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Hydrogeochemical Assessment of Asunle Waste Dumpsite, Obafemi Awolowo University Campus, Southwestern Nigeria

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Abstract - The soil and surface water around the Asunle dumpsite, Obafemi Awolowo University Campus, Ile-Ife, Osun State, southwestern Nigeria, were assessed in this study with a view to determining the contaminant level of heavy metals in the soils and surface water. Geophysical investigation revealed that the area was underlain by four subsurface layers of topsoil, weathered layer, partially weathered or fractured layer, and fresh basement. Sampling and analysis of the topsoil and weathered layer revealed that the hydraulic conductivity of the soils was classified as medium, decreases with depth, and the materials are semipervious. The hydraulic conductivity of the soil influences heavy metal transport. Hence, there is a marked variation in the concentrations of heavy metals around the dumpsite, with most concentrations above the maximum permissible limits recommended. Heavy metals and faecal microbial organisms have contaminated the subsoil and surface water around the Asunle dumpsite. The contamination levels ranged from low to very high. The study concluded that the soils around the Asunle dumpsite are contaminated by heavy metals, which have deteriorated the chemical and microbial qualities of the Asunle stream.

Keywords: soil, water assessment, heavy metal, microbial contamination, soil hydraulic conductivity

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Introduction

Background

Soil is a biologically active and porous medium that has developed in the uppermost layer of the earth crust. Soil has evolved through weathering processes driven by biological, climatic, geologic, and topographic influences. Soil serves as a reservoir of water and nutrients, and as a medium for the filtration and breakdown of injurious wastes (Sposito, 2021). These properties of soil vary with the soil type (sand, silt, and clay), grain size, and distribution. For instance, clayey soils are fine-grained, and have the ability to store water. Water does not pass through clayey materials easily. Hence, clayey materials act as good filter media. Sandy materials range from fine- to very coarse-grained, that allow water to pass through them. Therefore, sandy materials store and transmit water easily, making them poor filter materials. Silty soils have the characteristics of both sandy and clayey soils; having the ability to hold water, but not as much as clayey soils. Silty soils are moderate filter materials (Abiodun, 2013; Konwea and Ajayi, 2021).

Different materials come in contact with soil on the surface of the earth, and are either stored or transmitted through the soil. These materials could occur naturally such as rainwater, or are manmade such as human waste. Rain water either flows on the soils as runoff, or is transmitted through the soil into the subsurface. Waste in the form of solid or liquid can be deposited in soils on land, and are carried by flowing water into water bodies, or are transmitted through the soil until the waste comes in contact with groundwater (Mcintosh and Pontius, 2017). Studies have shown that wastes on land are capable of contaminating both surface water and groundwater (Edokpayi *et al*., 2017; Naveen *et al*., 2018), causing adverse effects on human and the environment.

Waste management is a major concern as human activities have resulted in increased pollution of soil and water bodies due to contamination by waste materials, leading to a variety of human health problems. Studies have shown that most dumpsites within and outside Nigeria are faced with primary problem of soil contamination. In Lagos, southwestern Nigeria, waste disposal in dumpsites has resulted in soil and groundwater contamination leading to the spread of diseases and death (Abioye and Perera, 2019). Joe-Ukairo and Oni (2018) reported soil and surface water contamination at the Asunle dumpsite in Obafemi Awolowo University (OAU) Campus, Ile-Ife, Osun State, southwestern Nigeria (Figure 1). However, no diseases or deaths have been linked to the soil and water contamination.

On the OAU campus, solid waste is generated in four major areas. These areas are the residential areas (student halls of residence and staff quarters), academic area, OAU central market, and the OAU Teaching Hospital Complex (OAUTHC). Waste generated in these areas is disposed of in several waste bins around these areas before it is finally transported to the dumpsite. The OAUTHC dumpsite and the Asunle dumpsite are the two main dumpsites in OAU. The OAUTHC waste is discarded in

