very low pH values and later with higher pH values at the methanogenic phase. Stabilised leachates usually show fairly constant pH in the alkaline range of 7.5 and 9 [15]. Therefore, the leachates in the three dumpsites with pH less than 6 is not in a stable condition as the dumpsites are still active and eceives waste on a daily basis.

The TDS reflects the extent of mineralization and a higher TDS concentration can change the physical and chemical characteristics of the receiving water [24, 5]. The dissolved organic and inorganic are the constituents of TDS. The TDS of the dumpsites investigated ranged from 1080 to 2870 mg/L. High level of total dissolved solids in leachate was due to the presence of large amount of anions and cations indicating presence of inorganic material [25] and represents the extent of mineralization of leachate [24].

High biological and chemical oxygen demands are indicative of high organic matter content in leachate [26]. In the present study, the leachates showed low to medium concentration of BOD and COD. BOD/COD ratio is the organic matter biodegradability measurement and indicates the leachate and landfill maturity [28]. The mean BOD/COD ratio at LC1, LC2and LC3 dump sites was 0.40, 0.40 and 0.37 respectively. Leachates from older waste dump sites usually have lower BOD/COD ratio as compared to the leachates from young waste.

Nitrate is present in leachate due to numerous combustion processes happening in dump sites that releases nitrogen oxide [8], while presence of phosphate in leachate is due to organic waste degradation containing phospho-proteins and phospholipids [25].

The concentration of heavy metals in landfill leachate was fairly low for all the locations analysed. Concentration of heavy metals in a landfill is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids [19]. With a low pH due to increased waste generation, there is a likely increase in metal solubility occurring as a result of rapid increase in concentration of heavy metals due to production of heavy metal complex with humic acids [27]. This assertion supports the likelihood of increase in the concentration of heavy metals in all the dumpsites in later years. This will be supported by the solubility and mobility of metals in the presence of natural and synthetic complexing ligands such as humic substances [29]. The presence of complexing ligands in the dumpsites analysed will increase the concentration of heavy metals. In general, the condition in each of the dumpsites investigated determines the concentration of heavy metals in later years.

High concentrations of heavy metals like Cr, Ni, Pb and Cd in leachate indicates that apart from domestic organic waste, there was presence of industrial and municipal wastes which might contain objects like fluorescents lamps, paint products, re-fused batteries and metallic items [30, 31]. Presence of Cr may be due to paint products, wood preservatives and high value of Mn suggests the presence of reducing environment in the dumping site [26]. The presence of these heavy metals were low in the investigated dumpsites, suggesting low industrial output among the wastes generated to these areas.

The contamination potential of leachate is effectively presented through Leachate Pollution Index (LPI). The calculated LPI values of these sites are 7.438, 6.963 and 6.377 for LC1, LC2 and LC3. These values is less when compared to the dump sites in other metropolitan areas such as Punjab, India [5, 6, 7, 32, 33, 34, 10] who all recorded LPI greater than 15, but a low LPI of 3.71, 4.71 and 7.12 was recorded by [15] in the Port-Harcourt City of Nigeria. Thus a low LPI value is not strange. Calculated LPI value is usually influenced by the age of the landfill. The higher value of LPI indicates that the dump site leachate has not been stabilized. According to [6], the low value of LPI for leachate indicates relatively lower contaminant potential. Low value of LPI may also be attributable to low concentrations of heavy metals in the Leachate. Landfill age also plays an important role in the leachate characteristics and hence, influences the LPI value.

The LPI value at all three dump sites in Warri Metropolis was less than the standard value of 7.4 [25] a similar value was obtained by [15] for Port-Harcourt Metropolis. The low LPI values of these dumpsites maybe due to low population and organic origin of the wastes as there are few industrial wastes collected from the metropolis compared to high values recorded in other studies. The low LPI reported may also be due to the lower individual pollution ratings of the sites. The lower LPI value for the three sample locations suggests that the landfill leachate is stabilized which is also indicated by the BOD5 and COD values (Table 2).

