



Potential environmental pollution and human health risk assessment due to leachate contamination of groundwater from anthropogenic impacted site

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ABSTRACT

One of the consequences of landfill systems is the emission of leachate, which is capable of causing contamination of the surrounding environment, including groundwater. Considering three major abandoned landfills in an urban area in Nigeria, the potential environmental pollution due to leachate generated from landfills and human health risk assessment of nearby groundwater were examined using laboratory standards (APHA 2012). The result revealed that the landfills' leachate pollution index (LPI) is 18.84, 19.57, and 19.66, indicating potential pollution of the environment, including groundwater and soil. Conformity of groundwater indicated that Arsenic (Ar-0.0001), Cadmium (Cd-0.002), Zinc (Zn-0.02), Barium (Ba-0.03), Manganese (Mn-0.05), Copper (Cu-0.02, 0.012), Chromium (Cr-0.006, 0.007), and Cobalt (Co-0.03, 0.015) are within the WHO permissible limit while Nickel (Ni-0.06) and Lead (Pb-0.05) exceeded the permissible limit. Using the USEPA model for human health risk assessment, the Total Hazard quotient (THQ) for ingestion and derma exposure indicated that the heavy metals have ≤ 1 across the three landfills, indicating that the exposed population experience no significant health risk. The THQ trended as $Cd > Co > Zn > Ba > Mn > Cu > Cr > Ni > As > Pb$ for children across all the landfills. The estimation for Total Carcinogenic Risk (TCR) for carcinogenic metals (As, Cd, Cr, Ni, and Pb) from various landfill indicated no carcinogenic risk ($TCR < 10^{-6}$). Although the abandoned landfills showed potential environmental pollution and contamination of groundwater; however, the health risk assessment of the groundwater revealed no significant carcinogenic risk to the population exposed to it. Hence, the need for water treatment and evaluation of the soil contamination status of landfills.

1. Introduction

Waste disposal through landfilling remains the most common method of solid waste management in many developing cities and poses a potential threat to various environmental components (Afolabi and Eludoyin, 2021; Aja et al., 2021). One of the landfilling system's consequences is leachate emission (Hussein et al., 2019). Leachate is aqueous waste discharged from solid waste due to various physical, chemical, and biological interference in landfill systems (Youcai, 2018; Parvin et al., 2021) and contains soluble organic compounds, inorganic contaminants, suspended solids, heavy metals, and dangerous substances (Wdowczyk and Szymanska-Pulikowska, 2021). The improper management of landfill/dumpsites and generated leachate can

cause a significant impact on the surrounding surface and groundwater (Olofade et al., 2019; Naminata et al., 2018; Mishra et al., 2019; Jabłonska-Trypuc et al., 2021) and farmland (Vaverková et al., 2020).

Heavy metals pose the most significant threat among various leachate compositions due to their non-biodegradable, toxicity, environmental persistence, bioaccumulative, endocrine-disrupting, and carcinogenic nature (Hazrat et al., 2019). Due to its persistent nature, heavy metals can be amassed in the environment over a period leading to possible contamination of the food chain. Accumulation of potentially toxic heavy metals in biota causes a potential health threat to their consumers, including humans (Hazrat et al., 2019). Conversion techniques of leachate analysis are primarily based on chemical testing to ascertain the concentration of heavy metals and organic compounds with carcino-

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genic, estrogenic, and toxic properties (Jabłonska-Trypuc et al., 2021). These methods allow for a preliminary estimation of the danger and risk leachate poses to the environment and humans (Clarke et al., 2015)

The primary concern about the leachate generated from landfills is their pollution capability due to mobilization through the subsoil into the surface (Parvin et al., 2021; Fadhullah et al., 2019) and infiltration into the groundwater aquifers (Enitan et al., 2018). In recent times, many water pollution studies have been linked to the impact of leachate on the physical, chemical and biological properties of the water bodies coming in contact with the leachate. Enitan et al. (2018) estimated carcinogenic risks (CR_{ing}) exceeded the suggested potential risk limits, with lead (Pb) having the highest CR_{ing} value for all age groups from surface water across a nearby landfill system. The values of pH, Electrical Conduct (EC), and the concentrations of Organic Nitrogen, Total Dissolve Solid (TDS), Total Suspended Solid (TSS), chloride, iron, and manganese had the most substantial influence on the properties of leachate. At the same time, leachate toxicity may also be a problem, as it may persist after the treatment process is completed (Wdowczyk and Szymanska-Pulikowska, 2021). Laniyan and Adewumi (2019) linked the exceeded concentration of Arsenic (As), Lead (Pb), Cadmium (Cd), and Potassium (K) in groundwater of their study to the reaction of the leachate of surrounding dumpsites.

Leachate is the primary concern to public health; therefore, a risk assessment of daily human exposure is essential. It involves characterizing physical settings, identifying potential exposure populations and pathways, and estimating the exposure concentrations and chemical intakes. Studies on possible human health-related risks through the intake of both surface and groundwater have been reported (Jabłonska-Trypuc et al., 2021; Khan et al., 2016; Elumalai et al., 2017; Edokpayi et al., 2018; Ahmad et al., 2021). The penetration of leachate from landfills can lead to contamination of groundwater, surface water, and environmental components, especially for uncontrolled leachate.

Groundwater plays a vital role in the survival of humans and remains the most reliable water source for many households in developing countries. Groundwater serves the purpose of drinking, irrigation, and many industrial activities but has been considered safe for household consumption; several studies have shown contamination due to human activities such as uncontrolled leachate from landfill systems (Majolagbe et al., 2016; Aslam et al., 2018). At the close of the landfills system, there is a need to carry out environmental and health risk assessment to ascertain the environment's safety before being subjected to activities such as building for living or industrial purposes. Many landfill systems in Nigeria are converted to housing, farmland, and industrial activities at the end of their usage; however, few risk assessments exist about the environment and human health. Therefore, the study examines the potential environmental pollution due to leachate generated from an abandoned landfill system and human health risk assessment of groundwater around the landfills.

2. Materials and methods

2.1. Study area

The landfills are located within the Ikwere and Obio/Akpor Local Government Area (LGA) of Rivers State, a maritime state in the southern

geopolitical zone of Nigeria. The two LGAs are part of Port Harcourt city, located between latitudes 4° 45' N and 4° 55' N and longitude 6° 55' E and 7° 05' E (Wali et al., 2018). The details of the three landfills (abandoned) involved in the study are presented in Table 1 and Fig. 1.

2.2. Collection of sample

The study samples include leachates from three abandoned landfills and nine (9) groundwater samples from nearby boreholes around the landfills. All the samples for the study were collected within November and December 2020 using suitable collection techniques. The influence of external factors such as rainfall was considered in selecting the period for sample collection. Future studies in the area are encouraged to consider other months of the year with high rainfall occurrence.

i. *Leachate*: The landfills lack a leachate collection system; therefore, the leachate gathering at the different spots of the dumpsite base was randomly collected and thoroughly mixed to make the whole sample. This method was adopted at each dumpsite, and the mixed samples were taken to the laboratory for analysis.

ii. *Water Sample*: Groundwater in the form of a borehole within <1 km of the landfills. Three (3) sampling points were selected from each landfill, making a total of nine (9) sampling points across the three (3) landfills, while the collection of water samples from various designated water sources with a labeled lucid bottle. Before the water collection, the lucid bottles were cleaned with a 70% sterilizer to prevent impurities and other forms of contamination. The borehole tap was left open to run before filling the water collection from each designated point and the bottles. After that, the filled bottles were immediately placed in the ice-parked cooling medium to arrest continuous microbial activities and preserve the water before being taken to the laboratory for analysis. The sample collection details were presented in Table (Supplementary Table, ST1) and Fig. 2.

