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Assessment of leachate contamination potential of landfills in Ibadan, Nigeria

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Environmental pollution leads to poor health and has been a worrisome experience to humanity for the past few decades. This research was conducted to determine the pollution potential of landfill leachates (LFL) in Sub-Saharan Africa, using Ibadan as case study. Survey of landfills in the metropolis was undertaken; the two major active unlined landfills (Ajakanga and Awotan), were considered for this study. During sampling, eighteen parameters of interest were analyzed. The leachate pollution indices (LPI) of each landfill were calculated. The LPI of Awotan landfill is 17.55 while that of Ajakanga is 15.67. With the exceedances of the 7.378 standard LPI value, all landfills in the metropolis is recommended to be closed down in line with international best practices and new sanitary landfills set up in their stead. Based on the sub-LPI values obtained, biological treatment would be the most viable treatment option for the LFL produced. The findings from this study are applicable in landfill management in other countries within the African sub-region; thereby contributing to the attainment of Sustainable Development Goals (SDGs).

Key words: Leachate pollution index, landfill, sustainable development goals, Ibadan, Nigeria, assessment.

INTRODUCTION

Landfilling still remains the most popular method of solid waste disposal practiced by municipal authorities worldwide, despite the use of Integrated Municipal Solid Waste Management. Landfills Leachates have been associated with the alteration of ecological balance, and has been a major source of environmental concern. In a rather responsive fashion, landfills have now evolved into well-engineered facilities that are equipped with bottom liners and leachate management setups to minimize the migration of this leachate into the environment. Regrettably, most developing economies, like Africa and Asia, have failed to keep up with the pace of this evolution (Johannessen and Boyer, 1999; Onibokun and Kumuyi, 1999; Rafizul et al., 2012; Waste Atlas Report, 2014). With the increasing volume and variety of waste constantly finding their way into landfills owing to rapid population growth and urbanization, chances are that the contiguous habitat, to say the least would continue to suffer from increasing impact of landfill leachate. Sub-Saharan Africa is of particular concern, being the region with the world highest annual urbanization rate (about 4.1%), not to mention the largely inadequate waste management infrastructure and poor land use planning bedevilling the region (Onibokun and Kumuyi, 1999; Saghir and Santoro, 2018).

Leachate contains a myriad of chemical constituents' consequent from the solubilisation of in-place waste as well as chemical cum biochemical reactions occurring

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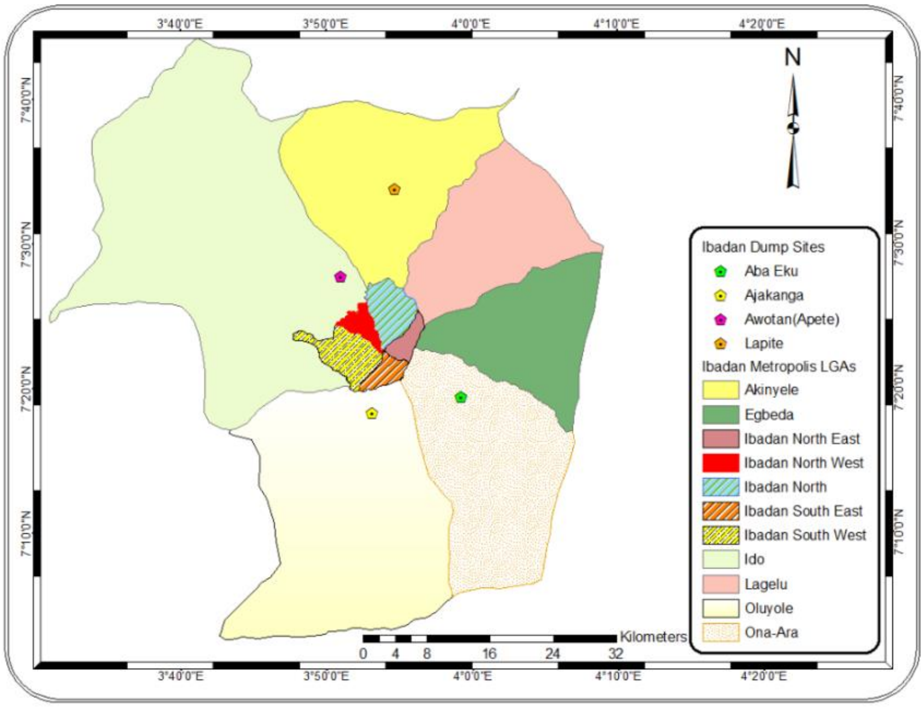

