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Research article

Integrated approach to unsaturated zone characterization as it relates to burial practices and its impact on the immediate environment

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ABSTRACT

Improper sitting positioning of cemeteries in Nigeria is mostly responsible for groundwater pollution. Poor water quality may lead to some communicable diseases in most rural and urban areas of the southwestern part of Nigeria. The environmental impact of cemeteries close to residential areas within the Edunabon metropolis, southwestern part of Nigeria, was assessed. The research is aimed to understand the impact (if any) of the cemetery on the quality of water and soil within the vicinity and to investigate the suitability of soil materials underlying the cemetery as a special lining material. An integrated approach using geotechnical characterization, vertical electrical sounding and groundwater quality assessment was used in the present study. The geotechnical test involved six bulk undisturbed soil samples taken from two borrow pits within the cemetery. Index property tests (grain size distribution, specific gravity, natural moisture content, and Atterberg limits), engineering property tests (compaction test), X-ray diffraction, and X-ray fluorescence tests were carried out on the soil samples with their porosities and permeability estimated according to BS 1377. The majority of the study area is a wetland with a topography that descends into a gaining stream around 10 m from the cemetery. The soil of the cemetery is made up of coarse-grained porous lateritic soil, clay, and silt (0.22–3.88 percent), with a significant amount of gravel/sand (73.50–83.96 percent). Except in the control well, water analysis revealed a high total coliform concentration of 14–89 and a total hardness of 86–380 mg/L. When compared to the World Health Organization (WHO) drinking water standard and the Nigerian drinking water standard, the majority of cation concentrations were greater than the safe limits. The depth to contamination correlates to the depth of the aquifer in the research region, according to the results of electrical resistivity. Because of the narrow unsaturated zone, the study found that the position of the cemetery has a high risk of environmental impact on its near vicinity.

1. Introduction

In some regions of Africa, cemeteries are built within or very close to residential communities, oblivious to the possibility for groundwater pollution in the area. Cemeteries have been identified as potential pollutant reservoirs, responsible for contamination of the environment with a potential to negatively compromise the health of people residing within its vicinity, as the corpses interred within decompose especially when they are not properly situated (Abia et al., 2019; Neckel et al., 2021).

Groundwater is the main source of potable water in Nigeria but due to cost, most communities cannot afford it, hence the dependence on surface water and streams which are most prone to contamination (Tijani et al., 2018). Among the various pathways of contaminants, exposure through drinking water has been identified as the most critical for trace elements to enter the human body (Caussy et al., 2003; Muchuweti et al., 2006 in Ricolfi et al., 2020).

Environmental factors such as climate, weather, precipitation rate and intensity, topography, soil conditions, and above-ground temperature, have a role in human decomposition (Rodriguez and Bass, 1985; Mann et al., 1990; Spongberg and Becks, 2000; Dippenaar, 2014). The type of soil used and the thickness of the unsaturated zone have both been discovered to play a role in influencing the impact of cemeteries on

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their immediate surroundings. Olajide and Abiodun (2013) on the socio-economic and environmental impact of indiscriminate burials practices on landed properties in Ado-Ekiti, Nigeria, concluded that the lack of proper regulation and facilities by the government was responsible for these challenges. According to EPA (2017), these practices could pose a whole lot of challenges to groundwater quality. Inadequate access to drinkable water is still a serious issue in poor countries. Rodrigues and Pacheco (2003) showed that cemeteries contribute to groundwater contamination and recommended a site-specific risk assessment for cemetery sites, taking into account geological and hydrogeological conditions as well as the proximity of receptors such as boreholes, hand-dug wells, and springs.