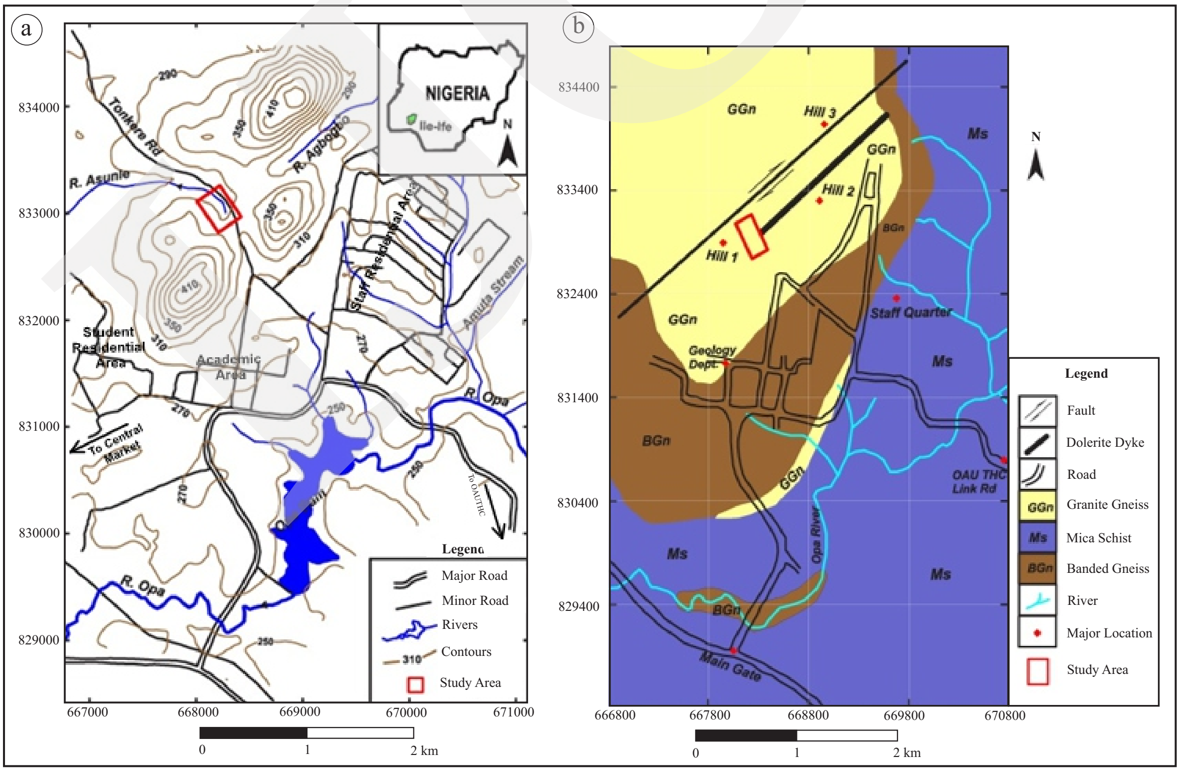

Figure 1. Location map of Obafemi Awolowo University Campus (a) Topographic map (b) Geologic map (Joe-Ukairo and Oni, 2018).

the OAUTHC dumpsite, while other municipal wastes within the OAU campus are discarded in the Asunle dumpsite (Figure 2). The Asunle dumpsite which has a total area of about 15,000 m^2 is the major dumpsite on the OAU campus, and has been in operation since the inception of the university in 1961. All municipal wastes generated on the OAU campus, such as nylons, bottles, plastics, food waste, batteries, papers, and appliances, are disposed of in the Asunle dumpsite, and incinerated openly. The dumpsite causes environmental pollution, because it lacks proper solid waste management facilities such as landfills and composting facilities. Open air incineration causes the release of toxic heavy metals from the waste into the air, soil, and water bodies.

The multiple industrial, domestic, agricultural, medical, and technological applications of heavy metals such as arsenic, copper, chromium, cadmium, iron, nickel, lead, mercury, and zinc have led to the wide distribution of heavy metals in the environment, raising concerns over their potential effects on human health and the environment. This study therefore seeks to determine the concentrations of heavy metals in the soil and surface water around the Asunle waste dumpsite, to assess the level of contamination of heavy metals in the soil, to determine the source of possible contaminants in the Asunle stream, and to assess the quality of the Asunle stream; all with a view to assessing the impact of the Asunle waste dumpsite on the soil and surface water around the area.

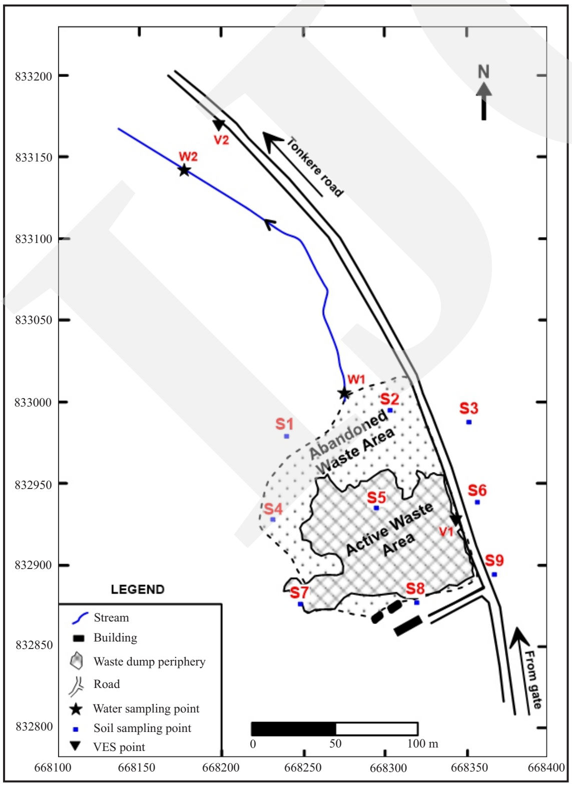

Figure 2. Waste dump location showing sampling points (Joe-Ukairo and Oni, 2018).

Study Area

The Asunle dumpsite is located in north of the OAU Campus Ile-Ife, Osun State, southwestern Nigeria (Figure 1). The dumpsite lies between latitudes 7°31'58"N and 7°32'10"N, and longitudes 4°31'22"E and 4°31'32"E. The studied area is accessible through paved motorable roads from the OAU Campus to the Tonkere gate, and then an unpaved road from the Tonkere gate to the studied area. The studied area is geographically located within the subequatorial climate belt of tropical rain-forest vegetation with evergreen and broad leaved trees. Tropical climates are characterized by monthly average temperature of 18^{o}C or higher year-round. Annual precipitation is often abundant in tropical climates, and shows a seasonal rhythm to varying degrees. The average annual precipitation in the studied area is 1,600 mm. There are normally only two seasons in the tropical climates, which are also experienced in the studied area. These are the wet and dry seasons. In the wet season, a double rainfall period is characterized by two high rainfall peaks, with a short dry season and a longer dry season falling between and after each peak, respectively.