2.3. Analysis of leachate and groundwater samples

2.3.1. Laboratory analysis of leachate and groundwater samples

The collected samples were analysed for relevant physicochemical (pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS)), cations (Magnesium (Mg^{2+}), Sodium (Na^{+}), and Calcium (Ca^{2+})), anions (Chloride (Cl^{-}), Nitrate (NO_3^{-}), Phosphate (PO_4^{3-}), sulphate (SO_4^{2-}) and heavy metals (Arsenic (As), Cadmium (Cd), Zinc (Zn), Barium (Ba), Manganese (Mn), Copper (Cu), Cobalt (Co), Chromium (Cr), Nickel (Ni) and Lead (Pb)) based on American Public Health Association standard-APHA (American Public Health Association – APHA 2012) and American Standard for Testing Materials- ASTM (American Society Testing Materials – ASTM 2012) accepted standard procedures. The summary of the analytical method used in analysing the sample parameters was presented in Table 2.

The samples' pH, EC, and TDS were determined electrometrically with a multi-parameter data logger (multi 340i/set). The concentration of Mg^{2+} and Ca^{2+} in samples was estimated by complexometric titration, while Na^{+} was determined by flame photometer. The values of NO_3^{-} and PO_4^{3-} were estimated by UV-visible spectrophotometer, the concentrations of Cl^{-} in the samples were determined by Argentometric titration method while and SO_4^{2-} was estimated based turbidimetric method

Table 1
Details of the landfill systems of the study.

Location	Study Site Code	Geographical Coordinate	Year of Establishment	Closedown Year	Area Cover
Eneka	LI-Eneka	N 4° 56' 6" E 7° 01' 55"	1995	2010	200 m by 120m
Aluu	LII-Aluu	N 4° 56' 10" E 6° 57' 54"	1997	2012	350 m by 200 m
Iwofe	LIII-Iwofe	N 4° 48' 23.4" E 6° 56' 35.6"	2002	2014	200 m by 150m

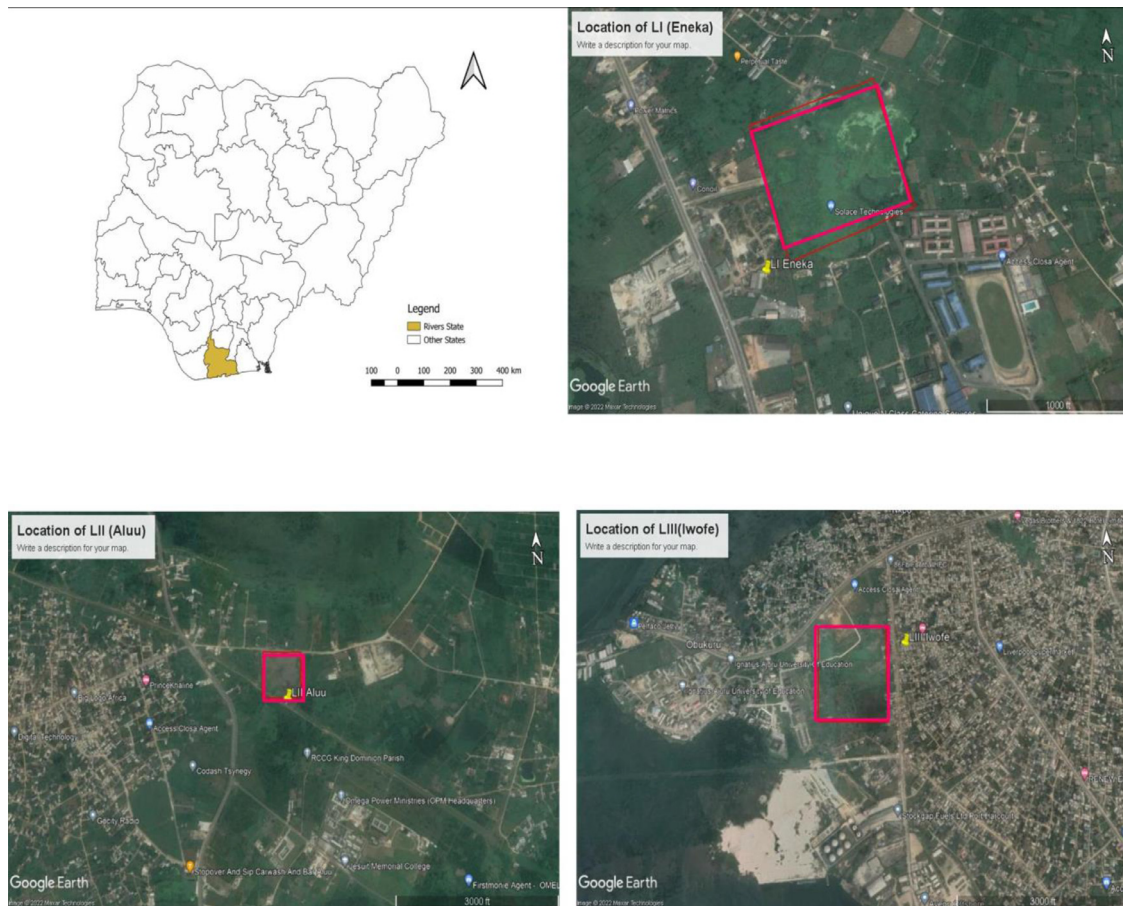


Fig. 1. Geographical representation of landfill systems.

Table 2
Analytical method for sample parameters.

Parameters	Analytical Method
pH	APHA 4500H ⁺ B
EC, TDS	APHA 2510A
Mg ²⁺ , Na ⁺ , Ca ²⁺	APHA 3111B
Cl ⁻ , NO ₃ ⁻ , PO ₄ ³⁻ , SO ₄ ²⁻	APHA 4500Cl ⁻ B, APHA 4500-NO ₃ E, APHA 4500-P D, APHA 4500 SO ₄ ²⁻ E
Cd, Zn, Mn, Cu, Co, Cr, Ni, and Pb	APHA 3111B
As, Ba	APHA 3114 C, ASTM D 3651

based on APHA 4500 SO₄²⁻E method (Visible Light Method). The concentration of heavy metals in the samples was determined by absorption spectrometer (Perkin Elmer 3100 model). All the parameters were analysed based on standard procedures described by [American Public Health Association – APHA \(2012\)](#), [American Society Testing Materials – ASTM \(2012\)](#), and [Sokpuwu \(2017\)](#).