Nigeria has no known leachate disposal standard and as a result a standard for the disposal of treated leachate from India was adopted. An LPI value which falls below the stipulated standard of 7.378 is accepted and any value above the standard is not accepted [6, 7, 33, 15]. The LPI values of the three dumpsites investigated were below 7.378. This implies the leachates from each of the dumpsites may not have high adverse potential to pollute the vegetation, soil, surface and groundwater within the vicinity of the dumpsites. This does not in any way preclude the continuous monitoring of the dumpsites as the values recorded are just slightly below the threshold level and this can be quickly altered in the nearest future as the dumpsite are still very active.

CONCLUSION

LPI is a very useful tool to assess and monitor the integrity of leachate generated from dumpsites and thus can assist in taking necessary decisions. At present Nigeria does not have a known leachate disposal standard, therefore standard from a similar country was adopted to compare LPI value obtained for this study. The three leachates from the Warri Metropolis dump sites had high contamination potential, though below the threshold standard level during the study. It is recommended that the state government through its waste management board and environmental protection agencies upgrade all identified open dumpsites to a standard engineered landfill and put in place an effective and robust monitoring plan. This will curtail future release of deleterious materials from these dumpsites to the surrounding environment.

References

[1] S. Mohajeri, M. H. Aziz, M. A. Zahed, M. N. Adlan, Statistical optimization of process parameters for landfill leachate treatment using electro-Fenton technique. *J. Hazard Mat.* 176(1–3) (2010)749–758.

[2] V. Tsarpali, M, Kamilari, S. Dailianis, Seasonal alterations of landfill leachate composition and toxic potency in semi-arid regions. *J Hazard Mat.* 233(234) (2012) 163–171.

[3] Z. Daud, A. Aziz, M. N. Adlan, Y. T. Hung, Application of combined filtration and coagulation for semi-aerobic leachate treatment. *International Journal of Environment and Waste Management*, 4(3) (2009) 457–469.

[4] A. A. Foul, H. A. Aziz, M. H. Isa, Y. Hung, Primary treatment of anaerobic landfill leachate using activated carbon and limestone: Batch and column studies. *International Journal of Environment and Waste Management*, 4(4) (2009) 282–298.

[5] U. Muhammad, A. Hamidi, S. Y. Mohd, Variability of parameters involved in leachate pollution index and determination of LPI from four Landfills in Malaysia. *International Journal of Chemical Engineering*. DOI.1155/2010/747953.

[6] I. M. Rafizul, M. Alamgir, M. M. Islam, Evaluation of Contamination Potential of Sanitary Landfill Lysimeter Using Leachate Pollution Index. *Proceedings of thirteenth International Waste Management and Landfill Symposium, Sardinia, Cagliari, Italy; 3 - 7 October 2011 CISA, Environmental Sanitary Engineering Centre, Italy.*

[7] I. M. Rafizul, M. Alamgir, S. M. Shahed Sharif, Analysis and Selection of Appropriate Aggregation Function for Calculating of Leachate Pollution Index of Landfill Lysimeter. *Iranica Journal of Energy & Environment* 3 (4) (2012) 370-379.

[8] S. O. Ojoawo, O. A. Agbede, A. Y. Sangodoyin, Characterization of Dumpsite Leachate: Case Study of Ogbomosoland, South-Western Nigeria. *Open Journal of Civil Engineering* 2(1) (2012) 33-41.

[9] O. Ohwoghere-Asuma, K. E. Aweto, Leachate characterization and assessment of groundwater and surface water qualities near a municipal solid waste dump site in Effurun, Delta State, Nigeria. *Journal of Environment and earth Science.* Vol. 3, No. 9, (2013) 126-134.

[10] B. M. Awaz, Leachate and Groundwater Assessment at Kirkuk Sanitary Landfill Site in Zindana Village, Iraq. *Int. J. Environ. Res.,* 9(2) (2015)457-466.