The first wet season runs from March to July, with a peak in June. This wet season is followed by the August break, which is a short dry break in August. The August break is broken by a short wet season starting around Early September and ending in Mid-October, with peak rainfall towards the end of September. The end of the wet season is followed by the beginning of a long dry season in October. The average daily temperature increases from 24.0 to 27.3°C between December and February. The fieldwork for this study took place between the end of July and the beginning of August, which was during the wet season.

The studied area is drained by the Opa River and its tributaries (Figure 1). The Opa River is a tributary of the Shasha River. The dominant drainage pattern observed within the OAU Campus is dendritic, where the tributary rivers join the main river at an acute angle. The Asunle stream, which is a tributary of the Opa River, originates from the Asunle dumpsite and flows from the southeast to the northwest (Figure 1).

The Asunle stream is a perennial stream that extends over a distance of about 10 km, cutting across communities such as Amuta, Agbogbo, and Abagbooro (Ogunfowokan *et al*., 2013). Studies have shown that streams situated close to dumpsites experience the leaching of harmful substances, including heavy metals, into the water body (Naveen *et al.*, 2018). The Asunle stream serves as a source of water for farmlands and domestic use in the Amuta, Agbogbo, and Abagbooro communities.

Geological Settings

The area around Ile-Ife falls within the western unit of the Precambrian Ilesha Schist Belt consisting of amphibolite, amphibole schists, pelitic schists, grey gneiss, granite gneiss, intrusive pegmatites, and dolerite dykes. The studied area, which is located 300 m north of the Tonkere gate on the OAU Campus, falls within the Ife-Ilesa schist belt.

The studied area is underlain by granitic gneiss occuring as a pink, fine- to medium-grained, high grade metamorphic rock (Figure 1b). The rock is composed of quartz, potassium feldspar, biotite, hornblende, garnet, and zircon. The granitic gneiss has foliation planes that are defined by the mineralogical alternation of quartzo-feldspathic and ferromagnesian minerals (mostly biotite).

The Asunle dumpsite within the OAU Campus, which is the main location for waste deposits within the campus, is located on granite gneiss. The wastes, consisting of both organic and inorganic materials, are destroyed through open air incineration, leading to the release of toxic heavy metals into the air, soil, surface water, and groundwater around the waste dumpsite.

High concentrations of these toxic metals, such as arsenic (As), copper (Cu), chromium (Cr), cobalt (Co), iron (Fe), nickel (Ni), and lead (Pb) from the Asunle waste dumpsite are capable of contaminating the soil, surface water, and groundwater around the dumpsite. The toxic metals cause adverse effects on humans, plants, and animals when their concentrations exceed the maximum tolerance limit. This study will help establish the direct impact of the Asunle dumpsite on the Asunle stream and the level of soil and surface water contamination arising from the open air incineration of the Asunle dumpsite.

Methods and Materials

The vertical electrical sounding (VES) technique of the electrical resistivity method was employed in this study. The Schlumberger electrode array configuration was used. The VES data for this study were acquired using an ABEM 300 Terrameter, together with basic accessories such as cable reels, measuring tapes, and metal electrodes. Parallel to the Asunle stream channel, two VES stations were occupied (Figure 2). No drainage pipe or electrical cables were avoided during the running of the VES profiles as the area was not residential. The electrode spacing (AB/2) was varied between 1 and 150 m. The intervals between the potential and current electrodes were increased systematically to ensure that the potential differences obtained were large enough to be measured with satisfactory precision. The interpretation of the VES data was carried out as described in Konwea *et al*. (2023). The Dar-Zarrouk Parameters of the total transverse unit resistance (T), total longitudinal unit conductance

(S), as well as the coefficient of anisotropy of the overburden materials (λ) were obtained using Equations 1, 2, and 3.

$$T = \sum_{i=1}^{n} h_i \rho_i = h_1\rho_1 + h_2\rho_2 + \cdots + h_n\rho_n \quad \text{.........(1)}$$

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \cdots + \frac{h_n}{\rho_n} \quad \text{....................(2)}$$

$$\lambda = \frac{\sqrt{T.S}}{H} \quad \text{..(3)}$$

where:
λ = coefficient of anisotropy,
T = transverse resistance (Ωm),
S = longitudinal conductance (Ω^{-1}),
H = overburden thickness (m),
h = layer thickness (m),
ρ = electrical resistivity of the layer (Ωm),
n = number of layers,
i = position of the layer in the section.

Soil samples of about 500 g each were collected manually from the different subsurface layers in the two VES locations within the studied area using the hand auger. A total of five soil samples were collected from two locations (Figure 2), and subjected to grain size analysis. The result obtained was used to determine the hydraulic conductivity of the soil materials using Hazen's formula.