Figure 1. Map of Ibadan metropolis showing the approved landfills.

within the landfill system, the composition of which varies throughout the lifespan of the landfill (Santoro, 2018). Leachate production rate is largely dependent on the precipitation, the in-place moisture content of waste, run-on cum run-off, evapotranspiration and the level of water table relative to the base of the landfill unit (Klinck and Stuart, 1999), water table level is of concern because shallow water table can be easily polluted, while deep water table may not because of natural soil purification process.

It is necessary to have a uniform scale assessment of leachate pollution data of various landfill facilities (or even same facility at different instants) are assessed. In fact, it was in response to this necessity that a quantitative tool (Leachate Pollution Index, LPI), based on Rand Corporation DELPHI Technique was developed for measuring leachate pollution potential of landfills (Kumar and Alappat, 2003). It is also relevant in providing guide as to what leachate treatment option to adopt; LPI is useful in landfill ranking, landfill trend analysis, public awareness campaigns and budgetary planning Vis à-vis site remediation. Manimekalai and Vijayalakshmi (2012) opine that result of leachate trend analysis for a particular landfill site can be used in the design of leachate treatment facilities for other sites having analogous conditions.

Though much energy have been geared towards characterization of landfill leachates and the assessment of their impacts, leachate pollution index data from landfills are still very limited despite their relevance. In Ibadan metropolis for instance, only one dumpsite has such empirical data (Aromolaran et al., 2019); this is very disturbing considering the fact that the metropolis, which has four approved dumpsites and more than a few illegal open dumps, is the largest in Sub-Saharan Africa and third most populous in Nigeria. This research endeavors to assess the contamination potential of leachate from two major landfill sites in Ibadan metropolis through leachate pollution index modelling.

Study area

Ibadan Metropolis is the largest settlement (approximately 3123km^2) in tropical Africa, south of the Sahara. With an estimated population of 3.4 million, Ibadan ranked third most populous Nigerian city (IUFMP, 2014; Lapworth et al., 2019). It has a tropical climate, having two distinct seasons: wet season (April to October) and dry season (November to March). It has a mean annual rainfall of about 1150 mm. Situated in Oyo State, South-Western Nigeria; Ibadan consists of eleven Local Government Areas (Figure 1). Four approved dumpsites, all located in the suburbs, receive commingled waste from the entire metropolis: Aba-Eku landfill, Ajakanga landfill, Awotan landfill and Lapite landfill. The unsanitary manner, in which they are managed, is one of the major reasons for Ajakanga and Awotan landfills (South and North of Ibadan urban respectively) to have been chosen.

Ajakanga landfill is a legal dumpsite lying approximately on latitude 7.3114N and longitude 3.8414E in close proximity with River Ona (only separated by Odo Ona Elewe Road) near Arapaja in Oluyole LGA (Omonigho, 2020). Situated in a rapidly developing community, a sizeable lot of the 10.03-hectare landfill has been allegedly encroached by adjacent human settlement. The government-owned landfill is operated by the Oyo State Waste Management Authority (OYWMA) and has been active since 1996. The dumpsite receives an average annual waste of about 205,000 tonnes (Falusi et al., 2016).

