



Empirical Study of the Groundwater Protection Potential and Water Quality Using the Electrical Resistivity Method and a PG990 Spectrometer Around Obafemi Awolowo University Dumpsite Southwestern Nigeria

O. O. Ajani¹, G. O. Olutona², A. A. Adeniji^{1*}

¹ Department of Physics and Solar Energy, Bowen University, Iwo, Nigeria

² Department of Industrial Chemistry, Bowen University, Iwo, Nigeria

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ABSTRACT

Groundwater plays a very important and fundamental part in human existence because of its essential role in living systems. The study aimed at carrying out an empirical study into groundwater protective potential and water quality around Obafemi Awolowo University solid waste facility and AbaGbor Community. This was achieved by using the electrical resistivity method to delineate the subsurface inhomogeneity around the dumpsite facility and also using the PG990 Atomic Absorption Spectrometer for metal analysis of water quality. The Schlumberger electrode array arrangement was engaged in the survey. A total of twelve vertical electrical soundings (VES) data was collected within the Obafemi Awolowo University dumpsite. The water samples were collected at two locations within the AbaGbor community which was 4.5 Km from the dumpsite to determine its quality. The results of the VES revealed the depth, resistivity, and thickness. The observed resistivity and the thickness values were further used in determining the groundwater protective potential, by calculating the Dar-Zarrouk parameters which showed that 91.7% of the study area is within poor/weak protective potential. The result from the water analysis of the hand-dug bore holes of the two different locations in the AbaGbor Community showed the presence of heavy metal concentrations as Pb, As, Mn, Cd, Zn, Cr and Co. Therefore, periodic assessment of water quality should always be carried out because we cannot anticipate when the groundwater will be contaminated due to relatively poor/weak groundwater protective potential.

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INTRODUCTION

The occurrence of groundwater resources is associated with different geological features of the earth internal formations such as fractures, fluid in the pores of rocks, and mapping of these different geological features is extremely important for groundwater potential which plays a very important and fundamental part of human existence because of its usefulness both in domestic and industrial activities [1]. The exploration and exploitation of groundwater availability especially within environments of dumpsite facility have been of greater importance and contribution to the geoscientist and

researchers from a shared view of science over the globe. The contamination of groundwater within or around the dumpsite facility takes place mainly because the contaminant percolating into the subsurface formations as leachate especially when the subsurface is fractured [2]. Ahmad et al. [3] have reported that leachate contents from the landfill that infiltrate the subsurface may contaminate nearby groundwater. Water contamination affects not only water quality but also poses a threat to human health, social prosperity, economic growth, and development [4]. Dumpsite has been reported to hold a household and commercial waste material which has both effects on groundwater and human health. In addition, Fahmida and

*Corresponding Author Email: adenijiyoadetunji@gmail.com
(A. A. Adeniji)

Rafizul [5] reported that there is environmental contamination around dumpsite area and reveal that monitoring of heavy metals pollution should be established. Besides, Ajani et al. [6] reported that the occurrence of a toxin in groundwater tend to promote high intensive threats and hazard on the health of humans. Therefore, there is always a necessity to investigate the subsurface geophysical formation for groundwater resources exclusively in an environment with dumpsite amenities, to study the vertical and horizontal variations within the subsurface by delineating the corresponding layers, depth to fresh or fracture basement, and the overburden thickness as reported by Aizebeokhai and Oyeyemi [7]. This will reveal whether the subsurface acts as protective potentials against the contaminant that could percolate down to the available groundwater. It has been shown from different research that the geophysical method of subsurface investigation is accurate and reliable when measuring the parameter that is associated with the subsurface structures in groundwater potential and dumpsite assessment as reported in literature [8-10]. Telford et al. [11] reported that geophysical investigation of the subsurface offers moderately rapid, fast, and cost-effective ways to derive enormous area information analysis of subsurface geology. In this regard, this research employs the vertical electrical sounding method to delineate the surrounding dumpsite aimed at assessing the groundwater protective potential of Obafemi Awolowo University (OAU) Dumpsite. The study of groundwater potential using geoelectrical resistivity method has been carried out by different researches [12-14]. The advantage of electrical resistivity method is that it gives detailed information in subsurface geology usually not easily achievable by other prospecting groundwater methods. Consequently, the water quality assessment was also conducted for two hand dug borehole sites located at AbaGboro Community. The justification for undergoing the water quality analysis was based on the fact that the high-quality groundwater availability is needful and a requisite for domestic, public health and industrial purposes. Milovanovic [4] reported that the quality of groundwater has given a unique and distinctive vast interest for domestic and irrigation needs. WHO [15] reported that diseases associated to drinking contaminated water constitute a key encumbrance on the health of human and the treatments in ameliorating the qualities of the water offers substantial aids. WHO [15] also reported that every effort should be made to achieve the quest for portable water with quality that makes it safe which must be feasible, applicable and practice.

MATERIAL AND METHODS

The study area

The layout map representing the geophysical survey of the Obafemi Awolowo University dumpsite is shown in

Figure 1 with coordinate latitude $7^{\circ} 32' 25''$ N and longitude $04^{\circ} 31' 16''$ E while the analysis of the water sample collected at two stations within AbaGboro Community with coordinates: location A (latitude $7^{\circ} 54' 456''$ N and longitude $4^{\circ} 51' 2186''$ E), coordinate location B (latitude $7^{\circ} 54' 544''$ N and longitude $4^{\circ} 51' 234''$ E), respectively. The study area has an elevation of 318 ± 6 m above the sea level above. A detailed description of the dumpsite was given by Olutona et al. [16].

Dumpsite functions as a station destination, where wastes composed from the university environment are dumped and are endangered to open-air combustion. In regards to this, activities result in surface and subsurface contamination because the burning of these wastes leads to the availability of potentially toxic metals which are harmful to the surface water and also the subsurface groundwater. Thus, the contamination can occur if there is a migration of surface water from the dumpsite to the adjoining stream and also to the groundwater which percolates as leachate. Furthermore, the two hand-dug borehole water samples were collected along 4.5 km to the dumpsite and the water serves as a major source for domestic and agricultural activities within the AbaGboro community. This revealed that human activities around the dumpsite are present and the rural dwellers living along the dumpsite rely major on the groundwater for household domestic chores. These factors were considered in establishing a potential result to carrying out a geophysical investigation on groundwater protective potential (GPP) and water quality around OAU dumpsite and AbaGboro Community.

The geophysical survey

The vertical electrical sounding method of geophysical prospecting was selected for the field survey. The ABEM SAS – 1000 resistivity-meter was employed for data collections. Depths to basement penetration were conducted adequately by engaging the Schlumberger electrode array arrangements (Figure 2a) with maximum current-electrode spacing AB/2 of 100 m. A total of twelve (12) VES sounding points were acquired from the

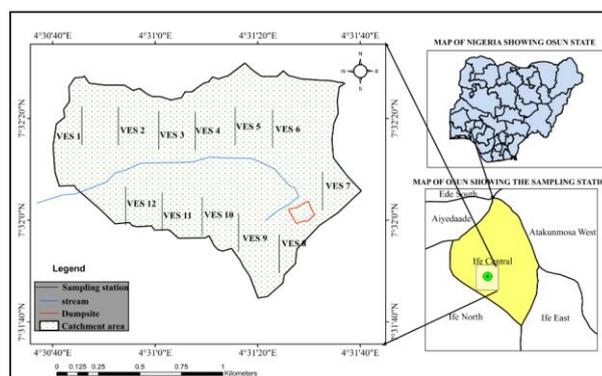


Figure 1. The layout map of the study area

field survey. Also, appropriate knowledge of earth resistivity techniques is essential in understanding the current electrode system in homogeneous earth. Alagbe [17] reported that a single point electrode is the simplest form of the electrode that is understood in practical as shown in Figure 2b.

Results received from the investigation has been subjected to qualitative and quantitative interpretation using computer software called Earth Imager, to establish a modelled pattern or layer that revealed the subsurface parameter such as the depth, the resistivity, and the thickness of each layer and also the examine their corresponding lithologies. The thickness (h) and the apparent resistivity were deduced from the interpreted data and were used to calculate the longitudinal conductance (Lc) and the Transverse resistance (Tr). These parameters Tr and Lc were used the reveal the groundwater protective potential.

Theoretical background

The major background to electrical resistivity technique is derived from ohm’s law [18]. It represents the relationship between resistivity (R), changes in voltage ΔV and current I.

$$\text{Such that: } R = \frac{\Delta V}{I} \tag{1}$$

However, since the subsurface of the earth is inhomogeneous i.e. not having the same layer and model, the resistivity is ascribed as the apparent resistivity (ρa), which depends on some properties such as the size, shape, layers, and resistivity of zones of anomalous, such that:

$$\rho_a = KR \tag{2}$$

where K is the geometry factor given as:

$$K = \pi \left(\frac{(\frac{AB}{2})^2 + (\frac{MN}{2})^2}{MN} \right) \text{ such that} \tag{3}$$

$$\text{Supposing } \frac{AB}{2} = Q, \text{ and } \frac{MN}{2} = P \tag{4}$$

Therefore,

$$K = \pi \left(\frac{(Q)^2 + (P)^2}{MN} \right) \tag{5}$$

Water quality analysis

Water for metal analysis was collected in two polyethylene bottles pre-treated with 10% nitric acid for 48 h to reduce the adsorption of metal ions on the surface of the bottle. 5 mL of nitric acid was added to 50 mL of water sample in a Teflon beaker. The mixture was evaporated to near dryness in a hot plate after which it was allowed to cool, then filtered into a 25 mL standard flask and made up to mark with double distilled water. The digested water was analyzed for their metal content using the PG990 Atomic Absorption Spectrometer (AAS) available at Bowen University Central Laboratory.

Groundwater protective potential determination

The subsurface of the earth is reported to become of a natural permeate; therefore, the ability to filter, retain and retard percolating top surface contaminant fluid is a measure of its protective potential discussed by Olorunfemi et al. [19]. According to Abiola et al. [20] and Henriet [21], the extremely impermeable clayey overburden, which has a relatively high longitudinal conductance (Lc) characteristic tends to offer a more protective potential to the aquifer. Maillet [22] and Batayneh [23] reported that the protective potential is fixed and invested in the Longitudinal conductance and the Traverse resistance of the aquifer. Their determination is obtained by using the apparent resistivity (ρa), the thickness (h) of the aquifer respectively, and the equation is given as follows:

$$\text{Longitudinal conductance (Lc)} = \frac{h}{\rho_a} \tag{6}$$

$$\text{Traverse resistance (Tr)} = h \times \rho_a \tag{7}$$

The parameter Lc and Tr constitute the Dar-Zarrouk parameter as reported by Henriet [21], Maillet [22] and Batayneh [23]. The Aquifer protective potential for groundwater analysis is shown in Table 1 [24].

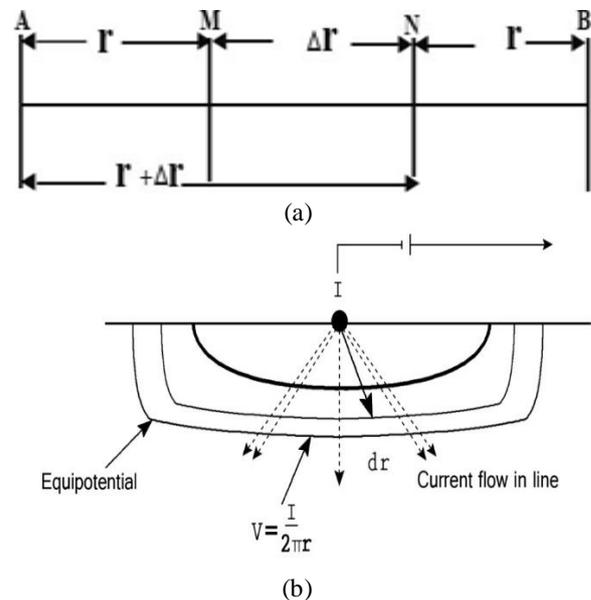


Figure 2. (a) The distance between electrodes for Schlumberger [25] (b) Current flow from a single surface electrode [17]

Table 1. Aquifer protective capacity rating [24]

| RATING | > than 10 | 5–10 | 0.2–4.9 | 0.1–0.19 | < 0.1 |
|--------|-----------|-----------|----------|----------|-------|
| REMARK | Excellent | Very Good | Moderate | Weak | Poor |

RESULTS AND DISCUSSION

Results for vertical electrical sounding

From the interpreted data in Figure 3 (a-l), the results revealed that the resistivity ranges between (87.6–390000 ohms), thickness ranges between (0.796–11.73 m) and depth ranges between (0.796–35.3 m). From the lithological units, the topsoil is majorly composed of clay, alluvium, and laterite. The clay material is shown from VES 2. The alluvium distributions are shown from VES 1, VES 3, VES 4, VES 5, VES 6, VES 7, VES 9, VES 10, and VES 11, due to the presence of both solid waste materials deposited and transported to and within the dumpsite. The laterite is shown from VES 8, due to an outcrop revealed within the study area as reported by Keller and Frischknecht [26]. However, the laterite poses a protective barrier for underlying groundwater. Beneath the topsoil is the weathered basement which is covered with sandy-clay and alluvium has shown from layers 2 and 3, respectively across the VES points. The thickness and depth composition of the topsoil across the VES points are generally of thin overburden. This suggests that the topsoil within the study area is prone to percolation of leachate over some time but the presence of thick overburden will help to reduce or shield the leachate migration down to the groundwater. In this regard, periodic assessment of the water quality should be carried out within and around the study area and its localities, since nobody knows when the leachate from the dumpsite will affect the groundwater quality.

Results for water analysis

Water analysis indicated the presence of heavy metals at the two hand-dug boreholes A and B such as Lead (Pb), Arsenic (As), Manganese (Mn), Cadmium (Cd), Zinc (Zn), Chromium (Cr) and Cobalt (Co). These heavy metals can be dangerous to the environment and health such as Cadmium (Cd), Lead (Pb) and Chromium (Cr). Some may cause corrosion such as Lead (Pb) and Zinc (Zn) while some of the heavy metals presences are essential for humans in a small amount such as Chromium (Cr) and Manganese (Mn). Some heavy metal presences are carcinogenic or poisonous such as manganese (Mn), Lead (Pb) and Arsenic (As) which affect the central nervous system, kidney, skin, bones and teeth [27, 28]. Results in Table 2 reveals that the mean values of Pb (p=0.000, p<0.01), As (p=0.021, p<0.05), Mn (p=0.000, p<0.01), and Zn (p=0.001, p<0.01) obtained in Location B was significantly higher than that obtained in Location A. It also revealed that there was no significant difference in Cr between water samples collected from Location A and (p>0.05). Result also shows that Co was significantly higher in Location A than Location B (p=0.021, p<0.05).

The result in Table 3 shows a correlation matrix between the heavy metals. Result reveals that Pb has significant positive relationship with Mn (r = 0.986, p<0.01) and Zn (r = 0.829, p<0.05) while As shows

significant positive relationship with Mn (r = 0.812, p<0.05) and significant negative relationship with both Cd (r = -0.899, p<0.05) and Co (r = -0.886, p<0.05). There was a significant positive relationship between Mn and Zn (r = 0.812, p<0.05) and also a significant positive relationship between Co and Cd (r = 0.928, p<0.01). Results obtained between other heavy metals were not significant (p>0.05).

Results in Table 4 indicate that Mn significantly predicts Pb, Co significantly predicts As, Pb and Mn significantly predict Cd, Pb and Cd significantly predict Zn while the only Cd significantly predicts Co with R² values of 0.997, 0.784, 0.997, 0.993, 0.9999, and 0.845 respectively. Result also shows that none of the heavy metals predicts the value of Cr. The comparison of the value of heavy metals parameters in Location A and B revealed a significant difference in means (p<0.05) and NS- No significant difference in means (p>0.05).

Table 2. Heavy metals concentration (mg/L) from 2 wells at AbaGboro community

| Metals | Location A | Location B | P- value | WHO Standards (mg/L) | Ref. |
|--------|-------------|-------------|----------|----------------------|------|
| Pb | 2.06±0.01 | 2.06±0.04* | 0.000** | 0.010 | [29] |
| As | 0.08±0.01 | 0.14±0.03* | 0.021* | 0.05 | [30] |
| | | | | 0.1 | [29] |
| Mn | 0.04±0.02 | 2.63±0.10* | 0.000** | 0.40 | [29] |
| | | | | 0.1 | [31] |
| Cd | 0.22±0.03 | 0.08±0.02* | 0.002** | 0.003 | [29] |
| | | | | 0.002 | [32] |
| Zn | 0.020±0.01 | 0.180±0.03* | 0.001** | 3.00 | [29] |
| Cr | 0.160±0.03 | 0.21±0.04 | 0.135 | 0.05 | [29] |
| Co | 0.120±0.01* | 0.06±0.03 | 0.021* | 0.005 | [32] |

**Significantly different at 1%, *significantly different at 5%. The Values are reported in the form of mean ±SD.

Table 3. Correlation matrix between heavy metals

| Metals | Pb | As | Mn | Cd | Zn | Cr | Co |
|--------|---------|---------|--------|---------|-------|--------|----|
| Pb | 1 | | | | | | |
| As | 0.771 | 1 | | | | | |
| Mn | 0.986** | 0.812* | 1 | | | | |
| Cd | -0.754 | -0.899* | -0.794 | 1 | | | |
| Zn | 0.829* | 0.600 | 0.812* | -0.580 | 1 | | |
| Cr | 0.371 | 0.429 | 0.435 | -0.667 | 0.60 | 1 | |
| Co | -0.771 | -0.886* | -0.754 | 0.928** | -0.60 | -0.486 | 1 |

*Correlation is significant at 5%, **Correlation is significant at 1%

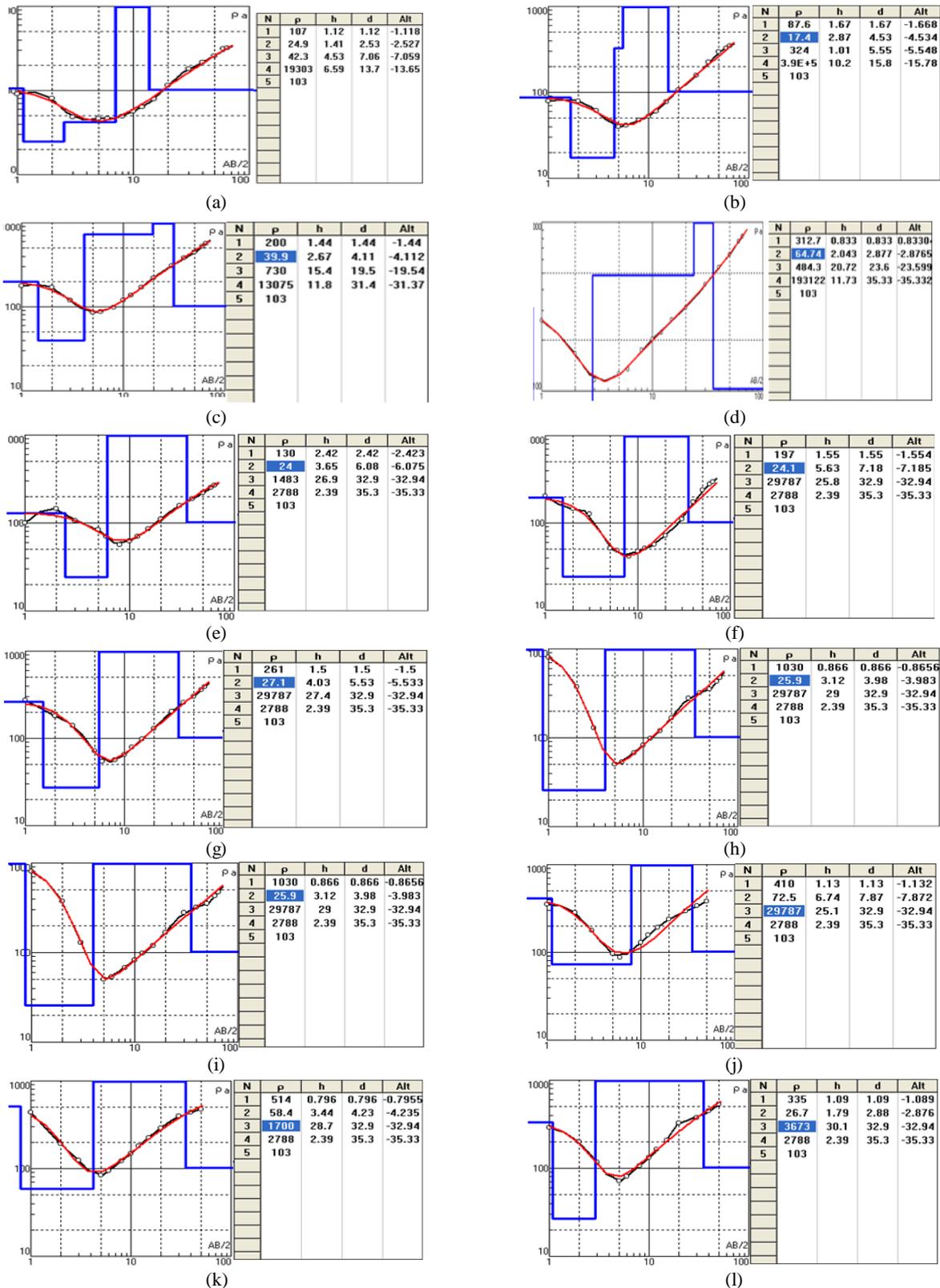


Figure 3. Modeled resist of (a) VES1, (b) VES2, (c) VES3 (d) VES4 (e) VES5 (f) VES6 (g) VES7 (h) VES8 (i) VES9 (j) VES10 (k) VES11 and (l) VES12

From the stepwise multiple regression results in Table 4, the correlation between the measured and estimated values of heavy metals where observed in Table 5. From the result, it was revealed that there are no differences between the mean measured and the mean estimated values of the heavy metals.

Results for groundwater protective potential

Figure 4 presented the results for the Lc and Tr respectively calculated from resistivity and thickness of the modelled Resist graph. This revealed that most of the modelled VES stations indicate poor/weak protective potential as shown in Table 1 [24].

This revealed that groundwater within the study areas may tend to be contaminated in the near or far future, preliminary above the subsurface to the groundwater. The Lc rating acquired from the study varies 0.0770 to 0.2501 Ohms. Figure 5 revealed that that area is zoned into poor, weak and moderate protective potential.

A total of five (5) zones within the study area show poor protective potential, where weak and moderate protective potential shows six (6) and one (1) zones, respectively. This revealed that groundwater within the study are may become vulnerable to toxins from time to time. The percentage distribution of the protective potential is shown in Figure 6.

Approximately 41.7% indicated poor; 50 % indicated weak and 8.3% indicate moderate protective potential, respectively. Therefore, the study area is revealed to be underlined by poor/weak protective potential since 91% of the study area is within the categories. The mean probability is 0.13513 and the standard deviation is 0.05574 as shown in Figure 7. Thus evaluating the groundwater protection potential of the study area is largely considered not favourable.

Correlation of the results

From the observed results, it was revealed that the hand-dug borehole has the presence of toxic metals within its vicinity and this was also confirmed according to the research conducted by Olutona et al. [33] where he carried out elemental pollution status of a University Dumpsite (OUA) soil in Ile-Ife using the Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Besides, Olutona et al. [33] unveils from his study that potential toxic metal in the dumpsite and its vicinity were higher in the topsoil than the subsoil, and metal concentrations in the wet seasonal period were higher than the dry seasonal period. It was also observed that the topsoil from the dumpsite has weak protective potential which could have easy migration of toxic metals inform of leachate to the subsurface.

Table 4. Stepwise multiple regression results for estimating heavy metals in water

| Metals | Regression Equation | R ² | F-value | P-value |
|--------|-----------------------------|----------------|----------|----------|
| Pb | Pb = 2.055+0.208Mn | 0.997 | 1500.213 | 0.0000** |
| As | As = 0.190-0.886Co | 0.784 | 14.561 | 0.019* |
| Mn | Mn = -9.842+4.791Pb | 0.997 | 1500.213 | 0.0000** |
| Cd | Cd =0.192-0.149Mn+1.530Zn | 0.993 | 210.384 | 0.0010** |
| Zn | Zn = -0.914+0.408Pb+0.425Cd | 0.9999 | 1848.356 | 0.0000** |
| Cr | No significant variable | - | - | - |
| Co | Co= 0.027+0.432Cd | 0.845 | 21.797 | 0.0100** |

*significant at 1% (p<0.01)

Table 5. Summary of the measured and estimated values of heavy metals Pb, As, Mn, Cd, Zn and Co

| S/N | Pb | | As | | Mn | |
|-----|----------|-----------|----------|-----------|----------|-----------|
| | Measured | Estimated | Measured | Estimated | Measured | Estimated |
| 1 | 2.05 | 2.06134 | 0.08 | 0.07457 | 0.03 | -0.00167 |
| 2 | 2.07 | 2.06758 | 0.09 | 0.09229 | 0.06 | 0.09414 |
| 3 | 2.06 | 2.06134 | 0.07 | 0.08343 | 0.03 | 0.04623 |
| 4 | 2.62 | 2.61299 | 0.17 | 0.14543 | 2.68 | 2.71479 |
| 5 | 2.63 | 2.61507 | 0.12 | 0.11 | 2.69 | 2.76749 |
| 6 | 2.55 | 2.57968 | 0.13 | 0.15429 | 2.52 | 2.38901 |
| S/N | Cd | | Zn | | Co | |
| | Measured | Estimated | Measured | Estimated | Measured | Estimated |
| 1 | 0.22 | 0.21826 | 0.02 | 0.02025 | 0.13 | 0.12166 |
| 2 | 0.19 | 0.1985 | 0.01 | 0.00969 | 0.11 | 0.10871 |
| 3 | 0.24 | 0.23355 | 0.03 | 0.03003 | 0.12 | 0.13029 |
| 4 | 0.09 | 0.08443 | 0.19 | 0.19036 | 0.05 | 0.06554 |
| 5 | 0.09 | 0.09824 | 0.2 | 0.19955 | 0.09 | 0.06554 |
| 6 | 0.05 | 0.04702 | 0.15 | 0.15013 | 0.04 | 0.04827 |

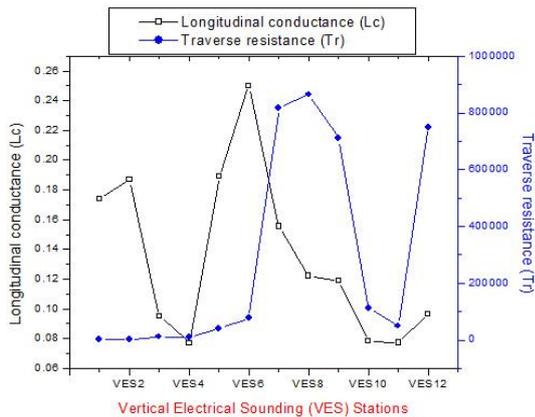


Figure 4. The Lc and Tr along the Vertical Electrical Sounding (VES) points

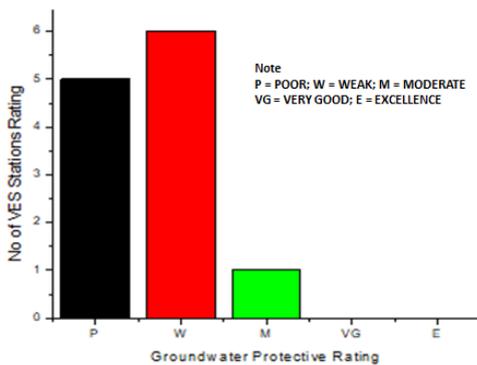


Figure 5. The number of VES station rating with aquifer protective potential rating

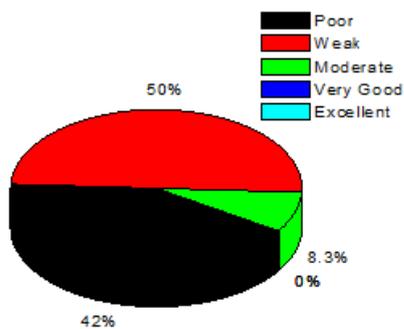


Figure 6. Percentage distribution of the groundwater protective potential

Groundwater is given guard by geological obstructions that have satisfactory overburden thickness called protective boundaries, and low in hydraulic conductivity. Silt and clay are seemly protective strata because when they are revealed as thick layers above the aquifer, they become a protective covering. During a prolonged percolating history, the occurrence of toxin degradation follows mechanical, physicochemical, and microbiological processes [34].

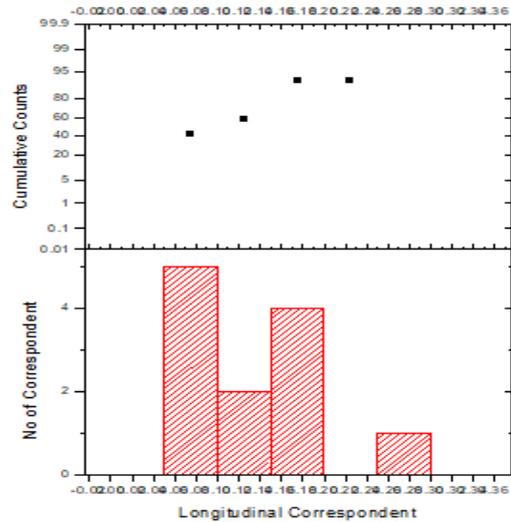


Figure 7. The probability distribution of the longitudinal conductance

CONCLUSION

The significance of the Lc observables is to establish a vivid formation about the protective potion of the vertical variation of the subsurface. This, therefore, revealed that groundwater exploration from the study area might be visible but the quality is harmful and toxic for consumption. This might be as a result of its proximity to the dumpsite where infiltration of leachate percolation occurs with microbial contaminants migrates into the aquifer.

The groundwater within and around the study area has the potential to be contaminated when percolation occurs in the near or far future. The Dar-Zarouk parameter and AAS have proved useful in providing the solution to understand the groundwater protective potential of the study area. Periodic assessment of the water quality within and around the study area especially at the AbaGboro community should be of esteem importance because nobody can speculate at what point the groundwater will be polluted and contaminated except with continuous research activities. This will mitigate any outbreak of disease that might unveil itself to the environment.

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Persian Abstract

چکیده

آب‌های زیرزمینی به دلیل استفاده ضروری در سیستم‌های زنده، نقش بسیار مهم و اساسی در حیات انسان ایفا می‌کنند. این مطالعه با هدف انجام یک مطالعه تجربی در مورد پتانسیل حفاظتی آب‌های زیرزمینی و کیفیت آب در اطراف تاسیسات زباله جامد دانشگاه Obafemi Awolowo و بخش آباگورو انجام شد. این کار با استفاده از روش مقاومت الکتریکی برای ترسیم ناهمگنی زیرسطحی در اطراف تاسیسات زباله و همچنین استفاده از طیف‌سنج جذب اتمی PG990 برای تجزیه و تحلیل فلز کیفیت آب به دست آمده است. آرایش آرایه الکتروود شلمبرگر در بررسی درگیر شد. در مجموع دوازده داده صوتی الکتریکی عمودی (VES) در محل جمع‌آوری زباله دانشگاه Obafemi Awolowo جمع‌آوری شد. نمونه‌های آب در دو مکان در جامعه AbaGbororo که ۴/۵ کیلومتر از محل تخلیه بود جمع‌آوری شد تا کیفیت آن تعیین شود. نتایج VES عمق، مقاومت و ضخامت را نشان داد. مقاومت مشاهده شده و مقادیر ضخامت بیشتر در تعیین پتانسیل حفاظتی آب‌های زیرزمینی، با محاسبه پارامترهای دار-زروک که نشان داد ۹۱/۷ درصد از منطقه مورد مطالعه در پتانسیل حفاظتی ضعیف/ضعیف قرار دارد، استفاده شد. نتایج حاصل از تجزیه و تحلیل آب چاله‌های حفر شده با دست در دو محل مختلف در بخش آباگورو وجود غلظت فلزات سنگین به صورت سرب، آرسنیک، منگنز، کادمیوم، روی، کروم و شرکت را نشان داد. لذا ارزیابی دوره‌ای آب انجام شد. بررسی کیفیت باید همیشه انجام پذیرد چرا که نمی‌توان پیش‌بینی کرد که آب‌های زیرزمینی چه زمانی آلوده می‌شوند که دلیل آن پتانسیل حفاظتی نسبتاً ضعیف/ضعیف از آب‌های زیرزمینی است.