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Seasonal Evaluation of Physicochemical Parameters, Heavy Metals Levels and Pollution Status in Leachate from Ikhueniro Open Solid Waste Dumpsite located in Benin City, Edo State, Nigeria

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ABSTRACT: In recent times, there is a rapid rate of growth in the cities of third-world countries. This rapid population growth has implications for municipal waste management. Hence, the objective of this work is seasonal evaluation of physicochemical parameters, heavy metals levels and pollution status in leachate from Ikhueniro open solid waste dumpsite located in Benin City, Edo State, Nigeria using standard methods. Data obtained reveals that the pH of leachate samples collected during the rainy and dry season was alkaline. Iron was the main heavy metal contaminant in the Ikhueniro dumpsite, with calculated contamination factors of discharged leachate estimated at 154.48 ± 3.56 and 167.38 ± 3.33 during rainy and dry seasons, respectively; while copper was the least heavy metal contaminant, as indicated by contamination factors of discharged leachate reported as 3.22 ± 0.04 and 14.15 ± 2.00 during rainy and dry seasons, respectively. The increasing order of contamination of the dumpsite with the analyzed heavy metals was as follows: Cu<Cr<Zn<Hg<Pb=Ni<Cd<Fe for rainy season and Cu<Cr<Zn<Ni<Hg<Pb<Cd<Fe for dry season. Heavy metal and other chemical contaminations were widespread in the examined samples due to poor waste management system at the Ikhueniro dumpsite; resulting in high levels of heavy metals above the limits set by regulatory agencies. The Ikhueniro dumpsite posed very high potential ecological risk during the rainy and dry seasons, respectively. Thus, there is urgent need to provide remediation systems that can help to significantly reduce concentrations of heavy metals and other toxicants from the dumpsite.

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Open waste dumping is the most common method for solid waste disposal in third-world countries (Collivignarelli *et al.*, 2011; Nnaji, 2015; Aluko *et al.*, 2022). Six of the biggest dumpsites in Africa are located in Nigeria. They include the *Olusosun*, *Solous*, *Epe*, *Awotan*, *Lapite* and *Eneka* open solid waste dumpsites (Waste Atlas, 2014). *Olusosun* dumpsite is the largest dumpsite in Nigeria. It receives approximately 2.1 million tonnes of municipal solid waste annually and covers a land area of approximately 43 hectares in Lagos State. *Solous* dumpsite occupies an area of 8 hectares in Lagos State and receives approximately 820,000 tonnes of municipal solid wastes annually. *Epe* dumpsite is also situated in Lagos State, and occupies approximately 80 hectares of land with a municipal solid waste input of 12000 tonnes. *Awotan* dumpsite is situated in Ibadan, Oyo State, and it receives 36000 tonnes of municipal solid wastes annually on a land area of 14 hectares. *Lapite* dumpsite is also situated in Ibadan, Oyo State, where it occupies an area of 20 hectares and receives approximately 9,000 tonnes of municipal solid waste annually. *Eneka* dumpsite is situated in Port Harcourt, River State, Nigeria. It receives approximately 45600 tonnes of municipal solid waste annually.The dumpsite investigated in the present study is the Ikhueniro open solid waste dumpsite located in Benin City, Edo State, Nigeria. The Edo State Waste Management Board (EDSWMB) is saddled with the operation of this dumpsite. The dumpsite occupies a