[11] D. Frascari, F. Bronzini, G. Giordano, G. Tedioli, M. Nocentini, Long-term characterization, lagoon treatment and migration potential of landfill leachate: a case study in an active Italian landfill. *Chemosphere* 54(3) (2004) 335–343.

[12] Z. Salem, K. Hamouri, R. Djemma, K. Allia, Evaluation of landfill leachate pollution and treatment. *Desalination* 220(1-3) (2008) 108-114.

[13] D. Kumar, B. J. Alappat, Evaluating leachate contamination potential of landfill sites using leachate pollution index. *Clean Tech and Environ Policy* 7(3) (2005) 190–197.

[14] J. Y. M. Alkassasbeh, L. Y. Heng, S. Surif, Toxicity testing and the effect of landfill leachate in Malaysia on behavior of common carp (*Cyprinuscarpio* L., 1758; Pisces, Cyprinidae). *Ame. J. Environ Sci*, 5 (3) (2009) 209–217.

[15] I. E. Agbozu, M. Nwosisi, Determination of pollution index between active and closed dumpsites in Port Harcourt Metropolis. *Journal of Chemical, Biological and Physical Sciences*, Vol. 5, No. 2 (2015) 2051-2061.

[16] NBS, Federal Republic of Nigeria, National Bureau of Statistics. 2009-03-25.

[17] APHA, AWWA, WEF, Standard Methods for the Examination of Water and Wastewater, 21[st]ed. American Public Health Association, the American Water Works Association and the Water Environment Federation Publication, Washington, DC 2005.

[18] D. Kumar, B. J. Alappat, A technique to quantify landfill leachate pollution. *Ninth International Landfill Symposium*, October 2003, Cagliari, Italy.

[19] T. H. Christensen, P. Kjeldsen, P. Kjelden, Biogeochemistry of landfill leachate plumes. *Applied Geochemistry*, 6(7) (2001)659–718.

[20] L. B. Jorstad, J. Jankowski, R. I. Acworth, Analysis of the distribution of inorganic constituents in a landfill leachate contaminated aquifers Astrolabe Park, Sydney, Australia. *Environ Geology* 46(2) (2004) 263–272.

[21] A. A. Abbas, G. Jingsong, L. Z. Ping, P. Y. Ya, W. S. Al-Rekabi, Review on landfill leachate treatments. *Journal of Applied Science Research*, 5(5) (2009) 534–545.

[22] B. J. Alloway, *Heavy metals in soils.*2[nd]edition. Chapman and Hall, London: UK. 1995

[23] P. Kjeldsen, M. A. Barlaz, A. P. Rooker, A. Baun, A. Ledin, T. H. Christensen, Present and long term composition of MSW landfill leachate: A review. *Critical Rev. Environ. Sci. Tech.*, 32(4) (2002) 297-336.

[24] A. F. Al-Yaqout, M. F. Hamoda, Evaluation of landfill leachate in arid climate - a case study. *Environmental International*, 29(5) (2003) 593–600.

[25] P. D. Dsouza, R. K. Somashekar, Assessment of Stabilization, Temporal Variation and Leachate Contamination Potential of Municipal Solid Waste Dumpsites in Bangalore. *International Journal of Environmental Protection* 3(1) (2013) 28-35.

[26] S. S. Kale, A. K. Kadam, S. Kumar, N. J. Pawar, Evaluating pollution potential of leachate from landfill site, from the Pune metropolitan city and its impact on shallow basaltic aquifers. *Environ Monitor Assess* 162(1-4) (2010) 327–346.

[27] Y. Deng, J. D. Englehardt, Electrochemical oxidation for landfill leachate treatment. *Waste Management*, 27(3) (2007) 380–388.

[28] M. E. Fadel, E. B. Zeid, W. Chahine, B. Alayli, Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content. *Waste Management,* 22(3) (2002) 269–282.