In terms of biological constituents, a relatively few groups of microorganisms have been recognized as major invaders of human corpses during putrefaction. Despite the fact that humans intestines are home to a diverse range of bacteria. *Clostridium* spp., *Streptococci*, and *Enterobacteriaceae* are among them. Putrefactive microorganisms such as Micrococci, Coliforms, and Diphtheroids are added to the mix. Bacillus spp., Staphylococcus spp., and Pseudomonas aeruginosa are among the bacteria detected (Üçisik and Rushbrook, 1998; Vass, 2001; Zychowski and Bryndal, 2015). *Micrococcaceae*, *Streptococci*, *Bacillus*, *Enterobacteria* (e.g. Salmonella), and viruses are among the microbes known to cause waterborne infections found in cemeteries seepage. Other microorganisms, like Saprophyte fungus and a variety of Entomofaunaact., have a role in the putrefaction of cadavers (Üçisik and Rushbrook, 1998; Vass, 2001). The impact of cemetery effluent on groundwater is generally similar to that of landfill leachate, according to Young et al. (2002) and Sawyer et al. (2003), with the common contaminants being labile organic compounds such as ammoniacal nitrogen, mobile anions such as Cl, NO_3, and SO_4, and alkali earth metals such as gypsum. K. Na, Chemicals used in the embalming of the corpses, as well as the chemical composition of the inorganic components of paints used in the coating of the coffin coupled with the coffin accessories contributes in no small way to contamination of surface and subsurface water in the vicinity of cemeteries.

In line with the WHO (1998) recommendation on safe sitting distance of about 250 m of a cemetery from any source of potable water, this research has become imperative to sensitize the large number of inhabitants who depend on unsafe water for consumption, as well as domestic use about the unwholesome practice of burial within close proximity to the main source of water.

It is against this backdrop that this research is carried out to investigate the impact of an old cemetery as a case study on the hydrological and geological conditions within the study area. The work is significant because several old cemeteries exist in Osun State Nigeria and most are found associated with religious worship centers. A case study of the St. Peter's Anglican Church cemetery located in Edunabon community in Osun State, Nigeria (latitude 07.33° N and longitude 04.26° E) was adopted in this study because of its unique topography, the age of the cemetery, and the proximity to a gaining stream as well as residential buildings.

As a result, the current research aims to determine the soil–water interaction in the area of selected cemeteries in order to establish an appropriate protocol for the safe sitting of cemeteries within the southwestern region of Nigeria. The objectives include, delineating through geophysical method any possibility of contamination within the cemetery, analysis of surface and groundwater together with the geotechnical investigation of soil to ascertain their suitability for cemetery construction.

2. Location and climate of study area

The study area is located at latitude 07°32 - 33.887' N and longitude 04°26 - 27.196' E in the southwestern part of Nigeria (see Figure 1). It is situated in Edunabon, Ife North Local Government, about 12 km toward the northern part of Osogbo metropolis along the Ile-Ife road. The cemetery is situated within the premises of St. Peters Anglican Church in Eduabon, Osun State Nigeria. The church building is situated on the left side of the cemetery, while St. Peter Anglican Primary School is