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land area of approximately 2 hectares. The wastes are haphazardly deposited in this dumpsite without segregation. However, some private individuals do sometimes visit the dumpsite to sort metal and plastic wastes for recycling. The Ikhueniro dumpsite is generally characterized by spontaneous fires largely as a result of spontaneous combustion that is very rampant during the dry season. The total number of dumpsites in Europe is estimated at approximately 500.000, of which about 90% of these dumpsites are regarded as non-sanitary dumpsites (Särkkä *et al.*, 2017). These dumpsites predated the European Landfill Directive. Hence the Landfill Directive is rather irrelevant for at least 450000 dumpsites. The non-sanitary dumpsites did not comply with the required environmental protection technologies, thus, requiring costly remediation. About 80% of Europe's dumpsites mainly contain urban solid waste, with only 20% carrying specific industrial wastes (Ławińska *et al.*, 2022). While the European industrial dumpsites are privately owned, the municipal solid waste dumpsites are publicly owned. In Nigeria, waste segregation in most open solid waste dumpsites is generally non-existent. There are no well-established waste management and treatment systems; and landfill systems (dumpsites) are often not properly designed to curtail leachate flow (Aluko *et al.*, 2022). Due to the lack of waste segregation, mixed waste materials are very rampant in these dumpsites. Hence, in a typical Nigerian open solid waste dumpsite, food wastes, discarded household materials, plastics, paints, batteries, mercury-containing wastes and other garbage consisting of heavy metals and other toxic substances are all present.In recent times, there is a rapid rate of growth in the cities of third-world countries when compared to those in developed countries. Findings from a United Nations Habitat report indicated that Africa is the fastest urbanizing continent, with cities in Nigeria and other African countries growing at rates that can triple their current sizes by the Year 2050. This rapid population growth has implications for municipal waste management (Khan *et al.*, 2022), with the open waste dumps littered with solid wastes that are covered with flies and other vectors of diseases.

Inefficient management of municipal solid wastes in open dumpsites, especially in Nigeria, is a serious public health concern (Adeniyi *et al.*, 2022; Gbadebo *et al.*, 2022). This is because the solid wastes, apart from harbouring vectors of diseases and producing greenhouse gases (Ngwabie *et al.*, 2019), also discharge leachates which contain toxic heavy metals that ultimately contaminate the soil and pollute ground and surface water bodies (Oyelami *et al.*, 2013; Aboyeji and Eigbokhan, 2016; Kumarathilaka *et al.*, 2016; El Fadili *et al.*, 2022; Gbadebo *et al.*, 2022). The management of dumpsite leachates is necessary to ensure the protection of the surrounding environment, particularly ground and surface waters (Wijekoon *et al.*, 2022). Though costly, the conventional methods of leachate treatment are physicochemical methods such as air stripping, membrane filtration, coagulation/flocculation and chemical oxidation (Siddiqi *et al.*, 2022; Lindamulla *et al.*, 2022). The remediation of dumpsite leachates using microorganisms is a cost-effective approach when compared to the conventional physicochemical treatment processes. Hence, the objective of this work is seasonal evaluation of physicochemical parameters, heavy metals levels and pollution status in leachate from Ikhueniro open solid waste dumpsite located in Benin City, Edo State, Nigeria.