[29] D. L. Jones, K. L. Wiliamson, A. G. Owen, Phytoremediation of landfill leachate. *Waste Management*, 26(8) (2006) 825–837.

[30] S. Mor, K. Ravindra, R. P. Dahiya, A. Chandra, Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environ Monitor Assess.* 118(1-3) (2006) 435-456.

[31] M. C. Z. Moturi, M. Rawat, V. Subramanian, Distribution and fractionation of heavy metals in solid waste from selected sites in the industrial belt of Delhi, India. *Environ Monitor Assess.* 95 (1-3) (2004) 183-199.

[32] B. Bhalla, M. S. Saini, M. K. Jha, Leachate contamination potential of unlined Municipal solid waste landfill sites by leachate Pollution index. *International Journal of Science, Environment and Technology*, Vol. 3, No 2 (2014a) 444 – 457.

[33] B. Bhalla, M. S. Saini, M. K. Jha, Assessment of Municipal Solid Waste Landfill Leachate Treatment Efficiency by Leachate Pollution Index. *International Journal of Innovative Research in Science, Engineering and Technology*. Vol. 3, Issue 1 (2014b) 8447-8454.

[34] S. Munir, A. B. Tabinda, A. Ilyas, T. Mushtaq, Characterization of Leachate and Leachate Pollution Index from Dumping Sites in Lahore, Pakista. *J. Appl. Environ. Biol. Sci.*, 4(4) (2014) 165-170.

Leachate Characterization and Leachate Pollution Index from Landfill Dump Sites in Warri Metropolis, Nigeria

DOI References

[1] S. Mohajeri, M. H. Aziz, M. A. Zahed, M. N. Adlan, Statistical optimization of process parameters for landfill leachate treatment using electro-Fenton technique. J. Hazard Mat. 176(1-3) (2010)749-758.

10.1016/j.jhazmat.2009.11.099

[2] V. Tsarpali, M, Kamilari, S. Dailianis, Seasonal alterations of landfill leachate composition and toxic potency in semi-arid regions. J Hazard Mat. 233(234) (2012) 163-171.

10.1016/j.jhazmat.2012.07.007

[3] Z. Daud, A. Aziz, M. N. Adlan, Y. T. Hung, Application of combined filtration and coagulation for semi-aerobic leachate treatment. International Journal of Environment and Waste Management, 4(3) (2009) 457-469.

10.1504/ijewm.2009.027409

[4] A. A. Foul, H. A. Aziz, M. H. Isa, Y. Hung, Primary treatment of anaerobic landfill leachate using activated carbon and limestone: Batch and column studies. International Journal of Environment and Waste Management, 4(4) (2009) 282-298.

10.1504/ijewm.2009.027397

[5] U. Muhammad, A. Hamidi, S. Y. Mohd, Variability of parameters involved in leachate pollution index and determination of LPI from four Landfills in Malaysia. International Journal of Chemical Engineering. DOI. 1155/2010/747953.

10.1155/2010/747953

[7] I. M. Rafizul, M. Alamgir, S. M. Shahed Sharif, Analysis and Selection of Appropriate Aggregation Function for Calculating of Leachate Pollution Index of Landfill Lysimeter. Iranica Journal of Energy & Environment 3 (4) (2012) 370-379.

10.5829/idosi.ijee.2012.03.04.11

[8] S. O. Ojoawo, O. A. Agbede, A. Y. Sangodoyin, Characterization of Dumpsite Leachate: Case Study of Ogbomosoland, South-Western Nigeria. Open Journal of Civil Engineering 2(1) (2012) 33-41.

10.4236/ojce.2012.21006

[11] D. Frascari, F. Bronzini, G. Giordano, G. Tedioli, M. Nocentini, Long-term characterization, lagoon treatment and migration potential of landfill leachate: a case study in an active Italian landfill. Chemosphere 54(3) (2004) 335-343.