Quality assurance/control

To ascertain the quality of the outcome from various analyses, standard procedures and laboratory quality assurance were strictly followed while samples were analysed in triplicates, and the mean was estimated for accuracy and precision. All analysis was subjected to a high-quality reagent from Fugro Nigeria Limited, Port Harcourt, and all instruments such as Pyrex glassware and containers for the analysis were properly washed in deionized water, then soaked overnight with a 10% HNO₃ in 1% HCl solution, and later washed with deionized water and desiccated. Detection limits including LOD and LOQ were estimated as LOD = 3 σ /S, LOQ = 10 σ /S respectively where σ is SD (standard deviation) of analyt-

ical blank measurement ($n = 18$) while S is the slope of the calibration curve ($y = mx + b$) ([Ahmad et al., 2021](#)).

2.3.2. Toxicity of leachate

i. Leachate Pollution Index (LPI)

The leachate pollution index (LPI) is an index used to quantify the degree of possible contamination from urban landfills on a scale from 5 to 100 ([Kumar and Alappat, 2005](#); [Koumalas et al., 2019](#)). Using LPI, the leachates' pollution data can be presented uniformly. The LPI estimation process includes the selection of pollutant variables and their respective weights, the formulation of their sub-indices curves, and finally, the aggregation of the selected variables for the final calculation of the LPI value ([Koumalas et al., 2019](#)).

The LPI was estimated by the use of the following equation (Eq. (1)):

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

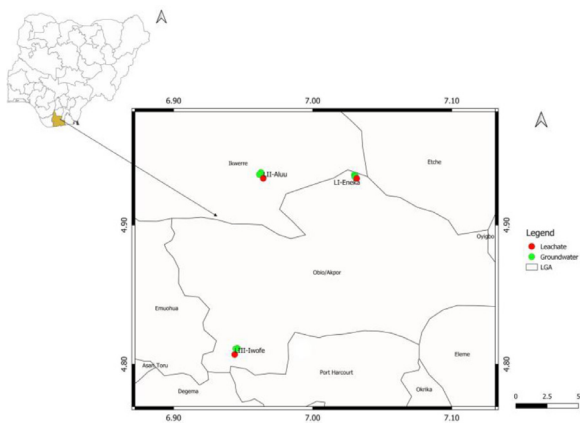


Fig. 2. Geographical representation of leachate and groundwater collection point.

Where: LPI= the weighted additive leachate pollution index;
 w_i = the weight for the i th pollutant parameter;
 p_i = the sub-index score of the i th leachate pollutant parameter;
 n = the number of leachate pollutant parameters used in the calculation of LPI

2.3.3. Health risk assessment of groundwater

To evaluate the health risk exposure of adults and children to heavy metals in groundwater, the average daily dose (ADD), the non-carcinogenic target hazard quotient (THQ), hazard index (HI), and lifetime carcinogenic risk (LCR) coefficients can be estimated (Ahmad et al., 2021; Kamunda et al., 2016; Boateng et al., 2019). Human exposure risk pathways of an individual to heavy metals contamination could be through three main pathways: inhalation via nose and mouth, direct ingestion, and dermal absorption through skin exposure (Edokpayi et al., 2018). Common exposure pathways to water are dermal absorption and ingestion routes. i. *Average Daily Dose (ADD)*

Exposure doses for determining human health risk through these two pathways have been described in the literature (Edokpayi et al., 2018; [USEPA] United States Environmental Protection Agency 1989, Asare-Donkor et al., 2016) and can be calculated using Eqs. (2) and 3 as adapted from the US EPA risk assessment guidance for superfund (RAGS) methodology (Edokpayi et al., 2018, [USEPA] United States Environmental Protection Agency 1989).

$$ADD_{ing} = C_{water} \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (2)$$

$$ADD_{derm} = C_{water} \times \frac{SA \times AF \times ABF \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (3)$$

Where; ADD_{ing} = Average daily dose through ingestion of water (mg/kg/day); ADD_{derm} = Average daily dose through dermal absorption (mg/kg/day); C_{water} = concentration of the heavy metals in water (mg/L); $IngR$: Ingestion rate; EF : Exposure Frequency; ED : Exposure Duration; BW : Body Weight; AT : Averaging Time; SA : Exposed Skin Area; AF : Skin Adherence Factor and ABF : Dermal Absorption Factor. All values are presented in Supplementary Table, ST2. ii. *Target Hazard Quotient (THQ) and Hazard Index (HI)*

Total hazard quotient: THQ is the ratio of ADD (from two exposure pathways for water) and RfD (chronic reference dose for each metal in mg/kg BW/day), which is typically used to estimate the potential non-carcinogenic risk of metals exposure to humans in different pathways (Ahmad et al., 2021).

$$THQ = \frac{ADD(ingestion \times Dermal)}{RfD} \quad (4)$$

Where $THQ < 1$ considers the exposed population experience no significant health risk. Table 3, Eqn. (4)-(6)

Hazard Index (HI): HI is the sum of all expected HQs (non-carcinogenic risks) through different pathways and is employed to compute the total potential non-carcinogenic risks of various contaminants (Ahmad et al., 2021, Mohammadi et al., 2019).

$$HQ = \frac{ADD}{RfD}; HI = \sum HQ = HQ_{ing} + HQ_{derm} \quad (5)$$

The value of $HI \leq 1$ indicates no significant risk of non-carcinogenic effects; however, $HI > 1$ implies the probability of non-carcinogenic effects occurring, and the probability increases with a rising value of HI (Ahmad et al., 2021).

iii. Carcinogenic Risk (CR) Coefficients

The estimation is that carcinogenic heavy metals determine the health risk through different exposure pathways. It is calculated based on the formula below;

$$CR = ADD(ingestion \times Dermal) \times CSF$$

$$TCR = \sum CR = CR_{ing} + CR_{derm} \quad (6)$$

Where CSF : Cancer Slope Factor. Whereas $TCR < 10^{-6}$, $TCR > 1 \times 10^{-4}$, and $LCR 1 \times 10^{-6}$ to 1×10^{-4} indicate no carcinogenic risk, high risk of developing cancer, and acceptable risk to humans, respectively.

3. Result and discussion

3.1. Physiochemical and heavy metal concentration in leachate

3.1.1. Physiochemical properties of leachate

From Table 3, the pH value of the leachates from the dumpsites ranges from 5.56 to 7.43, where the leachate from LI-Eneka and LII-Aluu dumpsites have the highest Iwofe dumpsite has the lowest pH value. It indicated the pH of Iwofe dumpsite is slightly acidic while that of LI-Eneka and LII-Aluu are Alkaline. It is influenced by the non-operational years of the dumpsite, where LIII-Iwofe has a lower pH (usually below 6.6) while older dumpsites reach values above 7.0. The finding was supported by Nájera-Aguilar et al. (2019) and Singh et al. (2016).

The EC in the leachate of LI-Eneka, LII-Aluu, and LIII-Iwofe was 194 μ S/cm, 889 μ S/cm, and 15700 μ S/cm, respectively. It was observed that dumpsites that have not been operational for a long time (LI-Eneka and LII-Aluu) have lower EC than the recently closed dumpsite

Table 3

Physiochemical and heavy metal concentrations in leachate samples from landfills.