Awotan landfill (also called Apete landfill) is located on latitude 7.463N and longitude 3.849E, along the deplorable Apete-Awotan-Akufo Road in Awotan, Ido Local Government Area of Oyo State. Awotan community plays host to a number of institutions, commercial outfits and residential settlements close to the landfill. The facility, which is owned by Oyo State Government and operated by same through the OYWMA, takes delivery of approximately 78,000 tonnes of waste annually (Falusi et al., 2016). Established in 1998, the second largest landfill (20.26 hectares) in the metropolis made the list of *The World's 50 Biggest Dumpsites* (Waste Atlas, 2014).

MATERIALS AND METHODS

There was field reconnaissance of all four major landfills in Ibadan metropolis after a familiarization visit to the Oyo State Waste Management Authority to obtain access to the facilities. Then stratified, purposeful selection base on records of propensity randomly selection of two landfill sites for the study: Ajakanga landfill and Awotan landfill, South and North of Ibadan urban respectively was carried out. Measurements of the geographical coordinates of the landfills with the aid of a handheld Global Positioning System (GPS) device were undertaken.

Samples were obtained between December 2019 and January 2020 when the harshest effects of leachate could be felt. It is during this time that leachate effects are felt more in relation to health as rural people often embark on rain harvesting during the raining season and result to ground water harvesting during dry season. The seasonal physicochemical analysis of the leachates showed that rainfall events increase the decomposition rate of the waste and affect pollutant concentration of the leachate (Falusi et al., 2016).

Composite leachate samples were obtained from three purposefully selected points from each dumpsite. The samples were collected into thoroughly pre-washed sterile 75 cl bottles on ice.

The pH and electrical conductivity (EC) were recorded on site at the time of sampling with digital pH meter and digital EC meter, respectively. For heavy metal analyses, samples were separately collected in pre-washed polypropylene containers of 50 cl capacity and acidified onsite to avoid precipitation of metals.

Analytical methods

The parameters were selected based on their relative importance in municipal landfill leachates composition, and their pollution potential on groundwater resource in particular (Bagchi 2004). The physicochemical parameters such as total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), major cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}), major anion such as chlorides (Cl-) of the leachate and groundwater samples were analyzed by titrimetric methods. Chloride was included in the water quality assessment because of its measure of extent of dispersion of leachates in groundwater body (Chapman 1992). Sulfates ($SO_4{}^{2-}$) in the groundwater samples were analyzed by nephelometric turbidity method (APHA, 1998). Nitrates (NO_3^-) and total organic carbon (TOC) determination in the groundwater samples were carried out by DR 2700 spectrometer. Estimation of chemical oxygen demand (COD) was done by closed reflux titrimetry method, while biochemical oxygen demand (BOD) was calculated using oxygen determination by Winkler titration for the preserved leachate sample. All the analyses in this study were repeated two or three times until concordant values were obtained, and all the tests were carried out according to the standard methods (APHA, 1998; APHA, 2005). The heavy metals such as Cd, Cu, Mn, Pb and Zn concentrations in the leachate and ground water samples were analyzed using atomic absorption spectrophotometer (AAS) supplied by Thermo Fisher Scientific, USA with D2 background correction lamp. Standard solutions of heavy metals viz. copper (Cu), cadmium (Cd), manganese (Mn), lead (Pb) and zinc (Zn) were prepared with distilled water using copper sulfate (CuSO45H2O), cadmium sulfate ($CdSO_{48}H_2O$), manganese sulfate ($MnSO_47H_2O$), lead nitrate [$Pb(NO_3)^2$], and zinc nitrate [$Zn(NO_3)^2$ $6H_2O$].

Their wastewater discharge limits were then compared with the laboratory results to determine their level of compliance. Calculation of pollution indices using leachate characterization results based on DELPHI technique using the linear weighted sum aggregation method given thus (Kumar and Alappat, 2005):

$$Overall\ LPI = 0.232LPI_{\mathrm{org}} + 0.257LPI_{\mathrm{in}} + 0.511LPI_{\mathrm{hm}} \quad (1)$$

Where, LPI is the acronym for Leachate Pollution Index; LPI_{org} is the sub-leachate pollution index organic component value; LPI_{in} is the sub-leachate pollution index inorganic component value; and LPI_{hm} is the sub-leachate pollution index heavy metal component value.