Another ten soil samples of approximately 100 g each were collected using the hand auger at depths ranging from 30 - 60 cm, depending on where the natural in situ soil was encountered (Figure 2). Nine out of the ten soil samples were collected around the waste dumpsite at a sample interval of 70 m, while the remaining one soil sample was collected away from the waste dumpsite to serve as a control. The soil samples were sealed in labelled sample bags and immediately transported to the Centre of Excellence, Nanotechnology and Advanced Material (NASENI), Akure, Ondo State, Nigeria, for sample preparation and analysis of the following heavy metals: As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn using the XRF machine.

Surface water samples were collected in duplicate using plastic water bottles from two locations along the Asunle stream. The first set of two water samples were collected upstream at the Asunle dumpsite, which was the source of the stream (Figure 2). The second set of two water samples was collected downstream, 300 m northwest of the Asunle dumpsite. Before the water sampling, each of the plastic bottles was thoroughly rinsed with distilled water and some of the sampled water. The first set of water samples collected at the first location was labelled 1a and 1b, while the second set of water samples collected at the second location was labelled 2a and 2b. Water samples 1a and 2a were transported to the Centre for Energy Research and Development (CERD), OAU Ile-Ife, for chemical analysis of the water sample for heavy metals such as: As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. Water samples 1b and 2b were taken to the Department of Microbiology, OAU, for the microbial analysis.

RESULTS

Subsoil Layer Characterization

The geo-electric section revealed four subsurface layers (Figure 3). The first layer corresponds to the topsoil, with layer resistivity ranging from 179 to 231 ohm-m. The layer thickness varies from 0.5 to 2.2 m, and comprises sandy clay and sand. The second layer has layer resis-

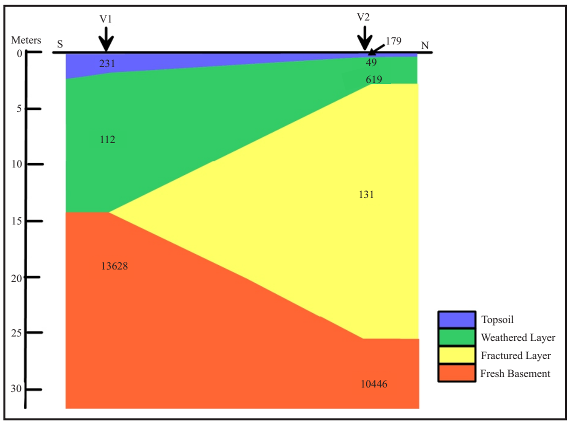

Figure 3. Geo-electric section beneath V_1 and V_2.

tivity ranging from 49 to 112 ohm-m, and it is predominantly weathered clayey material. The layer thickness varies from 2.3 to 12.0 m. The third layer is the partially weathered basement, with a layer resistivity of 619 ohm-m. The layer is 3.7 m thick beneath VES 1, and is absent beneath VES 2. The fourth layer is the fractured basement. This layer only occurs beneath VES 1, and is absent beneath VES 2. The thickness of the fourth layer is 26.5 m. The fifth layer constitutes the fresh basement. The resistivity of this layer is greater than 1,000 ohm-m beneath VES 1 and 2.

Assessment of Hydraulic Properties of The Subsoils

In order to determine the hydraulic properties of the subsoils, five soil samples obtained from the upper two layers beneath VES 1 and the upper three layers beneath VES 2 were subjected to grain size analysis. The results of the grain size analysis are presented in Table 1.

From the grain size analysis, the uniformity coefficient (Cu) obtained using Equation 5 ranged between 12.13 and 36.89 (Table 1) with an average of 22.25. While the coefficient of curvature (Cc) obtained using Equation 6 ranged between 2.0 x 10^{-5} and 2.0 x 10^{-3} with an average of 6.46 x 10^{-4}. The hydraulic conductivity of the different subsoils, which among other factors depend largely on the grain size distribution (Ajayi *et al.*, 2020), was obtained from the grain size distribution data using Hazen's formula (Equation 4). The hydraulic conductivity obtained over the topsoil, which is the first layer of soil within the granite gneiss, ranged between 7.0 x 10^{-4} and 3 x 10^{-3} cm/s with an average value of 1.85 x 10^{-3} cm/s. The hydraulic conductivity obtained over the weathered layer, which is the second layer of soil, ranged between 3.0 x 10^{-5} and 1 x 10^{-3} cm/s with an average value of 5.15 x 10^{-4} cm/s. The hydraulic conductivity obtained over the third layer of soil located only beneath VES 2 is 6.0 x 10^{-5} cm/s.

$$k = CD_{10}^{2} \quad \text{...(4)}$$

where:

k = Coefficient of permeability (cm.s^{-1}),

C = Constant, usually taken as 100 cm^{-1}.s^{-1},

D_{10} = Effective size, value corresponding to 10 % finer by weight (cm).

$$C_u = \frac{D_{60}}{D_{10}} \quad \text{..(5)}$$

$$C_c = \frac{D_{30}^{2}}{D_{10} \times D_{60}} \quad \text{..(6)}$$

where D_{10}, D_{30}, and D_{60} are values corresponding to the 10 %, 30 %, and 60 % finer by weight, respectively.