MATERIALS AND METHODS

Description of study area: The study area was Ikhueniro dumpsite situated in Uhunwode Local Government Area, Edo State, Nigeria at a longitude of 6.6342°N and latitude of 5.9304°E (Figure 1). It has a tropical climate, with an annual temperature that ranged from 23.78°C to 29.98°C and an annual precipitation that ranged from 22.44 mm to 332.95 mm. There is a well-defined rainy season which occurs from April to October and the dry season that occurs from November to March. The average temperature of the raw leachates collected from the Ikhueniro dumpsite ranged from 24.00°C during the rainy season to 26.06°C during the dry season, while the pH of the raw leachates ranged from 7.48 to 8.01 during the rainy and dry seasons, respectively. The major components of solid wastes deposited at the Ikhueniro dumpsite included food wastes, metals, papers, textiles, plastics, glass and other miscellaneous wastes. The percentage composition of these wastes were estimated at 70%, 10%, 5%, 4%, 3%, 4% and 4% for the food wastes, metals, papers, textiles, plastics, glass and other miscellaneous wastes, respectively The Edo State Waste Management Board (EDSWMB) is saddled with the operation of this dumpsite. The dumpsite occupies a land area of approximately 2 hectares, and its leachates flow into the Okhuahe River. Anthropogenic activities such as performance of household chores, discharge of agricultural effluents from cassava and palm fruit processing mills, discharge of fish pond wastewaters, as well as the discharge of dumpsite leachates are very rampant at the downstream station of the adjoining Okhuahe River. Conventional fishing activities by the local inhabitants were undertaking at the upstream station of the Okhuahe River throughout the year. The communities surrounding the Ikhueniro dumpsite include Iguevbiahiamwan, Irhue, Igueuwanghe, Ugiemwan, Igieduwa, Oghehe Ikhuen and Obadan. The distance of these neigbouring communities to Ikhueniro dumpsite ranged from 2.8 kilometers to 3.3 kilometers. Human scavengers are very rampant at the Ikhueniro dumpsite. They do regularly visit the dumpsite to sort metal and plastic wastes for recycling. Other animal scavengers such as birds also pay regular visits to the dumpsites to feed on dead animals and pick some debris during the rainy and dry seasons, while the cows were seen paying occasional visits to the dumpsite, particularly, around the downstream stations of the Okhuahe River to source for vegetation and water mostly during the rainy season. Most of the vegetation planted by farmers around thevicinity of the Ikhueniro dumpsite includes Cassava (*Manihot esculenta*) Okro (*Abelmoschus esculentus*) Pepper (*Capsicum annuum*) Tomatoes (*Solanuum lycopersicum*) and Garden egg (*Solanuum malegenum*) plantations. The wild vegetation seen growing at the Ikhueniro dumpsite were *C. annuum, S. lycopersicum*, Water melon (*Citrullus lanatus*), Melon (*Cucumis melo*), *S. malegenum* and Pawpaw (*Carica papaya*) plants, particularly during the rainy season. The soil type around the Ikhueniro dumpsite is generally regarded as sandy clay loam, some plants like Musa species (Plantain and Bananna) are also commonly found in the community. A pictorial presentation of some sections of the Ikhueniro dumpsite is shown in Figure 2.

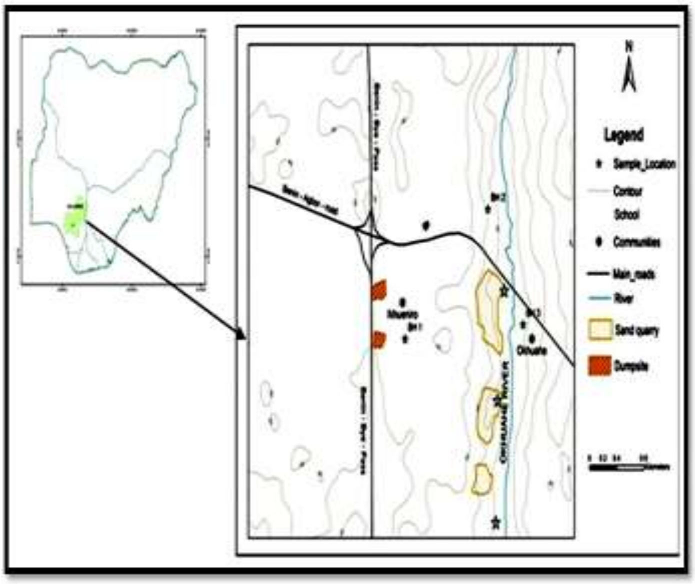

Fig 1: Map showing the Ikhueniro dumpsite

Fig 2: Some sections of the Ikhueniro dumpsite

Study design: The Ikhueniro dumpsite was visited in the months of July to October 2019 to collect samples for rainy season survey, as well as in the months of November 2019 to February 2020 for dry season survey. The Ikhueniro dumpsite was visited twice at each month of sampling. Overall, the Ikhueniro dumpsite was visited eight times during the rainy season and another eight visitations during the dry season. At each visitation, raw leachate was randomly scooped from the dumpsite to a depth of 15 cm into calibrated sterile 30 ml containers. Applying a grid sampling technique, the dumpsite was partitioned into an equilateral triangle and triplicate samples of the leachate (raw leachate) were collected from the three edges (sampling stations) of the triangle grid measuring 30 meters apart. Triplicate samples of the rhizosphere and *Citrullus lanatus* fruits were collected from plants that grew around the sampling stations in the Ikhueniro dumpsite.

Physicochemical analysis of samples: The measurements of physicochemical parameters in the samples were carried out according to the standard methods prescribed by the American Public Health Association (APHA) (APHA, 1998).

*Heavy Metal Analysis:*All the samples were acidified using nitric acid for reducing the pH to less than 2 to prevent theprecipitation of metals. Flame atomic absorption spectrometer (FAAS) supplied by Perkin Elmerwas used for the analysis of major and heavy metal content in the leachate samples. Calibrationstandards were prepared from AAS grade reagent for all the metals of interest.

Calculation of the pollution status

Calculation of contamination factor: The contamination factor (Cf) evaluates the impact of a single heavy metal contamination in the Ikhueniro dumpsite. It is defined as the concentration of an individual heavy metal to its background concentration (Håkanson, 1980) as expressed in Equation 1.

$$CF = \frac{C_{HM}}{BC_{HM}} \quad (1)$$

Where CF = Contamination factor, C_{HM} = concentration of heavy metals in sample; BC_{HM}= background concentration of heavy metals

For the description of contamination factor, the following terminologies were used: $C_f < 1$ represents low contamination with heavy metal; $1 \leq C_f \leq 3$ represents moderate contamination with heavy metal; $3 \leq C_f \leq 6$ represents considerable contamination with heavy metal; and $C_f > 6$ represents high contamination with the heavy metal (Caeiro *et al*., 2005).

Calculation of pollution load index: The Tomlinson's pollution load index (PLI) measured the combined heavy metal contamination status in the Ikhueniro dumpsite and adjoining Okhuahe River (Tomlinson *et al*., 1980). It is mathematically expressed as the n^{th}root of the product of the *n* contamination factors as follows:

$$PLI = \sqrt[n]{Cf1 \times Cf2 \times Cf3 \times Cf4 \times Cf5 \ldots\ldots \times Cfn} \quad (2)$$

Cf is the contamination factor and n is the number of heavy metals analyzed.

Calculation of geoaccumulation index: The geoaccumulation index (*Igeo*) measured the degree of contamination of heavy metals present in the sampling location (Benson *et al*., 2017; Zhang *et al*., 2017). The *Igeo* was calculated as follows:

$$I_{geo} = log_2 \frac{Cn}{1.5Bn} \quad (3)$$

Cn is the concentration of nth heavy metal. 1.5 is a correction factor adopted to address possible variations in the background concentration of heavy metals attributed to lithogenic and anthropogenic effects. *Bn* is the geochemical background concentration of the nth heavy metal.

For the description of *Igeo*, the following terminologies were used: $Igeo \leq 0$ (practically unpolluted by heavy metal); $1 < Igeo \leq 2$ (unpolluted to moderately polluted by heavy metal); $2 < Igeo \leq 3$ (moderately polluted by heavy metal); $3 < Igeo \leq 4$ (heavily polluted by heavy metal); $4 < Igeo \leq 5$ (heavily to extremely polluted by heavy metal); $Igeo > 5$ (extremely polluted by heavy metal).

Calculation of ecological risk factor: The ecological risk factor (Er) quantitatively expressed the potential ecological risk of the heavy metal contaminant in the sampling locations. It is expressed as in equation 3:

$$Er = Tr \times Cf \quad (4)$$

Cf is the contamination factor. Tr is the toxic-response factor for the heavy metal. Values of the toxic-response factors for the heavy metals (Håkanson, 1980; Zhang and Liu, 2014) are: Lead =5; Cadmium = 30; Chromium = 2; Copper = 5; Mercury = 40; Nickel = 5; Zinc = 1.

The ecological risk factor was described as follows: Er < 40 (low potential ecological risk); 40 ≤ Er ≤ 80 (moderate potential ecological risk); 80 ≤ Er ≤ 160 (considerable potential ecological risk); 160 ≤ Er ≤ 320 (high potential ecological risk); Er > 320 (very high ecological risk).

Calculation of potential ecological risk index: The potential ecological risk index (*RI*) is defined as the sum of the risk factors in a sampling location. The ecological risk factor was calculated as in equation 4:

$$RI = \sum_{n=1}^{\infty} \mathrm{Er} \qquad (5)$$

Where Er is the single index of ecological risk factor;∞ is the count of the heavy metal species
The following terminologies were used for evaluating the potential ecological risk index: *RI* < 150 represents low ecological risk; 150 ≤ *RI* < 300 represents moderate ecological risk; 300 ≤ *RI* < 600 represents considerable ecological risk; and *RI* > 600 represents very high ecological risk (Caeiro *et al*., 2005).

Statistical analysis: The NCSS ver. 12 data analysis software was used to carry out descriptive statistics of the datasets obtained from the study. Shapiro-Wilk normality test and Levene's test of homogeneity of variance, as well as the analysis of the variance (ANOVA) by the parametric Student's t-test and non-parametric Mann Whitney U (Wilcoxon rank-sum) test were also performed with NCSS ver. 12. The test of the hypothesis was considered statistically significant if the achieved level of significance (p) was less than 0.05.

RESULTS AND DISCUSSION

Data of some physicochemical parameters: Some physicochemical characteristics of the leachate discharging from the Ikhueniro dumpsite are presented in Table 1. The temperature of leachate samples ranged from 24.00 °C during the rainy season to 26.06 °C during the dry season. The pH of leachate samples collected during the rainy and dry season were alkaline. Datasets of the pH of the raw leachate during the rainy and dry seasons were normally distributed (p > 0.05) with equal variance (p > 0.05). Student's t-test indicated that the pH of the raw leachate during the rainy season significantly differed (p < 0.05) from those recorded during the dry season. Electrical conductivity of the raw leachate was estimated at 2180 µS/cm and 3140 µS/cm during the rainy and dry seasons. Student's t-test indicated that the electrical conductivity of the raw leachate during the rainy season significantly differed (p < 0.05) from those recorded during the dry season. Datasets of the TDS and TSS of the raw leachate during the rainy and dry seasons were normally distributed (p > 0.05 for TDS and TSS) with equal variances (p > 0.05 for TDS and p = 0.89 for TSS). Student's t-test indicated that the TDS and TSS of the raw leachate during the rainy season significantly differed (p < 0.05for TDS and TSS) from those recorded during the dry season. Datasets of the turbidity of raw leachate during the rainy and dry seasons were normally distributed (p > 0.05) with unequal variance (p < 0.05). Mann Whitney U (Wilcoxon rank-sum) test showed that turbidity of the raw leachate during the rainy season significantly differed (p < 0.05) from those recorded during the dry season. Datasets of the BOD of raw leachate during the rainy and dry seasons were normally distributed (p > 0.05) with equal variance (p > 0.05). The BOD of the raw leachate during the rainy season was significantly different (p < 0.05) from those recorded during the dry season. The leachate samples were found to have high alkalinity (mean alkalinity of raw leachate = 3980 mg/l and 3960 mg/l during the rainy and dry seasons, respectively).

Data of heavy metal parameters: The concentrations of heavy metals present in leachates discharging from the Ikhueniro dumpsite, inclusive of the rhizosphere and *Citrullus lanatus* (watermelon) fruits collected from the vicinity of the dumpsite are presented in Table 2. Amongst the heavy metals that were examined in the leachates, zinc had the highest concentration (mean concentration of zinc in the raw leachates during the rainy and dry seasons estimated at 22.88 ± 0.22 mg/l and 25.18 ± 0.40 mg/l, respectively) while cadmium had the lowest concentration with mean concentration reported as 1.18 ± 0.06 mg/l and 1.13 ± 0.03 mg/l during the rainy and dry seasons, respectively. Student's t-test revealed that the mean concentrations of all the heavy metals examined in the raw leachates during the rainy season significantly differed (p < 0.05 for Fe, Zn, Ni, Cu, Hg, Cr, Pb and Cd, respectively) from those of the dry season. In the rhizosphere and *C. lanatus* (watermelon) fruit samples collected from the vicinity of the Ikhueniro dumpsite during the rainy season, mean concentrations of zinc were estimated at 13.00 ± 0.13 mg/l and 8.76 ± 0.17 mg/l, respectively; while during the dry season the mean concentration of zinc in the rhizosphere was estimated at 17.04 ± 0.43 mg/l. Student's t-test indicated that the mean concentrations of all the heavy metals, except cadmium, examined in the rhizosphere during the rainy season significantly differed (p < 0.05for Fe, Zn, Ni, Cu, Hg, Cr and Pb, respectively) from those of the dry season. Mean concentrations of cadmium in the rhizosphere and

Citrullus lanatus (watermelon) fruit samples collected from the vicinity of the dumpsite during the rainy season were estimated at 0.83 ± 0.05 mg/l and 0.00 ± 0.00 mg/l, respectively; while during the dry season the mean concentration of mercury in the rhizosphere was estimated at 0.82 ± 0.11 mg/l. The contamination of the dumpsite with the array of heavy metals examined in this study in increasing order, as indicated by the concentration of the heavy metals in the leachates was as follows: Cadmium<Mercury<Chromium<Nickel<Lead<Iron<Copper<Zinc. A similar pattern of heavy metal contamination was observed in the rhizosphere and *C. lanatus* fruit samples collected from the vicinity of the Ikhueniro dumpsite.

Table 1: Some physicochemical parameters in the leachate samples

Season of sampling	Physicochemical parameters							
	Temperature Mean ± SE H = 8 °C	pH Mean ± SE H = 8	Conductivity Mean ± SE H = 8 (× 1000 µS/cm)	TDS Mean ± SE H = 8 (× 100 mg/l)	TSS Mean ± SE H = 8 (× 1000 mg/l)	Turbidity Mean ± SE H = 8 (× 10 NTU)	BOD Mean ± SE H = 8 (× 100 mg/l)	Alkalinity Mean ± SE H = 8 (× 1000 mg/l)
Rainy (July – October 2019)	24.00 ± 0.27	7.48 ± 0.15	2.18 ± 0.13	2.53 ± 0.15	1.75 ± 0.04	4.43 ± 0.26	9.60 ± 0.35	3.98 ± 0.08
Dry (Nov. 2019 – Feb. 2020)	26.06 ± 0.11	8.01 ± 0.16	3.14 ± 0.09	3.24 ± 0.12	1.90 ± 0.03	5.65 ± 0.09	8.34 ± 0.26	3.96 ± 0.10

SE: Standard error of mean; H: total number of samples examined

Table 2: Some heavy metals analyzed in the leachate, rhizosphere and *Citrullus lanatus* fruit samples

Season of sampling	Samples examined	Heavy metal parameters							
		Iron Mean ± SE H = 8	Zinc Mean ± SE H = 8	Nickel Mean ± SE H = 8	Copper Mean ± SE H = 8	Mercury Mean ± SE H = 8	Lead Mean ± SE H = 8	Chromium Mean ± SE H = 8	Cadmium Mean ± SE H = 8
Rainy (July – October 2019)	Leachate (mg/l)	7.72 ± 0.18	22.88 ± 0.22	4.62 ± 0.12	16.10 ± 0.19	0.33 ± 0.02	4.62 ± 0.17	2.14 ± 0.05	1.18 ± 0.06
	Rhizosphere (mg/kg)	7.62 ± 0.03	13.00 ± 0.13	2.60 ± 0.04	8.73 ± 0.07	0.26 ± 0.08	2.79 ± 0.12	0.80 ± 0.02	0.83 ± 0.05
	Citrullus lanatus fruit (mg/kg)	2.08 ± 0.03	8.76 ± 0.17	1.10 ± 0.08	4.46 ± 0.08	0.11 ± 0.01	0.09 ± 0.02	0.34 ± 0.02	0.00 ± 0.00
Dry (Nov. 2019 – Feb. 2020)	Leachate (mg/l)	8.39 ± 0.17	25.18 ± 0.40	3.12 ± 0.07	14.13 ± 0.22	0.39 ± 0.05	3.18 ± 0.13	1.59 ± 0.26	1.13 ± 0.04
	Rhizosphere (mg/kg)	8.25 ± 0.11	17.04 ± 0.43	3.63 ± 0.04	9.89 ± 0.07	0.30 ± 0.08	2.65 ± 0.11	0.62 ± 0.01	0.82 ± 0.11

SE: Standard error of mean; H: total number of samples examined

Table 3: Characterization of the pollution status of Ikhueniro dumpsite

Season of sampling	Ecotoxicological parameters	Heavy metals present in the leachate								
		Iron (Fe)	Zinc (Zn)	Nickel (Ni)	Copper (Cu)	Mercury (Hg)	Chromium (Cr)	Lead (Pb)	Cadmium (Cd)	
Rainy	Contamination factor	154.48±3.56	22.88 ± 0.22	92.33 ± 2.35	3.22 ± 0.04	25.80 ± 4.66	10.68 ± 0.26	92.30 ± 3.46	117.50 ± 5.90	
	Pollution load index									37.09
	Degree of contamination (*Igeo* index)	6.87	3.93	5.95	1.10	4.15	2.83	5.95	6.30	
	Ecological risk factor	NA	22.88 ± 0.22	461.65±11.75	16.10 ± 0.20	1032 ± 186.40	21.36 ± 0.52	461.50±17.30	3525 ± 177.00	
	Potential ecological risk index									5582/74
Dry	Contamination factor	167.38±3.33	25.18 ± 0.40	62.40 ± 1.47	2.83 ± 0.04	62.50 ± 2.44	7.94 ± 1.31	63.50 ± 2.56	112.50 ± 3.66	
	Pollution load index									34.29
	Degree of contamination (*Igeo* index)	6.81	4.07	5.38	0.91	5.40	2.41	5.41	6.24	
	Ecological risk factor	NA	25.18 ± 0.40	312.00 ± 7.35	14.15 ± 2.00	2500 ± 97.60	15.88 ± 2.62	317.50±12.80	3375.00 ± 100.80	
	Potential ecological risk index									6584.89

NA: toxic-response factor not available

Pollution status: The pollution indicators used to evaluate the pollution status of the Ikhueniro dumpsite are presented in Table 3. Heavy metal contaminants in the leachate that was discharged from the dumpsite were used to measure the pollution indicators. The pollution indicators that were examined included the contamination factor, pollution load index, degree of contamination (Igeo index), ecological risk factor and potential ecological risk index. Iron was found to be the main heavy metal contaminant in the Ikhueniro dumpsite, with calculated contamination factors of discharged leachate estimated at 154.48 ± 3.56 and 167.38 ± 3.33 during rainy and dry seasons, respectively; as well as reported *Igeo* index of 6.87 and 6.81 which indicated that the Ikhueniro dumpsite was extremely polluted with iron during the rainy and dry seasons, respectively. The Ikhueniro dumpsite was least contaminated with copper, as indicated by the contamination factors of discharged leachate reported as 3.22 ± 0.04 and 14.15 ± 2.00 during rainy and dry seasons, respectively; as well as reported *Igeo* index of 1.10 and 0.91 which indicated that the Ikhueniro dumpsite was unpolluted with copper. The increasing order of contamination of the dumpsite with the analyzed heavy metals was as follows: Cu<Cr<Zn<Hg<Pb=Ni<Cd<Fe for rainy season and

Cu<Cr<Zn<Ni<Hg<Pb<Cd<Fe for dry season. The Ikhueniro dumpsite was found to pose a very high potential ecological risk during the rainy and dry seasons, respectively.

Open waste dumping is the most common method for solid waste disposal in third-world countries (Collivignarelli *et al.*, 2011; Nnaji, 2015; Aluko *et al.*, 2022). The dumpsite investigated in the present study is the Ikhueniro open solid waste dumpsite located in Benin City, Edo State, Nigeria. The Edo State Waste Management Board (EDSWMB) is saddled with the operation of this dumpsite. The dumpsite occupies a land area of approximately 2 hectares. The wastes are haphazardly deposited in this dumpsite without segregation. The temperature of leachate samples ranged from 24.00 ^{o}C during the rainy season to 26.06 ^{o}C during the dry season. The temperatures of the leachates collected from the Ikhueniro were not significantly different from those reported in the study of Asibor and Edjere (2017). The pH of the leachates was found to be alkaline. The pH values of the leachates obtained from this study generally agreed with the values of pH (7.2 – 7.8) in the study of Salami and Sasu (2019) but were at variance to the acidic pH values (5.54 – 5.78) reported by Asibor and Edjere (2017). Christensen *et al.* (2001) indicated that the pH values of leachates generally varied between 4.5 and 9.0. Abbas *et al*. (2009) described young leachates as those that have pH values of ≤ 6.5 and old leachates as those that have pH values ≥ 7.5. Thus, the leachates that were collected from the Ikhueniro dumpsite can be described as old leachates. The levels of TDS indicate the degree of mineralization in the leachates (Al-Yaqout and Hamoda, 2003). Amongst the heavy metals that were examined in the leachates, zinc had the highest concentration while cadmium had the lowest concentration. However, the values of zinc and cadmium in the leachates exceeded the limits stipulated by FEPA (Salami and Susu, 2019).The levels of lead, copper, nickel, iron and chromium in the leachates significantly exceeded the limits stipulated by FEPA. The pollution load indices of the leachates were reported as 37.09 and 34.29 during the rainy and dry seasons, respectively. These values indicated that the leachates from the Ikhueniro dumpsites were highly polluted with heavy metals, particularly during the dry season. Only pollution load index that is greater than 35 generally indicates a poor environmental condition (Kumar and Alappat, 2005). The findings of the present study were markedly different from pollution load index (11.32) reported in the study of Ofomola *et al.* (2017). Low concentration of heavy metals in the leachate has a direct relationship with the age of the dumpsites, thus influencing the calculated load pollution index. Metamorphosis in the leachate environment due to the passage of time causes a decline in the amount of heavy metals. Some of the common changes in the environment include methanogenesis and the formation of soluble metallic forms.

Conclusion: Heavy metal and other chemical contaminations are widespread in the examined leachates due to poor waste management system at the Ikhueniro dumpsite. This contributes to high levels of heavy metals above the limits set by regulatory agencies. From this study, it can be concluded that there is an urgent need to provide remediation systems that can help to significantly reduce the concentrations of heavy metals and other toxicants from dumpsite leachates prior to discharge into nearby water bodies and soil environments. Iron was the most abundant heavy metal detected in all water samples collected from the crude oil-impacted Santa Barbara River and hand-dug well in communities surrounding the Santa Barbara River; but in fish collected from the Santa Barbara River and those sold in communities surrounding the Santa Barbara River zinc was found to be the most abundant metal.

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