Parameters	Units	LI-Eneka	LII-Aluu	LIII-Iwofe
pH		7.43	7.28	5.56
(EC)	μ S/cm	194	889	15,700
Total Dissolved Solids (TDS)	mg/l	2.14	2.32	2.67
Chloride (Cl)	mg/l	92.4	145	1408
Nitrate (NO ₃)	mgNO ₃ /l	8.45	1.08	0.04
Phosphate (PO ₄)	mgPO ₄ /l	9.93	1.13	0.02
Sulphate (SO ₄)	mgSO ₄ /l	4.80	3.11	764
Magnesium (Mg)	mg/l	6.43	3.75	103
Sodium (Na ⁺)	mg/l	54.2	82.4	678
Calcium (Ca)	mg/l	0.80	19.1	3464
Arsenic (As)	mg/l	0.0001	0.0010	0.0152
Cadmium (Cd)	mg/l	0.002	0.002	0.002
Zinc (Zn)	mg/l	0.09	0.02	0.87
Barium (Ba)	mg/l	0.03	0.03	0.03
Manganese (Mn)	mg/l	0.05	2.19	11.7
Copper (Cu)	mg/l	0.02	0.02	0.17
Cobalt (Co)	mg/l	0.03	0.03	0.03
Chromium (Cr)	mg/l	0.006	0.006	0.006
Nickel (Ni)	mg/l	0.06	0.06	0.06
Lead (Pb)	mg/l	0.008	0.008	0.008

(LIII-Iwofe). The value of EC of the LIII-Iwofe showed little significant difference from the operational leachates reported by [Wdowczyk and Szymanska-Pulikowska \(2021\)](#). EC is linked strongly to TDS- high EC values correspond to high concentrations of dissolved substances ([Fan et al., 2006](#), [Tatsi and Zouboulis, 2002](#)). The highest TDS value of 2.67 mg/l was found in the Iwofe dumpsite, where the EC was also the highest, while Eneka and Aluu dumpsites have TDS values of 2.14 mg/l and 2.32 mg/l, respectively. The outcome showed similarity with [Wdowczyk and Szymanska-Pulikowska \(2021\)](#) and confirms that EC and TDS content in leachate decreases with the aging of the landfill ([Tatsi and Zouboulis, 2002](#)).

The Cl value range from 92.4 mg/l for LI-Eneka dumpsite to 1408 mg/l for LIII-Iwofe; the finding showed the correlation in high Cl and TDS of Iwofe dumpsite as the recently closed dumpsites. The NO_3 value range from 0.04 mg NO_3 /l for the LIII-Iwofe dumpsite to 8.45 (mg NO_3 /l) for the LI-Eneka dumpsite; the value reported therein is less than those reported by [Wdowczyk and Szymanska-Pulikowska \(2021\)](#). The PO_4 values range from 0.02 mg PO_4 /l for LIII-Iwofe dumpsite to 9.93 mg PO_4 /l for LI-Eneka dumpsite, while the SO_4 values range from 3.11 mg SO_4 /l for LII-Aluu dumpsite to 764 mg SO_4 /l for LIII-Iwofe dumpsite. The higher concentration of SO_4 in Iwofe dumpsite indicated that the distribution of large amounts of organic matter is associated with high sulfate concentration ([Liu et al., 2011](#)).

The cations found in the leachate of the dumpsite include Mg, Na^+ , and Ca. The value of Mg ranges from 3.75 mg/l for LII-Aluu dumpsite to 103 mg/l for LIII-Iwofe dumpsite. The value of Na^+ ranges from 382.4 mg/l for LII-Aluu dumpsite to 678 mg/l for LIII-Iwofe dumpsite, while the value of Ca ranges from 19.1 mg/l for LII-Aluu dumpsite to 3464 mg/l for LIII-Iwofe dumpsite. The range values of Ca reported are higher than the Mg concentration, and this outcome showed similarity with that reported in similar studies ([Wdowczyk and Szymanska-Pulikowska, 2021](#), [Zhao et al., 2013](#)). The Na^+ presence in the leachate could indicate plant and other bio-waste residues at the dumpsite ([Christensen et al., 2001](#)). However, the presence does not necessarily impact the microbiological activities at the landfill.

3.1.2. Heavy metals concentration in leachate

From [Table 3](#), the Ar concentration in leachate range from 0.0001 mg/l from LI-Eneka to 0.015 mg/l at LIII-Iwofe landfill while Cd, Ba, Co, Cr, Ni and Pb showed similar concentration of 0.002 mg/l, 0.03 mg/l, 0.03 mg/l, 0.006 mg/l, 0.06 mg/l and 0.008 mg/l respectively for each the landfills. The Zn concentration in leachate ranges from 0.02 mg/l from LII-Aluu to 0.87 mg/l at the LIII-Iwofe landfill. Mn concentration in the leachate range ranges from 2.19 mg/l from LII-Aluu to 11.7 mg/l from LIII-Iwofe, while the Cu concentration in leachate range from 0.02 mg/l from LII-Aluu to 0.17 mg/l from LIII-Iwofe. Cd, Cr, Ni, Pb, and Cu reported therein are lesser concentrations than those reported in similar studies ([Parvin et al., 2021](#), [Jahan et al., 2016](#), [Hossain et al., 2018](#)). The heavy metal concentration of LI-Eneka dumpsite trended as; $\text{Zn} > \text{Ni} > \text{Mn} > \text{Ba} > \text{Co} > \text{Cu} > \text{Pb} > \text{Cr} > \text{Cd} > \text{As}$, LII-Aluu Dumpsite trended as $\text{Mn} > \text{Ni} > \text{Co} > \text{Ba} > \text{Cu} > \text{Zn} > \text{Pb} > \text{Cr} > \text{Cd} > \text{As}$ while the LIII-Iwofe dumpsite trended as $\text{Mn} > \text{Zn} > \text{Cu} > \text{Ni} > \text{Co} > \text{Ba} > \text{As} > \text{Pb} > \text{Cr} > \text{Cd}$. The trend concentration indicated different compositions at various dumpsites, and the finding showed similarity with a related study ([Ololade et al., 2019](#)).