The resultant horizontal hydraulic conductivity ranged between 1.21 x 10^{-4} and 5.4 x 10^{-3} cm/s with an average of 2.76 x 10^{-3} cm/s, while the resultant vertical hydraulic conductivity ranged

Table 1. Results of Grain Size Analysis

Location	S/N	Sieve aperture diameter (mm)						Pan	Grain size (mm)			C_u	C_c	K(cm.s^{-1})
		4.750	2.000	0.600	0.300	0.150	0.075		D_{10}	D_{30}	D_{60}			
		Cumulative % passing each sieve												
1	1	4.10	11.58	45.70	62.20	73.00	79.78	100.00	6.0x10^{-2}	0.16	0.70	12.13	2.0x10^{-3}	3.0x10^{-3}
	2	0.94	5.18	37.18	55.12	65.90	72.10	100.00	3.7x10^{-2}	0.11	0.50	13.56	8.1x10^{-4}	1.0x10^{-3}
2	1	5.34	14.12	34.24	52.32	64.34	69.16	100.00	2.5x10^{-2}	0.09	0.52	19.96	3.7x10^{-4}	7.0x10^{-4}
	2	0.54	3.74	21.90	37.88	47.54	52.16	100.00	5.6x10^{-3}	0.02	0.21	36.89	2.0x10^{-5}	3.0x10^{-5}
	3	0.82	1.90	14.46	33.82	48.20	55.16	100.00	7.4x10^{-3}	0.03	0.21	28.72	3.0x10^{-5}	6.0x10^{-5}

between 3.44×10^{-5} and 1.10×10^{-3} cm/s with an average of 5.67×10^{-4} cm/s.

Assessment of Heavy Metal Contamination of Subsoil

The results of the geochemical analysis of the soil samples for heavy metals: As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn are presented in Table 2. A quantitative interpretation of the results was carried out statistically in order to determine the level of impact of heavy metals on the soils.

Assessment Based on Contamination Factor

Contamination factor (CF) is a measure of contamination in comparison to either the average crustal composition of the metal in question or observed background values from geologically similar and uncontaminated areas (Tijani *et al.*, 2004). This method of assessment which is only applicable when the background metal concentration is greater than zero was applied, since the reference metals had background concentrations greater than zero. The CF of the studied area was computed using Equation 7, and the results presented in Table 3.

$$CF = \frac{C_m}{C_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where:

CF is contamination factor around the waste dumpsite,

C_m is mean concentration of the metal in soil,

C_b is background metal concentration in the control site.

Assessment Based on Geo-accumulation Index

The geo-accumulation (Igeo) index used in the assessment of the pollution of sediments by heavy metals was applied in the interpretation of the data obtained from the analysis of subsoil of the studied area using Equation 8. This method of assessment is only applicable when the background metal concentration is greater than zero was applied, since the reference metals had background concentrations greater than zero. The results of the interpretation are presented in Table 4.

Table 2. Results of Soil Geochemical Analysis of Heavy Metals (ppm)

Sample	Coordinates	Cr	Mn	Co	Fe	Ni	Cu	Zn	As	Pb
1	N832980.4 E668238.9	0	113	416	27,046	335	279	569	0	314
2	N833002.3 E668295.7	0	739	1,388	71,328	315	936	2,771	103	919
3	N832988.8 E668349.9	28	1,154	1,058	49,691	447	300	671	0	274
4	N832938.2 E668236.9	152	1,556	8,649	243,513	321	939	2,871	497	259
5	N832946.9 E668281.2	0	719	2,208	90,300	296	67	2,441	9	684
6	N832988.6 E668354.7	0	881	1,576	42,567	866	576	1,072	0	142
7	N832876.3 E668243.7	81	887	3,828	107,591	417	224	936	0	158
8	N832879.5 E668317.6	28	613	1,176	67,062	413	334	849	0	133
9	N832894.9 E668361.9	12	796	1035	50161	373	212	769	0	277
Control	N832567.2 E668368.7	14	403	1,164	53,410	408	292	812	0	102

Table 3. Contamination Factor of Heavy Metals in Soil Samples

Sample	Cr	Mn	Co	Fe	Ni	Cu	Zn	As	Pb	ΣCF	PLI
1	0.00	0.28	0.36	0.51	0.82	0.96	0.70	0.00	3.08	6.71	0.95
2	0.00	1.83	1.19	1.34	0.77	3.21	3.41	0.00	9.01	20.76	2.17
3	2.00	2.86	0.91	0.93	1.10	1.03	0.83	0.00	2.69	12.35	1.65
4	10.86	3.86	7.43	4.56	0.79	3.22	3.54	0.00	2.54	36.80	4.41
5	0.00	1.78	1.90	1.69	0.73	0.23	3.01	0.00	6.71	16.05	1.89
6	0.00	2.19	1.35	0.80	2.12	1.97	1.32	0.00	1.39	11.14	1.73
7	5.79	2.20	3.29	2.01	1.02	0.77	1.15	0.00	1.55	17.78	1.86
8	2.00	1.52	1.01	1.26	1.01	1.14	1.05	0.00	1.30	10.29	1.61
9	0.86	1.98	0.89	0.94	0.91	0.73	0.95	0.00	2.72	9.98	1.10