Each sub-LPI is given by the expression:

$$LPI_x = \frac{\sum_{i=1}^{m} w_i p_i}{\sum_{i=1}^{m} w_i} \quad (2)$$

Where w_i = weight factor and p_i = sub – index value of the applicable analytes

RESULTS AND DISCUSSION

Characterization of landfill leachates

The mean values obtained from the physicochemical and microbiological examination of the leachate samples compared with the WHO wastewater discharge limits are in Table 1. The result of leachate characterization presented shows high concentration of a myriad of physicochemical and microbial parameters, with the following exceeding the discharge limits stipulated by the World Health Organisation: TDS, DO, BOD, Na^+, Cr^{++}, Cu^{++}, Ag^{++} (Table 1).

The pH values of the leachate in Ajakanga and Awotan landfills are 7.6 and 8.3 respectively, revealing old leachates under steady state. These values are in line with the pH value of 8.03 reported in Aba-Eku in Ibadan by Aluko et al., 2003. The pH range of 7.15 to 7.80 reported in Soluos 1 and Soluos 2 landfills in Lagos

Table 1. Characterization of landfill leachates from Ajakanga and Awotan landfills.

Parameter	Ajakanga	Awotan	WHO wastewater discharge limit
pH	7.6	8.3	6-9
TDS	*1953*	1360	1500
DO	*0.13*	*0.13*	<0.1
BOD	*945.0*	*1343.7*	60
Na^+	*345.0*	*375.0*	200
Cl^-	48.5	42.6	350
Ammonia	9.3	16.3	<1
Cr^{++}	*0.040*	*0.080*	0.02
Cd^{++}	0.017	0.060	0.1
Pb^{++}	0.080	0.093	0.2
Ni^{++}	0.043	0.047	0.2
Mn^{++}	0.100	0.070	0.2
Zn^{++}	1.267	0.833	5
Fe^{++}	0.633	1.100	5
Cu^{++}	*0.467*	*0.833*	0.2
Ag^{++}	*0.060*	*0.057*	0.05
Total coliform bacteria count (TCB)	*3.10×10^5*	*7.20×10^5*	400*[a]
Total fungal count	*3.50×10^6*	*6.30×10^6*	

All parameters are measured in mg/L, save for pH (no unit) and Total Coliform/ Fungal Count (CFUs/ml); concentrations values that do not conform to the stipulated standard are italicized; *[a] indicates FEPA permissible limit for discharge into surface water as adapted from Salami and Susu (2019).

(Salami and Susu, 2019) and pH value of 8.97 observed in Sarbah landfill in Accra–Ghana (Sackey and Meizah, 2015); though in sharp contrast with the 5.11 pH value recorded in Olososun landfill in Lagos (Ogunyemi et al., 2018). The alkaline pH observed is expected because of the over two decade old landfills. Abbas et al. (2009) had posited that old leachate have pH higher than 7.5, whereas young leachates have acidic pH due to the overwhelming organic acids produced during such stage. This may be attributed to the decrease in the concentration of free volatile acids due to anaerobic decomposition, as fatty acids can be partially ionized and contribute to higher pH values. Alkaline pH is normally encountered at landfills, 10 years after disposal (El-Fadel et al., 2002).