10.1016/j.chemosphere.2003.08.013

[12] Z. Salem, K. Hamouri, R. Djemma, K. Allia, Evaluation of landfill leachate pollution and treatment. Desalination 220(1-3) (2008) 108-114.

10.1016/j.desal.2007.01.026

[13] D. Kumar, B. J. Alappat, Evaluating leachate contamination potential of landfill sites using leachate pollution index. Clean Tech and Environ Policy 7(3) (2005) 190-197.

10.1007/s10098-004-0269-4

[14] J. Y. M. Alkassasbeh, L. Y. Heng, S. Surif, Toxicity testing and the effect of landfill leachate in Malaysia on behavior of common carp (Cyprinuscarpio L., 1758; Pisces, Cyprinidae). Ame. J. Environ Sci, 5

(3) (2009) 209-217.

10.3844/ajessp.2009.209.217

[15] I. E. Agbozu, M. Nwosisi, Determination of pollution index between active and closed dumpsites in Port Harcourt Metropolis. Journal of Chemical, Biological and Physical Sciences, Vol. 5, No. 2 (2015) 2051-(2061).

10.4314/ijbcs.v9i2.46

[19] T. H. Christensen, P. Kjeldsen, P. Kjelden, Biogeochemistry of landfill leachate plumes. Applied Geochemistry, 6(7) (2001)659-718.

10.1016/s0883-2927(00)00082-2

[20] L. B. Jorstad, J. Jankowski, R. I. Acworth, Analysis of the distribution of inorganic constituents in a landfill leachate contaminated aquifers Astrolabe Park, Sydney, Australia. Environ Geology 46(2) (2004) 263-272.

10.1007/s00254-004-0978-3

[21] A. A. Abbas, G. Jingsong, L. Z. Ping, P. Y. Ya, W. S. Al-Rekabi, Review on landfill leachate treatments. Journal of Applied Science Research, 5(5) (2009) 534-545.

10.3844/ajas.2009.672.684

[23] P. Kjeldsen, M. A. Barlaz, A. P. Rooker, A. Baun, A. Ledin, T. H. Christensen, Present and long term composition of MSW landfill leachate: A review. Critical Rev. Environ. Sci. Tech., 32(4) (2002) 297-336.
10.1080/10643380290813462

[24] A. F. Al-Yaqout, M. F. Hamoda, Evaluation of landfill leachate in arid climate - a case study. Environmental International, 29(5) (2003) 593-600.

10.1016/s0160-4120(03)00018-7

[26] S. S. Kale, A. K. Kadam, S. Kumar, N. J. Pawar, Evaluating pollution potential of leachate from landfill site, from the Pune metropolitan city and its impact on shallow basaltic aquifers. Environ Monitor Assess 162(1-4) (2010) 327-346.

10.1007/s10661-009-0799-7

[27] Y. Deng, J. D. Englehardt, Electrochemical oxidation for landfill leachate treatment. Waste Management, 27(3) (2007) 380-388.

10.1016/j.wasman.2006.02.004

[28] M. E. Fadel, E. B. Zeid, W. Chahine, B. Alayli, Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content. Waste Management, 22(3) (2002) 269-282.

10.1016/s0956-053x(01)00040-x

[29] D. L. Jones, K. L. Wiliamson, A. G. Owen, Phytoremediation of landfill leachate. Waste Management, 26(8) (2006) 825-837.

10.1016/j.wasman.2005.06.014

[30] S. Mor, K. Ravindra, R. P. Dahiya, A. Chandra, Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Environ Monitor Assess. 118(1-3) (2006) 435-456.

10.1007/s10661-006-1505-7

[31] M. C. Z. Moturi, M. Rawat, V. Subramanian, Distribution and fractionation of heavy metals in solid waste from selected sites in the industrial belt of Delhi, India. Environ Monitor Assess. 95 (13) (2004) 183-199.

10.1023/b:emas.0000029900.86810.85