Table 4. Geo-accumulation Index of Soil Samples

Sample	Cr	Mn	Co	Fe	Ni	Cu	Zn	As	Pb
1	0.00	-1.68	-1.43	-1.09	-0.60	-0.45	-0.76	0.00	0.72
2	0.00	0.20	-0.23	-0.12	-0.66	0.76	0.82	0.00	1.79
3	0.29	0.65	-0.50	-0.48	-0.31	-0.38	-0.59	0.00	0.58
4	1.98	0.95	1.60	1.11	-0.65	0.76	0.86	0.00	0.53
5	0.00	0.17	0.23	0.12	-0.73	-1.88	0.70	0.00	1.50
6	0.00	0.38	-0.10	-0.63	0.35	0.27	-0.13	0.00	-0.08
7	0.00	0.38	0.79	0.29	-0.38	-0.67	-0.26	0.00	0.03
8	0.29	0.01	-0.40	-0.18	-0.39	-0.27	-0.36	0.00	-0.14
9	0.00	0.28	-0.52	-0.47	-0.50	-0.73	-0.46	0.00	0.59

$$\text{Igeo} = ln\left(\frac{C_m}{1.5 * C_b}\right) \quad \text{..(8)}$$

where:

Igeo is the geo-accumulation index,

C_m is the mean concentration of the metal in soil,

C_b is the background concentration.

Assessment Based on Degree of Contamination

The degree of contamination of the dumpsite was computed using all the heavy metals analyzed by means of Equation 9, and the result is displayed in Table 3.

$$C_{deg} = \sum CF \quad \text{..(9)}$$

Assessment Based on Pollution Load Index

The pollution load index (PLI) which provides a simple but comparative means for assessing the quality of a site, was carried out to assess the extent to which the heavy metals in the subsoil may have impacted the microflora and fauna of the soil. The three possible scenarios include:

i. PLI < 1 denote perfection;
ii. PLI = 1 present that only baseline levels of pollutants are present, and
iii. PLI > 1 would indicate deterioration of site quality.

The PLI for this study was computed using Equation 10, and the results are displayed in Table 3.

$$\text{PLI} = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n} \quad \text{.........(10)}$$

where:

CF is the contamination factor of each element,

n is the total number of elements.

Assessment of Surface Water Quality

The water quality assessment of the two surface water samples (Samples 1 and 2) collected from the Asunle stream was based on the concentrations of As, Cd, Cr, Cu, Co, Fe, Mn, Ni, Pb, and Zn, as well as the pH and microbial content of the water. The results of the water quality assessment are shown in Table 5.

DISCUSSION

The studied area is underlain by four layers of topsoil, weathered layer, fractured or partially weathered layer, and fresh basement (Figure 3). The topsoil with thickness decreasing from 2.2 m beneath VES1 to 0.5 m beneath VES 2 constitutes the protective covering over the groundwater resource of the studied area. Since the topsoil has interaction with the earth surface materials such as surface water, it controls the interaction of the earth surface materials with groundwater. Groundwater vulnerability increases with the decrease in the thickness of the topsoil (Konwea, 2021), hence groundwater vulnerability increases from the south to the north of the studied area. The weathered and fractured layers constitute the aquifer units within the studied area. The cumulative thicknesses of these layers vary from 12.2 m beneath VES 1 to 26.0 m beneath VES 2, indicating more potential for groundwater accumulation beneath VES 2 compared to VES 1. The geometry of the basement topography indicates that groundwater will flow from VES 1 to VES 2.

A uniform soil material has Cu < 4, while a well graded soil material has Cu > 4 for gravel and > 6 for sand. Also based on the grain size distribution curve, a smooth curved soil has a Cc between 1 and 3, while an irregularly curved soil has a higher or lower Cc value. Soil material with missing soil particle size (soil type) has a Cc < 1 or > 3 (Das, 2010). This soil material is usually referred to as a gap-graded soil. The soil materials from the studied area are well-graded with Cu > 6, having soil particles of various grain sizes. However, the Cc value of < 1 obtained for the soil samples indicates the absence of some soil particle sizes in the soil samples. Well-graded soil materials are less permeable than poorly-graded soil materials, because in well-graded soil material the smaller grain sizes occupy the pore spaces among larger grain sizes. Therefore, the soil materials of the studied area will have relatively low permeability, restricting the flow of groundwater within the soil materials.

The hydraulic conductivity of the granite gneiss subsoil is classified as medium and the material is semipervious (Bear, 1972). The hydraulic conductivity of the subsoil layers deceases with depth from an average value of 1.85×10^{-3} cm/s in the topsoil to an average value of 6.0×10^{-5} cm/s in the partially weathered or fractured layer. The higher hydraulic conductivity value obtained over the topsoil relative to other soil layers can be attributed to the greater amount of coarse grains which almost balance the clayey-size materials. While the lower hydraulic conductivity of the weathered layer can be attributed to the lesser amount of coarse materials contained in the partially weathered material relative to the greater amount of clayey sized materials as well as the effect of compaction of the soil materials. When there is large amount of clayey-sized materials

Table 5. Results of Assessment of Water Sample in ppm

Sample	Coordinates	Cu	Zn	Fe	Cr	Cd	Ni	Mn	As	Pb	Co	pH	MPN CFU/ ml
1	N668275 E833018	0.41	0.28	0.59	0.17	0.13	0.21	0.28	0.06	0.07	0.20	8.3	110
2	N668177 E833134	0.31	0.16	0.46	0.10	0.12	0.23	0.29	0.05	0.06	0.22	8.1	21
Max. Permissible Limit		1.00	3.00	0.30	0.05	0.003	0.02	0.20	0.01	0.01		6.5 – 8.5	10

within coarse materials, the clayey-sized materials clog the pore spaces between the coarse materials, preventing the free flow of fluid through the soil. The greater resultant horizontal hydraulic conductivity relative to the vertical hydraulic conductivity indicates that fluids will flow with greater ease in the horizontal direction of the soil layers than in the vertical direction.

The granite gneiss has a relatively thin succession of subsoil materials, resulting in a low longitudinal conductance of between 0.11 and 0.22 Ω^{-1}, with an average of 0.17 Ω^{-1}, indicating a low potential for groundwater storage within the thin weathered material. These subsoil materials would allow the flow of groundwater through them at a relatively moderate rate due to the low transverse resistance of between 1344 and 3657 Ω-m^2, with an average transverse resistance of 2496 Ω-m^2. Hence, the soil materials have fair transmissivity. The low average coefficient of anisotropy value of between 1.00 and 1.07, with an average value of 1.03, indicates that the granite gneiss subsoil materials are slightly hard and compact with low groundwater potential (Olayinka and Oyedele, 2019), hence would have relatively low porosity and permeability.

The contamination factor (CF) obtained for the studied area revealed that most of the soil samples had CF ranging from low degree of contamination to a considerable degree of contamination (Hakanson, 1980), except for Samples 2, 4, and 5 with a very high degree of contamination. Heavy metals with a very high degree of contamination include chromium, cobalt, arsenic, and lead. When these heavy metals in a high concentration find their way into the human body, they cause cancer, poor mental health development in infant, and complications of the nervous system (SON, 2007). The Igeo of most heavy metals analyzed for the studied area was less than 1 (Table 4), indicating unpolluted to moderately polluted subsoil (Muller, 1979). The Igeo obtained for lead and iron in Samples 2, 4, and 5 were greater than 1, indicating moderate pollution of the dumpsite with respect to the lead and iron concentrations. Lead contamination can cause cancer in human (SON, 2007). C_{deg} is divided into four categories: low, moderate, considerable, and very high contamination, with corresponding values of < 8, 8 - 16, 17 - 32, and >32, respectively (Hakanson, 1980). The results revealed that Sample 1 had a low degree of contamination; Samples 3, 6, 8, and 9 had a moderate degree of contamination; Samples 2, 5, and 7 had considerable degree of contamination, while Sample 4 had a very high degree of contamination. The variation in degree of contamination revealed that there is a general increase in degree of contamination from the east to the west of the studied area (Figure 4). The results of the PLI assessment of the subsoil revealed that all the soil samples collected from the studied area (with the exception of Sample 1) denote deterioration of site quality. Although Sample 1 shows the impact of heavy metal, the degree of impact is negligible, hence the location denotes perfect condition.

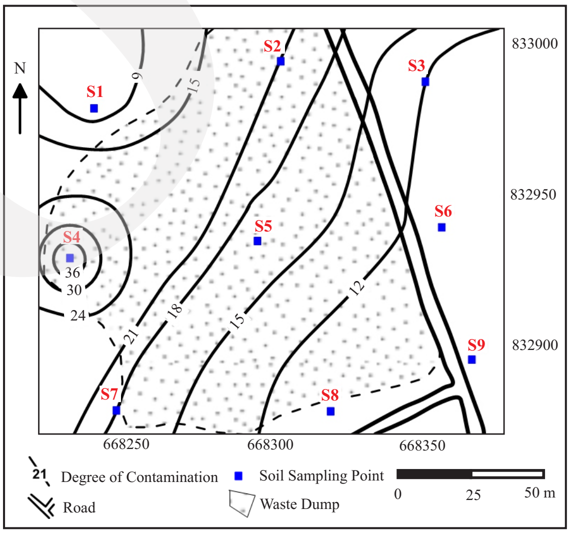

Figure 4. Soil contamination map of studied area.

The results revealed that the water was not suitable for drinking purposes as most of the heavy metals had concentrations above the maximum permissible limits (MPL) recommended (Table 5). The results of the chemical analysis revealed a marked decrease in the concentration of all the heavy metals from Sample 1 to Sample 2 locations, except for Co, Mn, and Ni. The decrease in concentration of the heavy metals in the surface water away from the dumpsite suggests the dumpsite as the possible contamination source. In the case of Co, Mn, and Ni, the slight increase in the concentrations of the heavy metals in the surface water away from the dumpsite suggests other sources of contamination such as geogenic effect of soil and water interaction (Konwea *et al*., 2023b). Although the pH recorded for the surface water samples falls within the permissible limits (Table 5), the pH values decrease away from the dumpsite. The decrease in pH of the surface water away from the dumpsite indicates the influence of the dumpsite on the pH of the water.

The microbial analysis of the surface water samples revealed that the total heterotrophic plate counts for the two water samples were $>10^5$ CFU/ml which is above the permissible limit of < 500 CFU/ml. The MPN of the total coliforms in the water was between 21 CFU/ml and 110 CFU/ml. These values were above the maximum permissible limit for the total coliform in water, which is 10 CFU/ml (SON, 2007). This indicates that the Asunle stream contains micro-organisms of faecal origin in excess of the allowable limit, and is thus unfit for drinking. The concentrations of the microbial organisms in the Asunle stream decrease away from the dumpsite from W_1 to W_2 (Figure 2 and Table 5), indicating the influence of the dumpsite on the faecal contamination of the Asunle stream.

CONCLUSIONS

The soil and surface water around the Asunle dumpsite, located in the north of the OAU campus Ile-Ife, Osun State, southwestern Nigeria, were assessed in this study with a view to determining the contaminant level of heavy metals in the soils and surface water. Heavy metals and faecal microbial organisms have contaminated the subsoil and surface water around the dumpsite. The contamination levels ranged from low to very high. Heavy metal and microbial organism concentrations in the Asunle stream decrease away from the dumpsite, indicating that the dumpsite has an impact on heavy metal contamination and faecal pollution in the Asunle stream.

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REFERENCES

Abiodun, O., 2013. Determination of Mechanical, Thermo-Physical and Filtration Properties of Dried Clay Mixtures of Different Sand Concentrations for Water Storage Vessel. *International Journal of Scientific and Technology Research*, 2 (12), p.248-257.

Abioye, S.O. and Perera, E.D.P., 2019. Public Health effects due to Insufficient Groundwater Quality Monitoring in Igando and Agbowo Regions in Nigeria: A Review. *Sustainable Water Resource Management*, 12pp. DOI:10.1007/s40899-019-00330-5.

Ajayi, O., Konwea, C.I., Fajobi, A.B., and Okewole, O.S., 2020. Engineering Properties of Residual Soils Underlying Proposed Soccer Pitch at Obafemi Awolowo University, Ile-Ife, Southwestern Nigeria. *International Journal of Science and Engineering Investigations*, 9 (100), p.36-40.

Bear, J., 1972. *Hydraulics of Groundwater*. McGraw-Hill Inc., New York, 645pp.

Das, B.M., 2010. *Principles of Geotechnical Engineering, 7th Edition*. Cengage Learning: Alberta, Canada, 683pp.

Edokpayi, J.N., Odiyo, J.O., and Durowoju, O.S., 2017. Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa. *Water quality*, p.401-416. DOI: 10.5772/66561.

Hakanson, L., 1980. An Ecological Risk Index for Aquatic Pollution Control: A Sedimentological Approach. *Water Research*, 14, p.975-1001.

Joe-Ukairo, A. and Oni, A.G., 2018. Geophysical and hydro-chemical investigations of OkeAsunle dumpsite in Ile-Ife, Southwestern Nigeria for subsoil and surface water pollution. *Journal of Health and Pollution*, 8 (20), p.181-209.

Konwea, C.I. and Ajayi, O., 2021. Effectiveness of Different Hand-Dug Well Treatment Methods in a Typical Basement Complex Environment. *Journal of Mining and Geology*, 57 (2), p.331-337.

Konwea, C.I., 2021. *Hydrogeological and Hydrogeophysical Appraisal of the Groundwater Resources of Obafemi Awolowo University Estate, Ile-Ife, Southwestern Nigeria*. Unpublished *PhD. Thesis,* Obafemi Awolowo University.

Konwea, C.I., Evurani, D.E., and Ajayi, O., 2023. Groundwater Potential Assessment of the Obafemi Awolowo University Estate, Southwestern Nigeria. *Scientific African,* 20 (6), e01597. DOI:10.1016/j.sciaf.2023.e01597.

Konwea, C.I., Eziagor, F.C., Evurani, D.E., and Ajayi, O., 2023. Characterization and Assessment of Groundwater from Obafemi Awolowo University Campus, Southwestern Nigeria. *Physics and Chemistry of the Earth,* 167. 103354. DOI:10.1016/j.pce.2022.103354.

Mcintosh, A. and Pontius, J., 2017. Human Impacts on the Global Landscape. *Science and the Global Environment*, 1, p.23-28.

Muller, G., 1979. Index of Geoaccumulation in Sediments of the Rhine River. *Journal of Geology,* 2, p.108-118.

Naveen, B.P., Sumalatha, J., and Malik, R.K., 2018. A study on contamination of ground and surface water bodies by leachate leakage from a landfill in Bangalore, India. *International Journal of Geo-Engineering*, 9, 27. DOI: 10.1186/s40703-018-0095-x.

Ogunfowokan, A.O., Oyekunle, J.A.O., Olutona, G.O., Atoyebi, A.O., and Lawal, A., 2013. Speciation study of heavy metals in water and sediments from Asunle River of the Obafemi Awolowo University, Ile-Ife. *Nigeria International Journal of environmental Protection,* 3 (3), p.6-16.

Olayinka, A.J. and Oyedele, E.A.A., 2019. On the Application of Coefficient of Anisotropy as an Index of Groundwater Potential in a Typical Basement Complex of Ado-Ekiti, Southwestern Nigeria. *Physical Science International Journal*, 22 (1), p.1-10. DOI:10.9734/PSIJ/2019/v22i130119.

Sposito, G., 2021. Soil. *Encyclopedia Britannica, https://www.britannica.com/science/soil/* [November 23, 2021].

SON (Standard Organization of Nigeria) (2007). *Nigerian Standard for Drinking Water Quality, ICS 13.060.20, Abuja*, 29pp.

Tijani, M.N., Jinno, K., and Hiroshiro, Y., 2004. Environmental impact of heavy metals distribution in water and sediments of Ogunpa River, Ibadan area, southwestern Nigeria. *Journal of Mining and Geology*, 40 (1), p.73-83. DOI:10.4314/jmg.v40i1.18811.