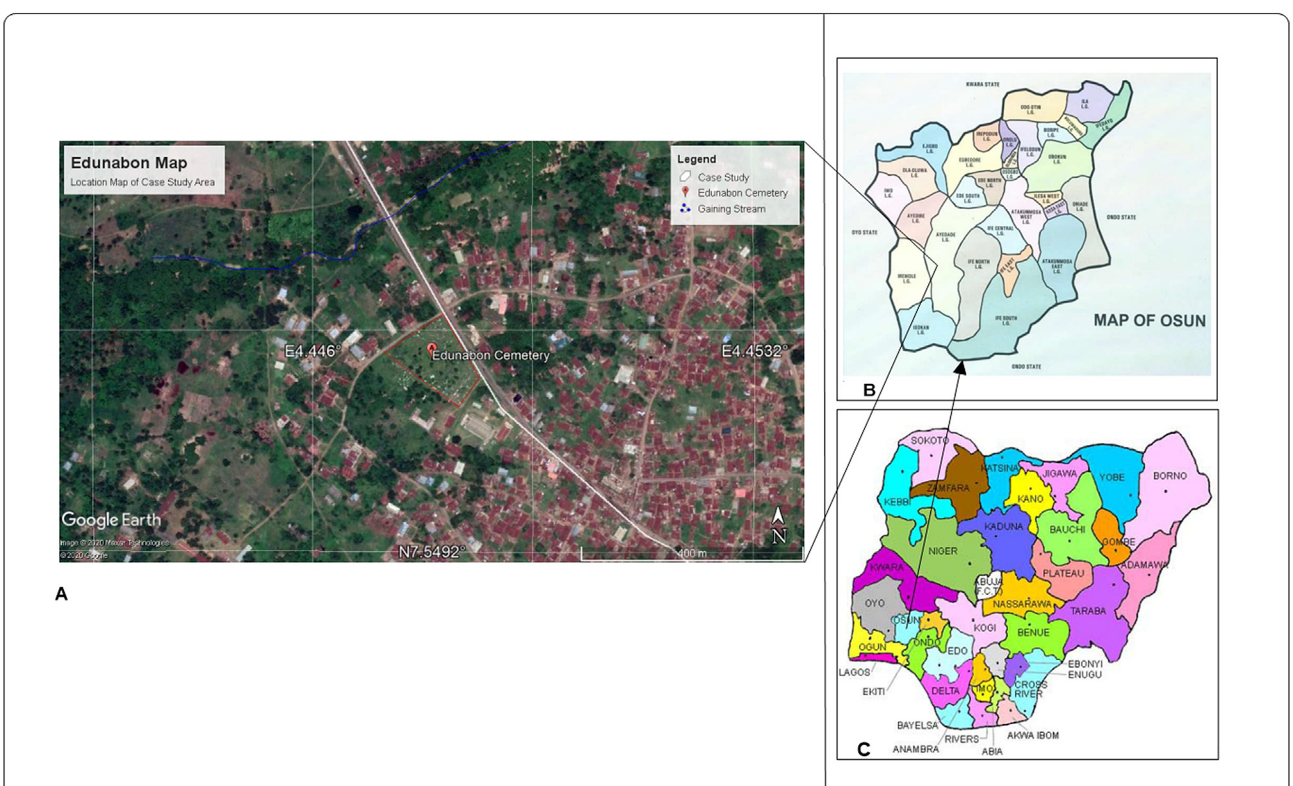

Figure 1. Location map of the study area showing sampling locations adapted from Google®2020 (Inset (B) Map of Osun State and (C) Map of Nigeria).

positioned at the back. A road borders the cemetery to the right, all situated along Sekona-Ife road. Edunabon is home to about 211,000 people according to the population database of the State of Osun (https://citypopulation.de/php/nigeria-admin.php?adm1id=NGA030). The total area of the cemetery is 15,029 km^2 and the first corpse buried within the cemetery was buried in 1950 (information from the inhabitants). The custom of burial practice in the study area is not different from what is obtained in most rural communities in southwestern Nigeria.

The climate of the study area falls within the tropical savannah climate of the middle belt and parts of the southwest of Koppen climate classification (Adeoluwa et al., 2017). Ecology within the tropical rainforest in the south. The Southwestern part falls within the tropical rain forest having an average annual temperature of about 26.5 °C and about 1298 mm of precipitation annually. The rainy season commences from April to October, with precipitation as high as 2596 mm in September and as low as 780 mm in April.

3. Geology and hydrogeology of the study area

The cemetery is located within soils derived from weathering of banded gneiss in the Basement Complex terrain of Nigeria which happens to be the most dominant rock type within the study area. The mineralogy of the gneiss includes minerals such as plagioclase feldspar, biotite, quartz hornblende with accessory minerals such as zircon apatite, allanite, etc. The conspicuous surface of the banded gneiss is marked by parallel layers composed of the preferred orientation of biotite flakes with alternating felsic bands. Other rock types identified within the study area include epidiorite and the undifferentiated schist. Figure 2 illustrates the geology of the area. Based on the structurally controlled drainage, the study area is sited next to a gaining stream coupled with the porous sandy silt sediments. Hence, the aquiferous interval in the study layer is shallow at about <2.1 m–3.9 m deep, hydraulic conductivity and transmissivity across the study area are expected to be high based on the nature of sediments and the topographical settings which slope into the stream (see Figure 3).