3.2. Toxicity of leachate

3.2.1. Leachate pollution index (LPI)

Establishing the leachate pollution potential from landfill is significant and can be carried out through a quantitative tool developed by [Kumar and Alappat \(2005\)](#) as an index known as LPI. The LPI was adopted in estimating the leachate contamination potential of three dumpsites understudied, and the outcome was presented in [Table 4](#) and [Fig. 3](#). [Mishra et al. \(2019\)](#) and [Arunbabu et al. \(2017\)](#) noted that leachate composition exhibits significant variations across landfills, and

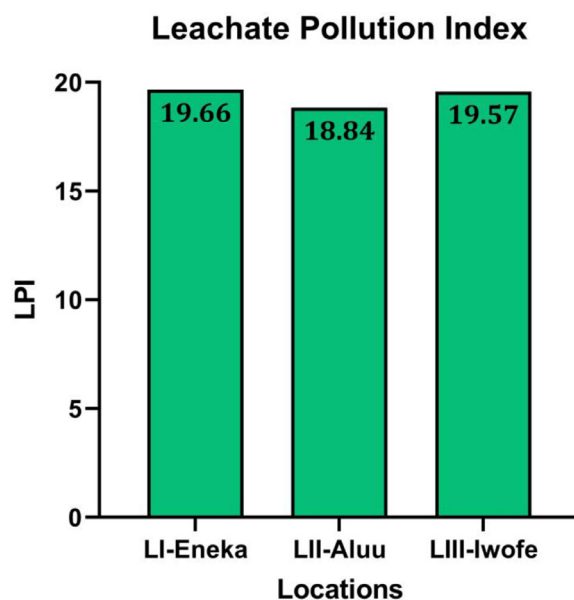


Fig. 3. LPI of sampled landfills.

the concentration can differ by several degree levels. Although, the LPI therein demonstrated uniformity which can be attributed to the quantitative tool. The analysis showed that the LPI of LI-Eneka dumpsite was 19.66, the LPI of LII-Aluu dumpsite was 18.84, and the LPI of LIII-Iwofe was 19.57. The higher value of LPI (>10) indicated a hazardous nature of the dumpsite, indicating potential contamination of surrounding groundwater ([Mishra et al., 2019](#), [Mor et al., 2018](#)).

[Arunbabu et al. \(2017\)](#) indicated that leachate with an LPI value greater than ten could have phytotoxic impacts on plants. The reported LPI (LII-Aluu-18.84) showed proximity with that reported for dumpsite in Brazil for 2004 (LPI=17.68) and 2006 (LPI=17.94) by [Mahler et al. \(2020\)](#). The LPI showed similarity with LPI reported for landfills (Matuail landfill-19.9) in Bangladesh ([Parvin et al., 2021](#)); however, LPI reported (LI-Eneka-19.66; LIII-Iwofe-19.57) therein is higher when compared to the Rowfabad landfill, Bangladesh (6.4) ([Parvin et al., 2021](#)), Ramna landfill site, India (15.6) ([Mishra et al., 2019](#)) and semi aerobic Ampang Jajar, Malaysia (16.4) ([Aziz et al., 2010](#)). Compared with Nigerian dumpsite, the reported LPI therein is higher than LPIs (5.693, 6.184, and 5.895) of Warri dumpsite ([American Public Health Association – APHA 2012](#)), LPIs (17.85 and 16.87) of Soluos and Ewu Elepe dumpsite in Lagos ([Salami et al., 2015](#)); however, the LPI therein was lower in comparison to the LPI (23.54) reported for Olusosun dumpsite in Lagos ([Salami et al., 2015](#)).

3.3. Physicochemical and heavy metal concentration in groundwater

The results of the groundwater physicochemical and heavy metals concentration from various point sources close to the landfills are provided in supplementary tables ST3.

3.3.1. Physicochemical properties of groundwater

The mean concentration of the physicochemical and heavy metals analysis of groundwater samples is presented in [Table 5](#). The pH means the value of the groundwater ranges from 4.44 to 4.75, with LIII-Iwofe having the lowest pH and LII-Aluu with the highest pH value. This indicated that the groundwater across the landfills is acidic and below the WHO permissible limit. According to [Edokpayi et al. \(2018\)](#), this is a possible corrosion issue and potential heavy metal contamination.

EC of the groundwater ranges from 14.7 $\mu\text{S}/\text{cm}$, 25.47 $\mu\text{S}/\text{cm}$, and 57.93 $\mu\text{S}/\text{cm}$ for LII-Aluu, LI-Eneka, and LIII-Iwofe, respectively. The EC of the sample is low and within the WHO permissible limit of

Table 4
Leachate Pollution Index (LPI) in samples.

Parameters	LI-Eneka				LII-Aluu				LIII-Iwofe			
	Conc.	w _i	p _i	w _i p _i	Conc.	w _i	p _i	w _i p _i	Conc.	w _i	p _i	w _i p _i
pH	7.43	0.055	6	0.33	7.28	0.055	5.5	0.30	5.56	0.055	6.5	0.36
EC	194	–	–	–	889	–	–	–	15,700	–	–	–
TDS	0.08	0.05	28	1.4	2.32	0.05	24	1.2	2.67	0.05	23	1.15
Cl	2.14	0.048	30	1.44	145	0.048	25	1.2	1408	0.048	30	1.44
NO ₃	117	0.053	100	5.3	1.08	0.053	100	5.3	0.04	0.053	98	5.19
PO ₄	92.4	–	–	–	1.13	–	–	–	0.02	–	–	–
SO ₄	8.45	–	–	–	3.11	–	–	–	764	–	–	–
Mg	9.93	–	–	–	3.75	–	–	–	103	–	–	–
Na ⁺	4.80	–	–	–	82.4	–	–	–	678	–	–	–
Ca	6.43	–	–	–	19.1	–	–	–	3464	–	–	–
As	54.2	0.061	5.5	0.34	0.0010	0.061	10	0.61	0.0152	0.061	10	0.61
Cd	0.80	–	–	–	0.002	–	–	–	0.002	–	–	–
Zn	7.43	0.056	5	0.28	0.02	0.056	5.5	0.31	0.87	0.056	6.5	0.36
Ba	194	–	–	–	0.03	–	–	–	0.03	–	–	–
Mn	0.08	–	–	–	2.19	–	–	–	11.7	–	–	–
Cu	2.14	0.05	7	0.35	0.02	0.05	6	0.3	0.17	0.05	7	0.35
Co	117	–	–	–	0.03	–	–	–	0.03	–	–	–
Cr	92.4	0.064	6.5	0.42	0.006	0.064	6.5	0.42	0.006	0.064	6.5	0.42
Ni	8.45	0.052	8	0.42	0.06	0.052	5	0.26	0.06	0.052	8	0.42
Pb	9.93	0.063	9	0.57	0.008	0.063	8	0.50	0.008	0.063	8	0.50
Σw _i		0.552										
Σw _i p _i				10.85				10.4				10.8
LPI		19.66			18.84			19.57				

Conc. = Concentration, LPI= Leachate Pollution Index, w_i = the weight of pollutant parameter, p_i = the sub-index score of pollutant parameter.

Table 5
Mean concentration of physiochemical and heavy metal in groundwater close to landfills.

Parameters	Units	LI-Eneka	LII-Aluu	LIII-Iwofe	WHO
pH		4.62	4.75	4.44	6.5–9.2
(EC)	μS/cm	25.47	14.7	57.93	300
Total Dissolved Solids (TDS)	mg/l	15.3	8.83	34.77	500
Chloride (Cl)	mg/l	1.0	1.0	1.00	250
Nitrate (NO ₃)	mgNO ₃ /l	0.02	0.02	0.02	50
Phosphate (PO ₄)	mgPO ₄ /l	0.02	0.02	0.02	
Sulphate (SO ₄)	mgSO ₄ /l	1.55	2.5	4.15	400
Magnesium (Mg)	mg/l	0.15	0.15	0.12	150
Sodium (Na ⁺)	mg/l	0.07	0.07	0.39	200
Calcium (Ca)	mg/l	1.02	0.55	0.81	75–200
Arsenic (As)	mg/l	0.0001	0.0001	0.0001	0.01
Cadmium (Cd)	mg/l	0.002	0.002	0.002	0.003
Zinc (Zn)	mg/l	0.02	0.02	0.02	3.0
Barium (Ba)	mg/l	0.03	0.03	0.03	0.7
Manganese (Mn)	mg/l	0.05	0.05	0.05	0.05
Copper (Cu)	mg/l	0.02	0.012	0.02	2
Cobalt (Co)	mg/l	0.03	0.015	0.03	0.05
Chromium (Cr)	mg/l	0.006	0.007	0.006	0.05
Nickel (Ni)	mg/l	0.06	0.06	0.06	0.02
Lead (Pb)	mg/l	0.008	0.008	0.05	0.01

300 μS/cm ([WHO] World Health Organization 2011). The outcome indicates low mineralization (Naminata et al., 2018), and the extent of EC can be influenced by natural weathering and anthropogenic activities. It is directly proportional to the TDS (Hameed et al., 2010). The TDS concentration of LI-Eneka, LII-Aluu and LIII-Iwofe groundwater are 15.3 mg/l, 8.83 mg/l, and 34.77 mg/l, respectively, within the WHO permissible limit of 500 mg/l. Similar but higher concentration was reported by Afolabi et al. (2021), while Adebayo et al. (2015) and Ganiyu et al. (2018) noted that a TDS value of less than 1000 mg/l implies that the water samples can be classified as freshwater. Considering inorganic elements, the concentration of Cl, NO₃, and PO₄ in groundwater across the sampled locations was 1.0 mg/l, 0.02 mgNO₃/l, and 0.02 mgPO₄/l, respectively. The mean concentration of SO₄ in sampled groundwater was 1.55 mgSO₄/l, 2.5 mgSO₄/l, and 4.15 mgSO₄/l for LII-Aluu, LI-Eneka, and LIII-Iwofe, respectively. The mean concentration of Mg in sampled groundwater was 0.15 mg/l for LI-Eneka and LII-Aluu and 0.12 mg/l for LIII-Iwofe. The mean concentration

of Na⁺ in sampled groundwater was 0.07 mg/l for LI-Eneka and LII-Aluu and 0.39 mg/l for LIII-Iwofe. The mean concentration of Ca in sampled groundwater was 1.02 mg/l, 0.55 mg/l, and 0.81 mg/l for LI-Eneka, LII-Aluu, and LIII-Iwofe, respectively, and the mean concentration of all the inorganic elements of the sampled groundwater was within the permissible limit ([WHO] World Health Organization 2011). They are from natural sources, although anthropogenic activities can also increase their concentration in groundwater (Adimalla and Wu, 2019). NO₃ is of human origin from activities such as fertilizer application (Hansen et al., 2017, Zhang et al., 2018, He and Wu, 2019).

3.3.2. Heavy metals concentration in groundwater

From Table 5, the concentration of As, Cd, Zn, Ba, and Mn in groundwater across the sampled locations was 0.0001 mg/l, 0.002 mg/l, 0.02 mg/l, 0.03 mg/l and 0.05 mg/l respectively. The mean concentration of Cu in sampled groundwater was 0.02 mg/l for LI-Eneka and

Table 6

ADD (Ingestion and Derma) from groundwater for adult and children across the landfills.

HM	Adult-ADD _{ingestion}			Adult-ADD _{Derm}			Children-ADD _{ingestion}			Children-ADD _{Derm}		
	LI	LII	LIII	LI	LII	LIII	LI	LII	LIII	LI	LII	LIII
As	4.51×10 ⁻¹¹	4.51×10 ⁻¹¹	4.51×10 ⁻¹¹	2.9×10 ⁻¹²	2.9×10 ⁻¹²	2.9×10 ⁻¹²	2.64×10 ⁻¹¹	2.64×10 ⁻¹¹	2.64×10 ⁻¹¹	6.4 × 10 ⁻¹³	6.4 × 10 ⁻¹³	6.4 × 10 ⁻¹³
Cd	9.02×10 ⁻¹⁰	9.02×10 ⁻¹⁰	9.02×10 ⁻¹⁰	1.94×10 ⁻¹²	1.94×10 ⁻¹²	1.94×10 ⁻¹²	5.28×10 ⁻¹⁰	5.28×10 ⁻¹⁰	5.28×10 ⁻¹⁰	4.2 × 10 ⁻¹³	4.2 × 10 ⁻¹³	4.2 × 10 ⁻¹³
Zn	2.64×10 ⁻⁸	2.64×10 ⁻⁸	2.64×10 ⁻⁸	5.6 × 10 ⁻¹¹	5.6 × 10 ⁻¹¹	5.6 × 10 ⁻¹¹	6.16×10 ⁻⁸	6.16×10 ⁻⁸	6.16×10 ⁻⁸	5 × 10 ⁻¹¹	5 × 10 ⁻¹¹	5 × 10 ⁻¹¹
Ba	3.96×10 ⁻⁸	3.96×10 ⁻⁸	3.96×10 ⁻⁸	8.4 × 10 ⁻¹⁰	8.4 × 10 ⁻¹⁰	8.4 × 10 ⁻¹⁰	9.24×10 ⁻⁸	9.24×10 ⁻⁸	9.24×10 ⁻⁸	7.5 × 10 ⁻¹¹	7.5 × 10 ⁻¹¹	7.5 × 10 ⁻¹¹
Mn	6.6 × 10 ⁻⁸	6.6 × 10 ⁻⁸	6.6 × 10 ⁻⁸	1.4 × 10 ⁻¹⁰	1.4 × 10 ⁻¹⁰	1.4 × 10 ⁻¹⁰	1.54×10 ⁻⁷	1.54×10 ⁻⁷	1.54×10 ⁻⁷	1.25×10 ⁻¹⁰	1.25×10 ⁻¹⁰	1.25×10 ⁻¹⁰
Cu	2.64×10 ⁻⁸	1.58×10 ⁻⁸	2.64×10 ⁻⁸	5.6 × 10 ⁻¹¹	3.36×10 ⁻¹¹	5.6 × 10 ⁻¹¹	6.16×10 ⁻⁸	3.70×10 ⁻⁸	6.16×10 ⁻⁸	5 × 10 ⁻¹¹	3 × 10 ⁻¹¹	5 × 10 ⁻¹¹
Co	3.96×10 ⁻⁸	1.98×10 ⁻⁸	3.96×10 ⁻⁸	8.4 × 10 ⁻¹⁰	4.2 × 10 ⁻¹¹	8.4 × 10 ⁻¹⁰	9.24×10 ⁻⁸	4.62×10 ⁻⁸	9.24×10 ⁻⁸	7.5 × 10 ⁻¹¹	3.75×10 ⁻¹¹	7.5 × 10 ⁻¹¹
Cr	2.71×10 ⁻⁹	3.16×10 ⁻⁹	2.71×10 ⁻⁹	5.82×10 ⁻¹²	6.79×10 ⁻¹²	5.82×10 ⁻¹²	1.58×10 ⁻⁹	1.85×10 ⁻⁹	1.58×10 ⁻⁹	1.26×10 ⁻¹²	1.47×10 ⁻¹²	1.26×10 ⁻¹²
Ni	2.71×10 ⁻⁸	2.71×10 ⁻⁸	2.71×10 ⁻⁸	5.82×10 ⁻¹¹	5.82×10 ⁻¹¹	5.82×10 ⁻¹¹	1.58×10 ⁻⁸	1.58×10 ⁻⁸	1.58×10 ⁻⁸	1.26×10 ⁻¹²	1.26×10 ⁻¹²	1.26×10 ⁻¹²
Pb	3.61×10 ⁻⁸	3.61×10 ⁻⁸	2.26×10 ⁻⁸	7.76×10 ⁻¹²	7.76×10 ⁻¹²	4.85×10 ⁻¹²	2.11×10 ⁻⁹	2.11×10 ⁻⁹	1.32×10 ⁻⁸	1.68×10 ⁻¹²	1.68×10 ⁻¹²	1.05×10 ⁻¹²

LI=LI-Eneka, LII=LII-Aluu, LIII=LIII-Iwofe, HM=Heavy Metals.

Table 7

THQ and TCR from groundwater for adult and children across the landfills.

HM	LI-Eneka				LII-Aluu				LIII-Iwofe			
	Adult		Children		Adult		Children		Adult		Children	
	THQ	TCR	THQ	TCR	THQ	TCR	THQ	TCR	THQ	TCR	THQ	TCR
As	3.54×10 ⁻³³	7.21×10 ⁻¹¹	4.58×10 ⁻¹⁶	4.06×10 ⁻¹¹	3.54×10 ⁻³³	7.21×10 ⁻¹¹	4.58×10 ⁻¹⁶	4.06×10 ⁻¹¹	3.54×10 ⁻³³	7.21×10 ⁻¹¹	4.58×10 ⁻¹⁶	4.06×10 ⁻¹¹
Cd	6.99×10 ⁻²⁹	3.55×10 ⁻¹⁰	8.87×10 ⁻⁶	4.65×10 ⁻¹⁰	6.99×10 ⁻²⁹	3.55×10 ⁻¹⁰	8.87×10 ⁻⁶	4.65×10 ⁻¹⁰	6.99×10 ⁻²⁹	3.55×10 ⁻¹⁰	8.87×10 ⁻⁶	4.65×10 ⁻¹⁰
Zn	8.21×10 ⁻¹⁶	–	1.71×10 ⁻¹⁴	–	8.21×10 ⁻¹⁶	–	1.71×10 ⁻¹⁴	–	8.21×10 ⁻¹⁶	–	1.71×10 ⁻¹⁴	–
Ba	9.69×10 ⁻²⁴	–	2.62×10 ⁻¹⁴	–	9.69×10 ⁻²⁴	–	2.62×10 ⁻¹⁴	–	9.69×10 ⁻²⁴	–	2.62×10 ⁻¹⁴	–
Mn	3.69×10 ⁻¹⁴	–	7.64×10 ⁻¹²	–	3.69×10 ⁻¹⁴	–	7.64×10 ⁻¹²	–	3.69×10 ⁻¹⁴	–	7.64×10 ⁻¹²	–
Cu	3.08×10 ⁻¹⁵	–	6.42×10 ⁻¹⁵	–	1.11×10 ⁻¹⁵	–	2.31×10 ⁻¹⁵	–	3.08×10 ⁻¹⁵	–	6.42×10 ⁻¹⁵	–
Co	2.92×10 ⁻⁸	–	6.08×10 ⁻¹¹	–	7.29×10 ⁻⁸	–	1.52×10 ⁻¹¹	–	2.92×10 ⁻⁸	–	6.08×10 ⁻¹¹	–
Cr	1.75×10 ⁻¹⁵	1.59×10 ⁻⁹	2.21×10 ⁻¹⁶	8.42×10 ⁻¹⁰	2.15×10 ⁻²⁰	1.86×10 ⁻⁹	3.02×10 ⁻¹⁶	9.85×10 ⁻¹⁰	1.75×10 ⁻¹⁵	1.59×10 ⁻⁹	2.21×10 ⁻¹⁶	8.42×10 ⁻¹⁰
Ni	1.46×10 ⁻¹⁵	4.64×10 ⁻⁸	1.84×10 ⁻¹⁶	2.69×10 ⁻⁸	1.46×10 ⁻¹⁵	4.64×10 ⁻⁸	1.84×10 ⁻¹⁶	2.69×10 ⁻⁸	1.46×10 ⁻¹⁵	4.64×10 ⁻⁸	1.84×10 ⁻¹⁶	2.69×10 ⁻⁸
Pb	3.82×10 ⁻¹³	3.07×10 ⁻⁹	4.83×10 ⁻¹⁶	1.79×10 ⁻¹¹	3.82×10 ⁻¹³	3.07×10 ⁻⁹	4.83×10 ⁻¹⁶	1.79×10 ⁻¹¹	1.49×10 ⁻¹³	3.84×10 ⁻⁸	1.89×10 ⁻¹⁴	1.20×10 ⁻¹⁰

TCR>1: No Significant Health Risk, TCR <10⁻⁶: No Carcinogenic Risk.

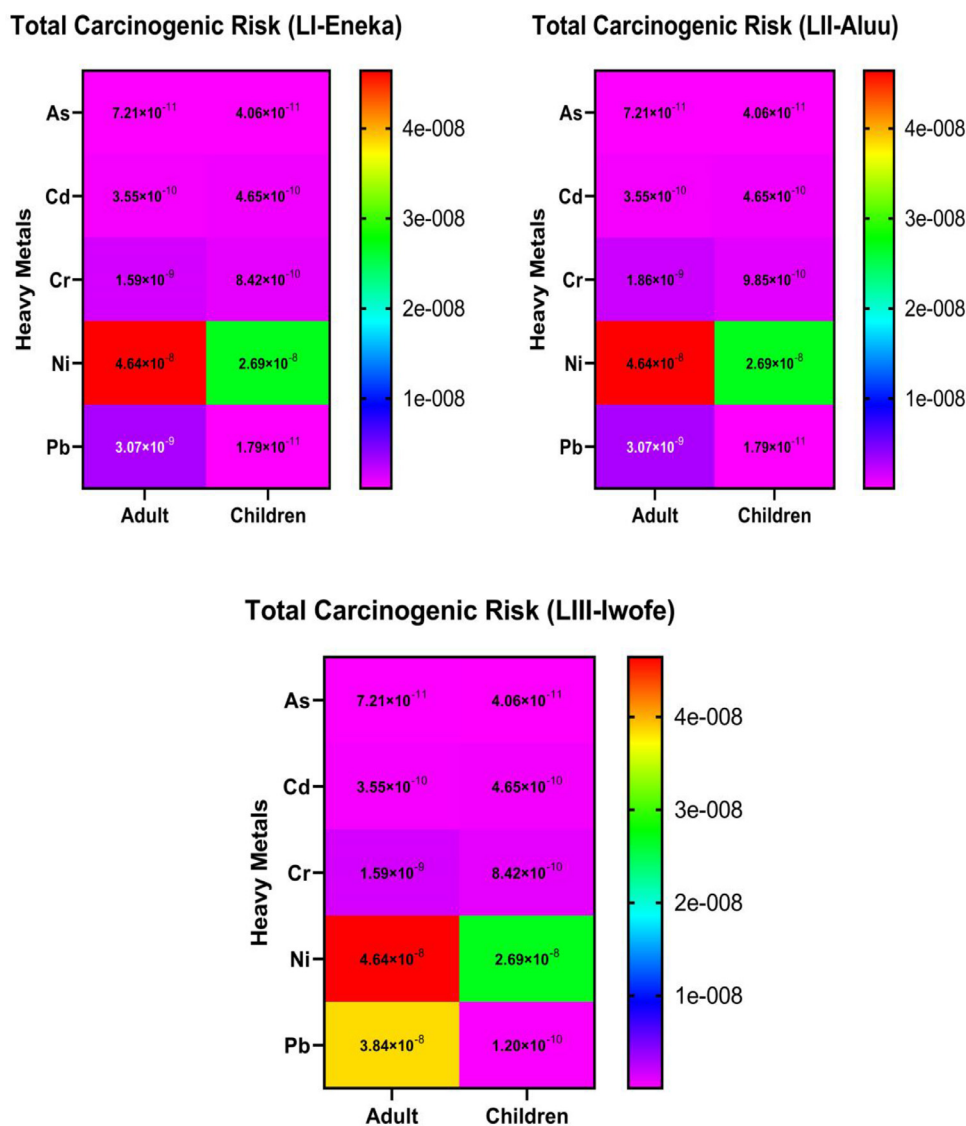


Fig. 4. Total Carcinogenic Risk (TCR) assessment of groundwater with potential leachate contamination.

LIII-Iwofe and 0.12 mg/l for LII-Aluu. The mean concentration of Co in sampled groundwater was 0.03 mg/l for LI-Eneka and LIII-Iwofe and 0.15 mg/l for LII-Aluu. The mean concentration of Cr in sampled groundwater was 0.006 mg/l for LI-Eneka and LIII-Iwofe and 0.007 mg/l for LII-Aluu. The mean concentration of Ni in sampled groundwater was 0.06 mg/l for all the studied locations. The mean concentration of Pb in sampled groundwater was 0.008 mg/l for LI-Eneka and LII-Aluu and 0.12 mg/l for LIII-Iwofe. Heavy metals such as As, Cd, Zn, Mn, Cu, Cr, and Co are within the permissible limit of WHO standards; however, Ni and Pb (of LIII-Iwofe) exceeded the permissible limit. This showed similarity with Saheed et al. (2020), Laniyan and Adewumi (2019), and Naminata et al. (2018), who all reported Cr, Ni, and Pb contamination of groundwater due to leachate of landfill systems. Cr, Ni, and Pb are metals with no biological advantage, and their high concentration in groundwater is dangerous to human health and adversely affects children in many ways (Saheed et al., 2020). Pb poisoning in humans damages the kidneys, liver, heart, brain, skeleton, and nervous system (Flora et al., 2006, Kinuthia et al., 2020). Chronic exposure to low Pb levels can limit the intelligence capacity of children (Kinuthia et al., 2020). In its compounded form, Cr, chromates of Ca, Zn, Sr, and Pb are highly soluble in water, toxic, and carcinogenic (Nwaichi et al., 2016). Human exposure to Ni can result in health impacts such as allergies,

cardiovascular and kidney diseases, lung fibrosis, and lung and nasal cancer (Kinuthia et al., 2020).

3.4. Human health risk assessment of heavy metals in groundwater

The human risk of exposure to carcinogenic and non-carcinogenic heavy metals as potential groundwater contamination due to leachate from abandoned landfills was evaluated for adults and children based on average daily dose-ADD (ingestion and derma) in Table 6, hazard quotient-HQ (supplementary tables ST4-5) and total carcinogenic risk-TCR in Table 7 and Fig. 4. The total hazard quotient (THQ) indicated that heavy metals have ≤ 1 across the three landfills, implying that the exposed population experience no significant health risk. The THQ (adult) trended in descending order of $\text{Co} > \text{Pb} > \text{Mn} > \text{Ni} > \text{Cr} > \text{Cu} > \text{Zn} > \text{Ba} > \text{Cd} > \text{As}$ for LI-Eneka and LIII-Iwofe while LII-Aluu trended as $\text{Co} > \text{Pb} > \text{Mn} > \text{Cr} > \text{Ni} > \text{Cu} > \text{Zn} > \text{Ba} > \text{Cd} > \text{As}$. The THQ (children) trended in descending order of $\text{Cd} > \text{Co} > \text{Zn} > \text{Ba} > \text{Mn} > \text{Cu} > \text{Cr} > \text{Ni} > \text{As} > \text{Pb}$ for all the locations. The estimation for TCR for carcinogenic heavy metals (As, Cd, Cr, Ni, and Pb) from various landfills indicated no carcinogenic risk ($\text{TCR} < 10^{-6}$). According to USEPA, CR and TCR values below 1×10^{-6} are considered negligible, and the metals of interest are non-carcinogenic

risk (Alsafran et al., 2021). This outcome implies that exposure through ingestion and derma has no carcinogenic risk to the population exposed to the groundwater.

4. Conclusion

Turning the environment of abandoned landfill areas into various human activities is a common practice in Nigeria; however, many of these environments are deemed contaminated due to their past engagement. Assessing the potential environmental and health risk associated with such an environment is considered significant, hence, the purpose of the present study. The LPI of the study indicated the potential pollution of various environmental components, including groundwater, due to the continuous discharge of leachate from the landfill. The study revealed that among the physiochemical and heavy metals parameters analysed, Cr, Ni, and Pb are the parameters exceeding the WHO permissible limit indicating some level of contamination and the need for water treatment before consumption and other related use. Although the abandoned landfill showed potential environmental pollution and contamination of groundwater; however, the health risk assessment of the groundwater revealed no significant carcinogenic risk to the population exposed to it. The study recommended further evaluation of the surrounding soil and edible crops for total coverage of various environmental components.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Omobolaji O. Afolabi: Conceptualization, Methodology, Writing – original draft, Formal analysis. **Elekwachi Wali:** Conceptualization, Data curation, Methodology, Formal analysis. **Eze C. Ihunda:** Conceptualization, Data curation, Methodology, Formal analysis. **Maureen C. Orji:** Writing – original draft, Writing – review & editing, Resources, Visualization. **Victoria O. Emelu:** Conceptualization, Data curation, Methodology, Formal analysis, Funding acquisition, Resources, Project administration, Validation. **Lilian C. Bosco-Abiahu:** Data curation, Formal analysis. **Nnamdi C. Ogbuehi:** Writing – original draft, Writing – review & editing, Resources, Visualization. **Sunny O. Asomaku:** Funding acquisition, Resources, Project administration, Validation. **Odinaka A. Wali:** Data curation, Formal analysis.

Data availability

Supplementary file containing the research data was submitted along with the article.

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