The high BOD values recorded in leachates from both landfills is expected of landfills that receives such high proportion of food (organic) waste. Several reports validate the observation made on the landfill sites regarding their waste composition (Palczynski, 2002; CPE, 2010; Ogungbuyi, 2013). Similar BOD values (912 and 1396mg/L) were reported in LFL from Soluos 3 landfill in Lagos, Nigeria (Salami and Susu, 2019). High BOD of leachate suggests the leachates have high biodegradable organic load, indicative of potentially great microbiological activities and consequential depletion in the oxygen content of the leachate, as observed in the values of total coliform, total fungi and DO in Table 1. If the leachates from these landfills continue to find their way to nearby surface water, particularly River Ona which is barely 50 m from the Ajakanga landfill (Omonigho, 2020), it will be difficult to realize the agena of Agenda 14's *Life below Water* of the Sustainable Development Goal. Ammoniacal nitrogen content of the LFL is attributable to the biological degradation of amino acids and other nitrogenous organic component of the waste (predominantly food and animal waste). The values of the parameter in this study are akin to those obtained from Soluos 2 and Soluos 3 landfills in Lagos, which ranged between 26.3 to 36.30 mg/L and 7.98 to 8.77 mg/L respectively (Salami and Susu, 2019), and Aba-Eku landfill in Ibadan, which ranged between 98.01mg/L to 134.01mg/L (Aromolaran et al., 2019). Although its concentration is low when compared with results (exceeding 1000mg/L) obtained elsewhere (Wichitsathian et al., 2004; Robinson, 2007; Visvanathan et al., 2007; Aloui et al., 2009; Hasar et al., 2009; Svojitka et al., 2009; Puszczało et al., 2010; Chiemchaisri et al., 2011), the need for treatment of the leachate cannot be overemphasized. This is because NH_4-N has been identified as a priority parameter responsible for the toxicity of LFL and could have harmful effect even as an air pollutant upon its volatilization from the leachate when it exceeds 0.50 mg/l (Cameron and Koch, 1980; USEPA, 1984, 1989).

The 0.63 and 1.10 mg/L iron contents in both leachates examined fall within the WHO permissible limit for discharge to the environment. Leachate value of

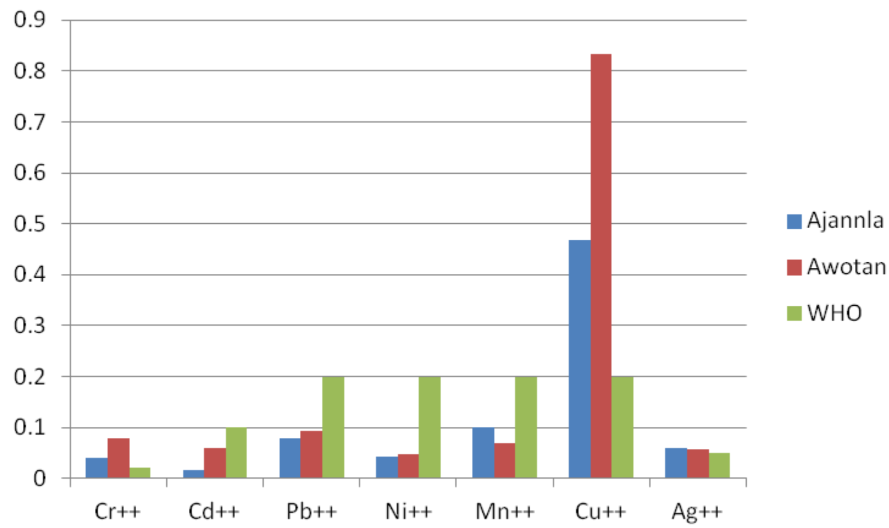

Figure 2. Heavy metal concentration AT Ajanla and Awotan.

2.08 mg/L has been reported by Aromolaran et al. (2019) in Aba-Eku while value of 1.20 mg/L has been reported by Salami and Susu (2019) in Soluos 1, Lagos Aromolaran et al., 2019; Salami and Susu, 2019 had reported values of 2.08 and 1.20 mg/L in Aba-Eku and Soluos 1 respectively. The presence of iron in the leachate is attributable to the presence of ferrous metal scrap in the waste stream; left of after scavengers had rummaged through the in-place waste. The oxidation of the ferrous iron to the ferric hydroxide colloid and other ferric forms is partly responsible for the depleted dissolved oxygen and the characteristic darkish brown colour of the leachates so obtained in this research.

The concentrations of heavy metals in the leachate from both landfills studied are generally low and are only very marginally higher than obtained by Nubi et al. (2008) from Aba-Eku landfill, except for cadmium where Ajakanga has a somewhat lower value as graphically represented in Figure 2. Aromolaran et al. (2019) and Salami and Susu (2019) also reported analogous heavy metal concentrations for Aba-Eku and Soluos 1 landfills respectively. The level of heavy metals in the decreasing hierarchy in Ajakanga is Zn > Fe > Cu > Mn > Pb > Ag > Ni > Cr > Cd and Awotan (Fe > Zn > Cu > Pb > Cr > Mn > Cd > Ag > Ni). Heavy metals have bioaccumulation and biomagnifying tendencies and are therefore particularly toxic. The possible source of chloride is food wastes. The presence of high BOD indicates the high organic strength. Fe in the leachate sample suggests that steel scraps are also dumped in the landfill. The dark brown color of the leachate is mainly attributed to the oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with fulvic/humic substance. The concentration of Zn in the leachate shows that the dumping site receives waste from batteries and fluorescent lamps. The possible source of lead may be batteries, chemicals for photograph processing, older lead-based paints and lead pipes disposed at the landfill.

Figure 2 indicate that Cr^{++}, Cu^{++} and Ag^{++} are the only heavy metal analytes that did not satisfy wastewater discharge guideline having values greater than 0.02, 0.5 and 0.05 stipulated respectively by WHO. Copper can lead to increased corrosion of galvanized iron and steel plumbing fittings, staining of sanitary wares and laundry as well as bitter taste in water if the leachates find their way to water supplies. The corrosion process may have accelerated due to the galvanic effect between copper and galvanized iron and also the dampness of the environment. Health-wise, Wilson's disease gastrointestinal distress and jaundice may result (Gossel and Bricker, 1990). In addition, arsenic-contaminated water supplies can cause damage to the vital organs as well as the circulatory system; nasal ulcers; peripheral vascular disease; dermal lesions; peripheral neuropathy may also result (WHO, 2008).

High total coliform and total fungal values recorded in both landfills is an attestation of the poor sanitary condition of the metropolis (Ologuneru, 2019), especially the low income slums like Adeoyo, Beere and Sabo, where residents resort to defecating indiscriminately due to grossly inadequate sewage disposal facilities – only to be inadvertently evacuated commingled with solid waste by waste collectors. Isolates of TCB identified include *Enterobacter sp., Aeromonas sp., E coli; Proteus sp. and Salmonella sp.,* while those of total fungi identified include *Aspergillus sp., Geotricum sp., Rhizopus sp. and Penicillium sp.* The higher TCB recorded in leachate from Awotan landfill may not be unconnected with the higher volume of health care waste (containing beddings,

Table 2. Leachate pollution index of selected landfills in Ibadan Metropolis.

Parameter	Ajakanga				Awotan			
	c_i	w_i	p_i	$\frac{\sum_{i=1}^{m} w_i p_i}{\sum_{i=1}^{m} w_i}$	c_i	w_i	p_i	$\frac{\sum_{i=1}^{m} w_i p_i}{\sum_{i=1}^{m} w_i}$
Organic (LPI_{org})								
BOD	945	0.263	27	14.58	1343.7	0.263	32	17.28
TCB	3100	0.224	78	35.88	7200	0.224	88	40.48
		0.487		**50.46**		*0.487*		**57.76**
Inorganic (LPI_{in})								
pH	7.6	0.214	5	1.35	8.3	0.214	5	1.35
Ammonia	9.3	0.198	5	1.25	16.3	0.198	6	1.50
TDS	1953	0.195	6	1.47	1360	0.195	5.5	1.35
Cl^-	48.5	0.187	5	1.18	42.6	0.187	5	1.18
		0.794		**5.25**		*0.794*		**5.37**
Heavy metals (LPI_{hm})								
Cr^{++}	0.04	0.125	5	0.82	0.08	0.125	5	0.82
Pb^{++}	0.08	0.123	5	0.80	0.093	0.123	6	0.96
As^{++}	0.06	0.119	5	0.78	0.057	0.119	5	0.78
Zn^{++}	1.267	0.11	5	0.72	0.833	0.11	5	0.72
Ni^{++}	0.043	0.102	5	0.67	0.047	0.102	5	0.67
Cu^{++}	0.467	0.098	6	0.77	0.833	0.098	7	0.90
Fe^{++}	0.633	0.088	5	0.58	1.1	0.088	5	0.58
		0.765		**5.13**		*0.765*		**5.42**
Overall LPI				**15.67**				**17.55**