River Isasa, the only major river in the study area which flows towards the Southwest and its numerous tributaries elsewhere, provides the surface water resource of the surveyed area. This river dries temporarily during the dry season and gets recharged during the rainy season. Figure 3 presents the terrain map of the area which gives an idea of the potential flow of water. For instance, the gaining stream within the vicinity of the study area is located within a valley to the North of the cemetery (see Figure 3).

The dry season lasts from November through February. This high level of rainfall experienced throughout the year helps to improve groundwater recharge in some ways. Abstraction from shallow hand-dug wells/boreholes and evapotranspiration are two groundwater discharge sources in this area.

4. Materials and methods

In this research, an integrated approach was used, which included a preliminary water quality assessment to identify the probability of contamination within the study area. This was followed by a geophysical

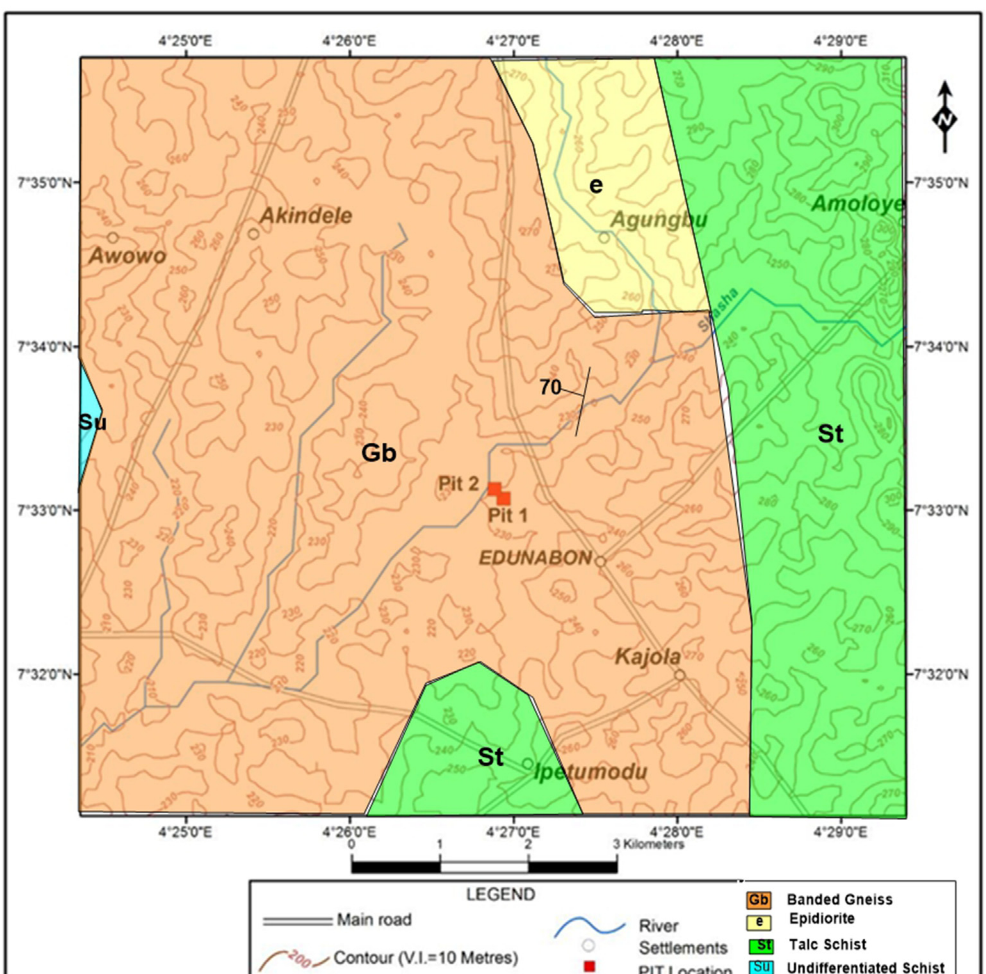

Figure 2. