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Investigation of the impact of Gadon Kaya gate dumpsite on the underground water system in Kano Metropolis using the passive electrical resistivity profiling

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Abstract

The rapid urbanization and population growth in Kano, Nigeria, have led to an increase in waste generation, with dumpsites such as Gadon Kaya becoming significant contributors to environmental pollution, particularly the groundwater system. This study focuses on assessing the impact of Gadon Kaya dumpsite on the groundwater system in Kano, employing electrical resistivity as a geophysical technique. The ADMT 300SX device was used for the data acquisition at the dumpsite. Three profiles were taken across the dumpsite and one additional profile 100m away from the dumpsite as a control profile. The first profile has a length of 30m and a sampling interval of 2m, while the second, third, and control profiles are 60m in length with a sampling interval of 5m respectively. The results from these profiles showed that the leachate had contaminated the top layer and the weathered basement with deeper leachate migration where fractures in the basement complex connect with the weathered layer. The results also showed the area of highly resistive material interpreted as the crystalline basement which is without water content. From other studies, we deduced that the contaminated zone is beyond the water table or the aquifer materials in the region.

Keywords: Dumpsite, Passive Resistivity, Groundwater, Leachate, Kano.

INTRODUCTION

Groundwater contamination is a global concern particularly to geoscientists because of its adverse effects on both the environment and human health (Li et al., 2021). The accelerated pace of industrial development coupled with the uncontrolled growth of the urban population experienced in our cities, such as Kano has resulted in the increasing production of both solid and liquid waste (Alagbe et al., 2019; Lin et al., 2022). Globally, waste generation rates are increasing, with the world estimated to generate 0.79 kilograms of solid waste per person per day, leading to an estimated 3.38 billion tonnes of waste in the year 2020 (UN-HABITAT, 2018). This enormous waste usually finds its way into the underground water system, contaminating it and creating adverse effects on human health and relevant ecosystems (Lin et al., 2022). The impact of water contamination is more severe in the least developed countries with population crises and poor sanitation and wastewater treatment facilities. Groundwater

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is water located beneath the ground surface in soil pore spaces and in the fractures of rock formations (Alagbe et al., 2019) and the main source of water in Kano state is groundwater, which can be taped either by open wells or boreholes. Groundwater is (naturally) recharged by rainfall and snowmelt or from water that leaks through the bottom of some lakes and rivers (Ismaila et al., 2020). In an urban city like Kano, groundwater can be recharged through drainage, and due to poor maintenance most of the drainage contains solid waste, this solid waste decomposes and forms leachate that combines and goes into the ground and contaminates the groundwater.

Waste is linked to virtually every aspect of human activity and is generated from our daily activities. It results from an event or process that does not have immediate economic value or demand and must be discarded (Adedinni et al., 2023). Waste generally exists as solid, liquid, and gas. Solid waste is unwanted materials formed in a given area, such as suburban, manufacturing, or commercial activities. In areas like Kano, the dumping of refuse is controlled by the government which is poorly maintained. Dumping of solid waste is usually at dumpsites or landfill sites. Unfortunately, the selection of these sites in most developing cities does not follow recommendations from sophisticated geophysical and/or engineering studies to reduce the impact of contaminants from the dumpsites on groundwater resources (Chounlamany et al., 2019; Ngoc & Schnitzer, 2009). Where such sites exist, monitoring exercises are important to detect possible contamination timely and measures to be taken to clean up and prevent further damage. Therefore, it is important to assess the potential impact of dumpsite leachate on groundwater quality and quantity. The problem at hand is to determine the extent of groundwater contamination due to the unregulated disposal of waste in dumpsites using geophysical approaches.

Electrical resistivity imaging is a non-invasive and cost-effective geophysical technique that can provide valuable insight into the subsurface electrical properties of the soil. The study aims to evaluate the resistivity method to image possible contaminant plumes beneath the dump site. Electrical Methods involve the use of electric current (natural or artificial, direct or alternating) introduced on the surface or into the ground to investigate the variations in the electrical properties of the subsurface materials (rocks), (Loke et al., 2013; Ugbor et al., 2021). The potential difference (PD) in the ground due to the flow of current can then be measured from the ground surface and these will provide information in the form of electrical properties of such subsurface inhomogeneities (Ugbor et al., 2021; Wu et al., 2023). The important contrasting physical parameter here is the resistivity (or conductivity) of the subsurface rocks. A soil material with leachate is characterized by a very low resistivity or high conductivity. By imaging the subsurface structure beneath a refuse dumpsite using electrical methods, one can map leachate migration path or accumulations in or near saturation layers. This is the basis of the use of electrical resistivity in this research. The naturally occurring electromagnetic fields in the ground was employed as the energy sources using a piece of special electromagnetic equipment to obtain the 2-D image of the subsurface beneath the Gadon Kaya Gate dumpsite (GKGD) in Kano State, north-western Nigeria.

The study area, geology, and hydrology

The study area of GKGD is along Bayero University Kano (BUK) Road, Gwale Local government in Kano State (Figure 1). It is located a few meters away from a private University called Khalifa Isyaku University, Kano), which means the mean source of water (groundwater) used by the university might be vulnerable to contaminants from the dumpsite. This dumpsite has been in existence for the past ten years, in a densely populated area and is accumulated with different waste materials such as leather, rubber, dry plant, animal waste, etc. Because Kano depends heavily on agricultural resources, waste from agriculture is not left out. Nitrogen contaminants, such as nitrate, nitrite, and ammonia nitrogen (Li et al., 2021), are likely to be present due to the huge tons of agricultural waste dumped on the dumpiste. The high concentration of Nitrogen contaminants in water can cause chronic conditions like "blue baby syndrome," also known as infant methemoglobinemia.

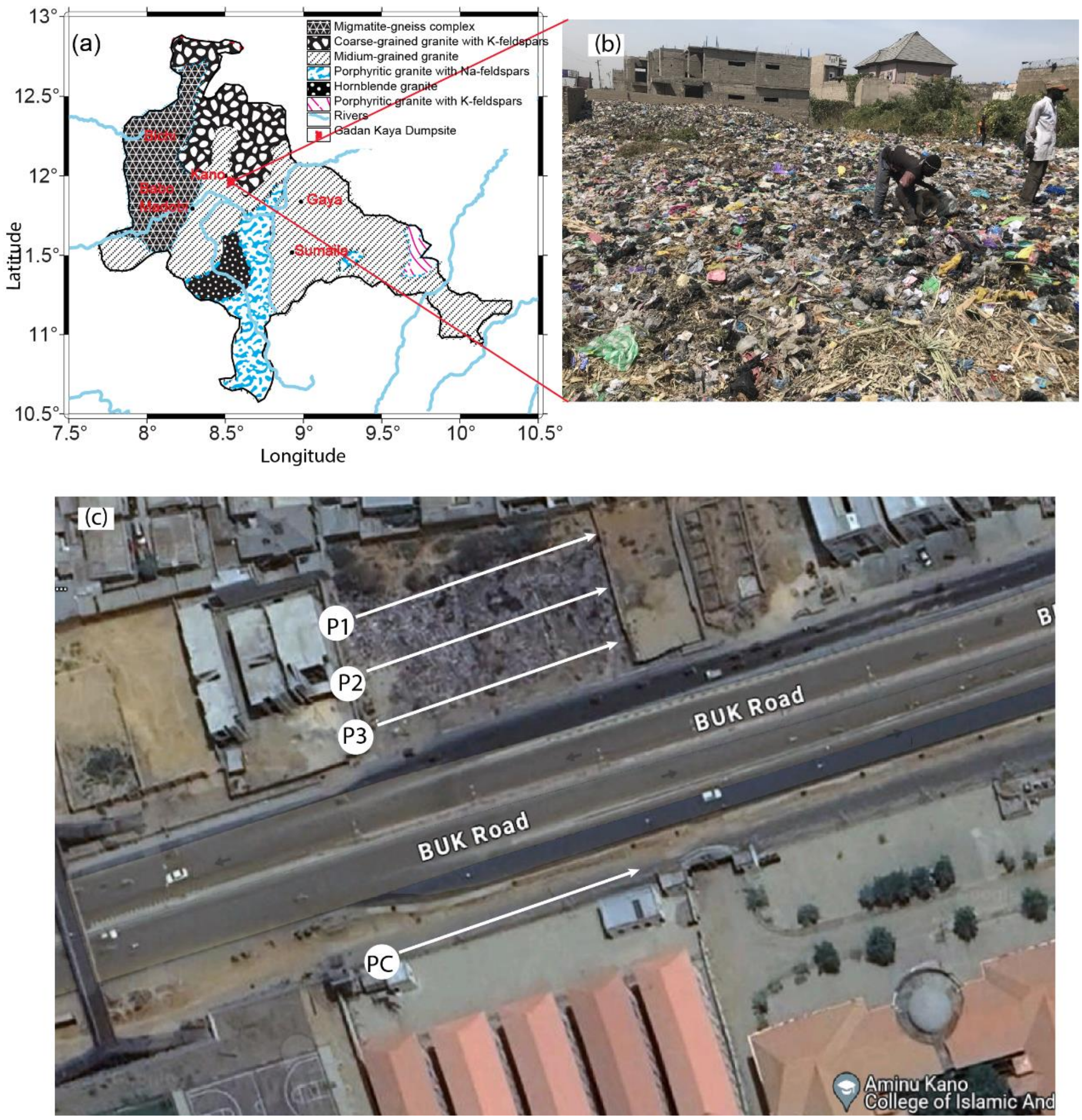

Figure 1. Geological map of Kano State showing the study area (a) and the physical state of Gadon Kaya Dumpsite during field survey (b). The location of data acquisition profiles (P1, P2, and P3) across the dumpsite and a control profile 100m away (PC) as shown in (c).

Geologically, Kano State falls within two main geologic formations namely: the basement complex in the southern and western parts of Kano and the Chad formation in the north-eastern part of Kano (Ismaila et al., 2020). The project area falls within the basement complex area (Figure 1). The basement complex of Nigeria comprises migmatite and gneisses which are formed from the metamorphism (high grade) and granitization of Birrimian sedimentary rocks, (Ismaila et al., 2020; Obaje, 2009; Yelwa et al., 2015). The upper proterozoic younger metasediment of low grade was folded along with the migmatite and gneisses during the

African Orogeny (Yelwa et al., 2015). The hydrology of Kano shows that the underground water productivity in Kano varies from place to place depending mainly on the geology. Studies show that productivity decreases from the Chad Formation to the Basement Complex region. The Chad Formation in the Kano region is one of the largest accessible stores of fresh groundwater, and for that groundwater is often considered a logical resource in the region. Conversely, in the Basement Complex region, rapid rising population growth in association with urbanization and climate change has led to intensive exploitation of groundwater through the construction of boreholes, principally for domestic water supply. Groundwater in the urban Kano area for instance appears to be a common and low-cost alternative to surface water for many uses because it occurs generally in a more potable quality compared to surface water, (Tukur et al., 2018). Usually the weathered and/or fractured layers are the main reservoirs for underground water development due to the improved porosity and hydraulic conductivity.

METHODOLOGY

Basic principle of ADMT device

The method used is based on the principle of Magnetotelluric (MT) which involves the use of a magnetic sensor to measure naturally occurring electromagnetic fields in the earth into electrical resistivity of the Gadon Kaya Gate Dumpsite. The technology uses the audio frequency band spanning from 0.1Hz to 5 kHz, which is typically under the MT frequency range spectrum (Gomo & Ngobe, 2024; Melchinov & Pavlov, 2022). The approach is also known as the "audio earth electric field method or frequency selection of earth electric method" (Gomo & Ngobe, 2024; Yulong et al., 2023). The ADMT meter operates two modes namely- the electrode mode (MN) and the magnetic sensor mode (TT). The MN mode measures the potential difference (PD) between two electrodes due to the electric component of the electromagnetic fields in the ground. When the TT mode is used, it measures the magnetic component into the electric field. Since the time-varying EM fields obey Maxwell's equations, by assuming that soil is non-magnetic and is uniformly conductive such that there is no charge accumulation and the displacement current can be ignored, we can simplify the Maxwell equation as:

$$\nabla^2 \left(\frac{E}{H}\right) + k^2 \left(\frac{E}{H}\right) = 0, \qquad 1$$

Where $k = -i\omega\mu\sigma$; E and H are the electrical and magnetic components respectively. $\omega, \mu, and\ \sigma$ are the frequency, permeability, and conductivity respectively.
The solution Equation (1) under natural earth induction will yield the surface impedance Z defined as the ratio of the surface electric field and the horizontal component of the magnetic field. This is the shielding effectiveness of the subsurface geological materials on the induced EM waves. It is independent of the polarization of the incident field and is related to the earth's resistivity and the frequency (ω) of the electromagnetic field.

$$Z = \frac{E}{H} = (\omega\mu\rho)^{\frac{1}{2}} exp^{(i\pi/4)}. \qquad 2$$

The ADMT-300SX device comes with an Android screen that integrates data acquisition, real-time imaging, and data synchronization with multiple terminals. It is equipped with a 10-inch (5-inch or 7-inch for a single channel, a measurement board, MN electrodes input access, and a TT probe sensor. After data collection is completed, the instrument can check the data and form a graph immediately. The theoretical framework of an ADMT device is measuring the skin depth which is also the depth of the earth's subsurface at different frequencies. Where

δ is the skin depth, f is the frequencies at different ranges and ρ is the resistivity of the subsurface as shown below (Gomo & Ngobe, 2024; Yulong et al., 2023)

$$\delta \approx 503\sqrt{\rho}/_{f}. \quad 3$$

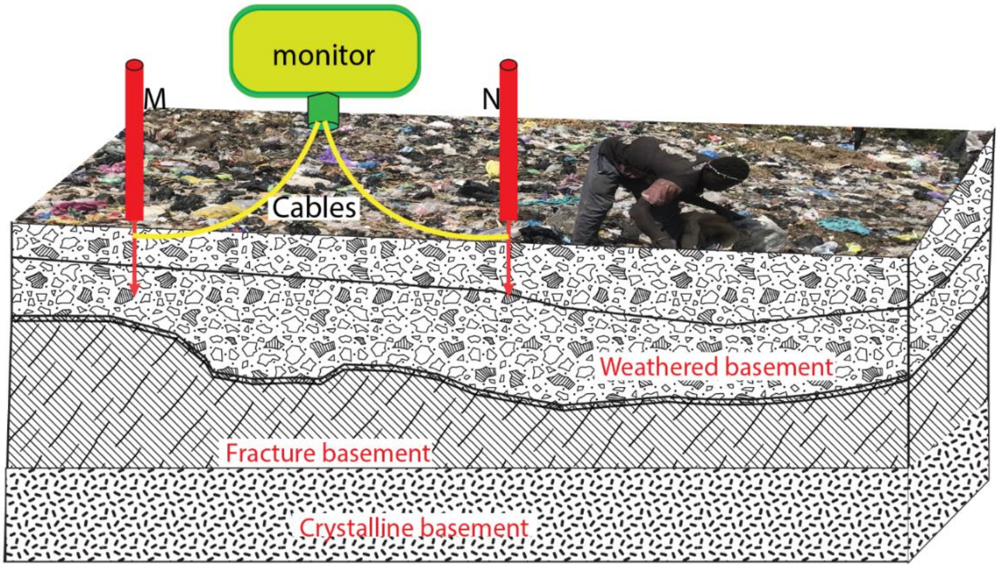

Fig. 2 Field arrangement of ADMT-300SX single channel using electrode (MN) probe on a dumpsite for data collection.

Field measurement and data processing

The data acquisition was carried out using the TT probe of the ADMT-300SX at the dumpsite due to the high pile of nylon bags that might hinder proper contact with the ground in an electrode probe (Fig 2). After the instrument is turned on and the magnetic sensor is connected to the instrument, the sensor is placed on the ground, similar to the electrode probe (Fig. 2). The measurement point is directly below the sensor. The sensor placement direction is not required, but the placement direction of each measuring point on a survey line is required to be consistent. The device measures the potential difference in the range of 0–200 mV with a 0.1 mV resolution. The sampling frequency is 1 Hz to 8 kHz, offering a sampling depth of about 300m (Melchinov & Pavlov, 2022).

To perform a measurement, the ADMT smart receiver was connected to the magnetic probe sensor using a cable and placed on the data point along the survey line. After sampling is completed at the ith point, the sensor is moved to the $(i+n)th$ position for the $i+n$ data sampling. We completed a total of 3 profiles and one additional profile about 200m away from the dumpsite that serves as the control (Fig 3). The sampling depth was set at 100m. After all the data acquisition was completed, a layered initial model was selected for modeling near-surface structures, and the data was inverted using an inbuilt software of the ADMT-300SX. For this work, the processed data is reorganized into XYZ format and saved for use with other imaging tools like Matlab. We wrote a dedicated Matlab script to image the data in 2-D to produce high-quality images suitable for publication.

RESULTS AND DISCUSSION

The results from the resistivity data interpretation to detect the leachate plumes were presented as resistivity profiles. Four profiles were established as shown in Fig. 3 and all trend W-E. The depth of coverage of profile 1 (P1) is about 100m with a length ranging from 0 to 30m. The resistivity ranges from $3-20\Omega m$. The topmost layer is characterized by a deep blue and marked below with a dashed line giving the depth of lowest resistivity. Below the dashed line is the weathered and/or fractured basement which is characterized by a light-blue color. The deep red color is interpreted as the fresh basement rock. This part is highly resistive and without any capacity to hold and release water. It also means that it cannot be contaminated by leachate. The fresh basement is generally between the depths of 50m and extends beyond 100m depth.

Profile 2 (P2) is similar to P1 with the same resistivity distribution mainly because the two profiles are just about 5m apart. A deep conductive layer (deep blue) is located on the eastern side of the dumpsite as revealed on the profile. The delineated leachate penetration could be down to 100m depth. The western side is characterized by a deep weathered basement and interconnected fractures at depth that could have aided deeper percolation of leachates. On the western side, the leachate is shallow within a depth of about 10m. Along Profile (P3), the dark blue represents the leachate which is relatively shallower compared to P1 and P2. The average depth penetration is about 20m. However, where fractures connect to the weathered layer, the low resistivity anomaly sinks deeper than the average depth. This implies that the targeted aquifers which are the weathered and fractured rock in this region are contaminated.

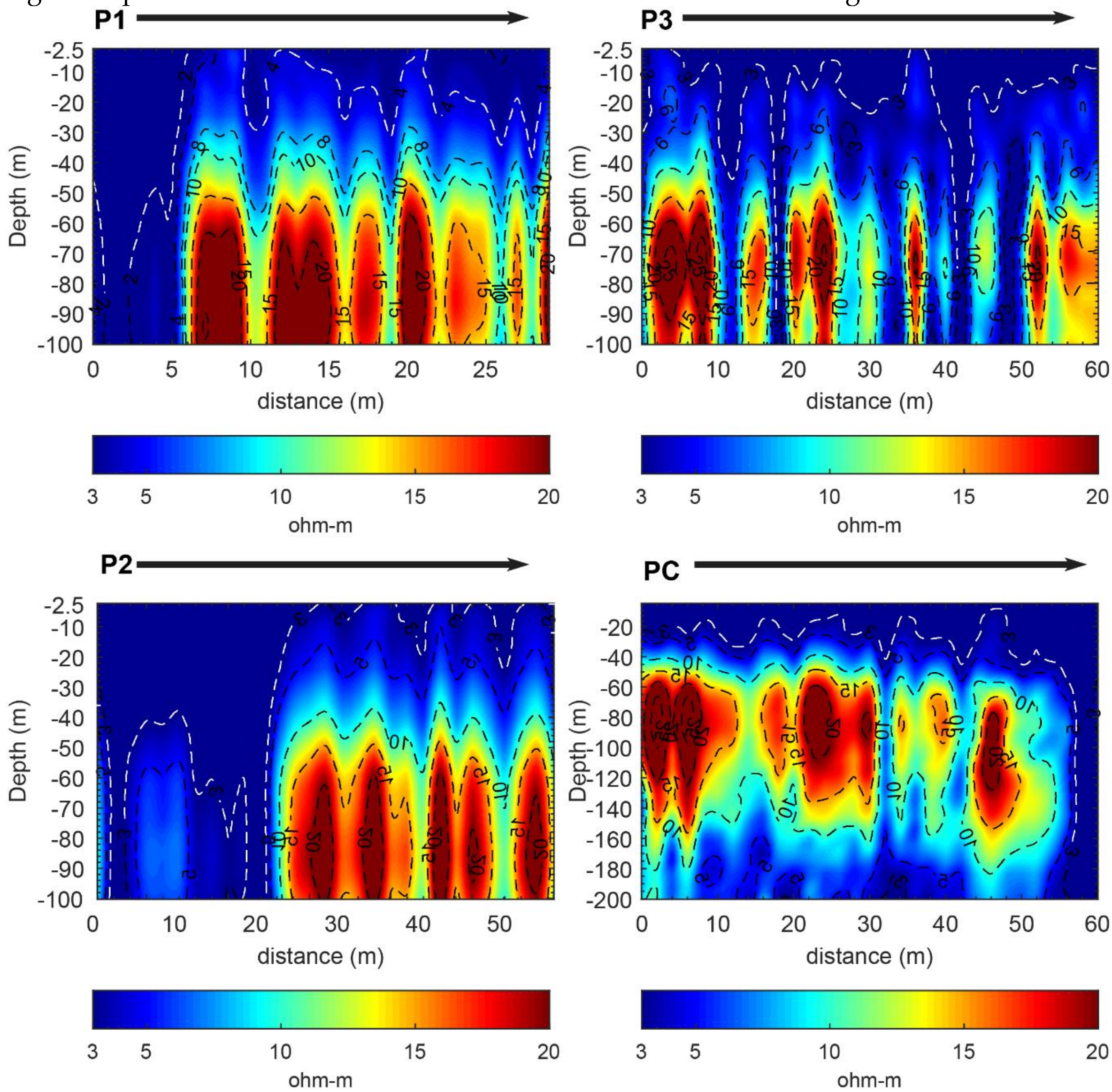

Fig 3. The results of the four profiles show the resistivity variation beneath the dumpsite. Arrows indicate the direction of the trend of profiles relative to the dumpsite (Fig. 2)

We measured the resistivity about 100m away from the dumpsite to check the extent of leachate migration toward Khalifa Isyaku University, Kano. This profile is called Profile Control (PC). The profile revealed a thin conductive layer of about 20m thick and underlain by a compact resistive basement block. The presence of this impermeable material means a lateral flow of leachate is only within the shallow 20m depth except where deep fractures connect to the regolith. Across all the profiles, the low resistivity anomaly connected to the surface is indicative of possible leachate contamination from the decomposition of the refuse materials associated with the GKGD. It could also indicate the saturated zones with the migration of leachate into the subsurface starting from the ground surface. The strike lines showed that the basement rock at that zone is fractured; an indication that the water table in this area may have been contaminated as could be seen with a low resistivity value of 3 Ωm at deep depths below 50m. The dark blue indicates high conductivity or a weak zone (fault or fracture), and the profiles show that the study area is predominately leachate-contaminated zones.

Generally, this is within the weathered and fractured basement. These layers constitute the aquifer layer in a typical basement complex. Studies have shown that the aquifers are Porous and permeable rock units as well as the presence of thick weathered basement (regolith) and fractured rock formations, (Hamza et al., 2016). This means that the aquifer beneath P1 is heavily contaminated by the leachate. Our study with the natural ground electrical resistivity method has revealed that the Gadon Kaya region of the Kano basement complex comprises regolith and a fractured basement in the first 100m. In this type of formation, the targeted aquifer materials are the saturated zones of the regolith and fractured basement (Bianchi et al., 2020; Etuk et al., 2022). Studies within the Kano metropolis have shown that the aquifer depths are shallow and the average static water level is shallower than 20m (Bala et al., 2011; Hamza et al., 2016). Besides, most of the boreholes drilled in the area terminate between 37-60m (Bala et al., 2011; Hamza et al., 2016). With our results revealing contamination of the entire weathered zone, we concluded that the shallow underground aquifer is extremely vulnerable and within proximity to dumpsite could be contaminated.

CONCLUSION

The results show the locations and lateral extent of the contamination migration from the Gadon Kaya Gate dumpsite. The resistivity profiles depict the geometry of the leachate plumes inside the waste disposal site as conductive anomalies near the surface down to the regolith (weathered basement). The contaminant plume is characterized by the lowest resistivity (0-4 Ωm), while the crystalline basement is characterized by the highest resistivity values. Previous studies show that the water level is below 20m in the region. However, the average contamination depth is about 40m. We infer that the contaminants are not migrating from the host rocks which act as aquifers but from the decayed organic materials in the dumpsite. We recommend the use of a modern dumpsite design that will introduce an impermeable layer to prevent both vertical and lateral migration of leachate. Also, a portable water treatment is necessary for all boreholes near dumpsites in Kano.

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