Unit of Total Coliform Bacterial (TCB) is CFUs/ml; pH has no unit; other parameters are measured in mg/L. The significance, pollutant weight (w_i) and sub-index values (p_i) for each parameter in Table 2 were adapted from Kumar and Alappat (2005).

swaps, pads and the likes that may be soiled with faecal discharges and urine of in-patients) deposited in Awotan landfill. TCB values obtained in Aba-Eku landfill, Ibadan ($8.7x10^5$ CFUs/ml) and Sarbah landfill, Accra-Ghana ($2.6x10^5$ CFUs/ml) Aromolaran et al., 2019; Sackey and Meizah, 2015). The impact of the LFL on the underlying aquifer and nearby surface water can be better-imagined (WHO, 1996, 2008).

Computation of leachate pollution indices

Deploying the leachate pollution index (LPI) hazard identification tool, the leachate pollution data is as summarized in Table 2. Although all three sub LPIs computed are higher in Awotan landfill than Ajakanga landfill, the difference is somewhat significant in the sub LPI–organic component LPI_{org}, attributable largely to the conspicuously higher total coliform bacterial count TCB in Awotan leachate. In addition, of all three sub pollution indices, the organic modules are the highest ranking – suggesting high organic load and microbial load in both LFLs.

The low values of heavy metals sub-LPIs (LPI_{hm}) are consistent with the findings in Harewood Whin Landfill in UK (Kumar and Alappat, 2005). The observed higher value of the calculated LPI_{hm} in Awotan, can be attributed to slightly higher concentration of all the individual heavy metal analytes studied (excepting manganese and zinc) as shown in Figure 2. The observable difference could be traceable to the comparatively larger volume of hazardous waste constituents deposited in Awotan landfill, predominantly laboratory, pharmaceutical and health care wastes (HCW) from the University College Hospital (UCH), University of Ibadan and The Polytechnic–Ibadan. Lamentably, Coker and Sridhar (2010) had described the proliferation of health care facilities in the metropolis as a "technological paradox" that could promote the spread of diseases; the continued co-disposal of these laboratory and HCW with municipal waste portends dire health consequences for not just for those living close by, but for an unimaginably greater population. The significance, pollutant weight (wi) and sub-index values (pi) for each parameter in Table 2 were adapted from Kumar and Alappat (2005).

The high values of LPI_{org} are indicative of acetogenic processes (Kumar and Alappat, 2005). Meanwhile, high pH does not promote the solubilisation and mobility of inorganic constituent, and is conceivably responsible for the low computed values of the inorganic and heavy

Table 3. Comparison of pollution indices of landfills from various locations.

Ranking	Location	Computed LPI	References
1	Pallikkaranai landfill (Chennai, India)	37.11	Naveen and Malik (2019)
2	Pallikkaranai landfill (Chennai, India)	37.01	Manimekalai and Vijayalakshmi (2012)
3	Guanajuato (Mexico)	34.84	Guerrero-Rodríguez et al. (2014)
4	Dhapa (Kolkata, India) [active]	34.02	De et al. (2016)
5	Brahmapuram landfill (Kochi, Kerala, India)	31.99	Arunbabu et al. (2017)
6	Dhapa (Kolkata, India) [closed]	31.80	De et al. (2016)
7	Mavallipura landfill (Bangalore, India)	30.10	Naveen and Malik (2019)
8	Dhapa landfill (Kolkata, India)	28.90	Naveen and Malik (2019)
9	Ghazipur landfill (Delhi, India)	28.41	Naveen and Malik (2019)
10	Jamalpur landfill (Punjab, India)	26.45	Bhalla et al. (2014)
11	Turbhe landfill (Maharashtra, India)	25.10	Naveen and Malik (2019)
12	Ikhueniro dumpsite (Benin, Nigeria)	22.31	Ibezute and Erhunmwunse (2018)
13	Harewood Whin landfill (North Yorkshire, UK)	19.67	Kumar and Alappat (2005)
14	Toluca (Mexico)	18.46	Guerrero-Rodríguez et al. (2014)
15	Awotan landfill (Ibadan, Nigeria)	17.55	Present study
16	Don-Parkar landfill (Warri, Nigeria)	16.57	Odia et al. (2016)
17	Niger Cat landfill (Warri, Nigeria)	15.72	Odia et al. (2016)
18	Ajakanga landfill (Ibadan, Nigeria)	15.67	Present study
19	Aba-Eku landfill (Ibadan, Nigeria)	14.46	Aromolaran et al. (2019) – wet season
20	Aba-Eku landfill (Ibadan, Nigeria)	12.70	Aromolaran et al. (2019) – dry season
21	Orhuwhorun landfill (Warri, Nigeria)	12.13	Odia et al. (2016)

metal components of the LPI. These conditions suggest that faster methanogenic processes are running concurrently with the acetogenic processes within the methane fermentation phase (Kjeldsen et al., 2002; Kamaruddin et al., 2017). The low LPI_{hm} support the thriving of microorganisms and thereby supports biological leachate treatment. The low inorganic sub-LPI (LPI_{in}) values further lend support to this wastewater treatment option.

The LPI values obtained from the landfills in this research are greater than the recommended standard by Kumar an Alappat (2003) in their studies. The overall LPI values of both landfills studied exceed in the standard LPI value of 7.378 (Kumar and Alappat, 2003), portending grave multifaceted environmental impact that transcends beyond the surrounding soil and water resources. These indices are comparable with those obtained elsewhere: Table 3 outlines the LPI data of various landfills across different geographical locations as computed by various researchers. The ranking of these landfills shows that landfills within a geographical area tend to have similar pollution indices and are somewhat different from those outside their region. To illustrate, apart from the observed skew in Ikhueniro landfill in Benin metropolis, all identified landfills in Nigeria (Southern Nigeria) rank 15th to 22nd position (with LPI range of 12 to 18); just as all the landfill sites in India rank 1st to 11th. This observed cluster is expected because of the peculiarity of the region in terms of climatic condition, geologic settings, and demographics, level of technological advancement, lifestyle of the people, socio-economic activities and the existing solid waste management strategies.

The LPI of Awotan (17.55) was found to be greater than that of Ajakanga (15.67), with both values obtained from the present study greater than an already existing LPI for Aba-Eku landfill (12.70 and 14.46). Based on available data, with three of the four landfills in Ibadan falling within this cluster, it is very likely that the LPI of the fourth (Lapite landfill) would be within 12 and 18, *ceteris paribus*.

Conclusion

Leachate pollution index (LPI) is a quantitative tool used in measuring the contamination potential of landfill leachate (LFL). This work examines the leachate from two major unlined landfills in Africa's largest settlement (Ibadan metropolis) with a view to informing necessary decision. The LPI of Ajakanga and Awotan landfills were found to be 15.57 and 17.55 respectively. Both landfills have the capacity of altering the ecological balance of the nearby ecosystem and unimaginable wider population as they exceed the 7.378 standard LPI value. Results of LPI sub group's reveals that biological waste treatment is the best for the treatment of the LFLs. All four landfills are recommended for closure in line with international best practices. LPI is a very useful tool that gives an unambiguous reportage of the environmental status of landfill leachates.

CONFLICTS OF INTEREST

The authors have not declared any conflict of interest.

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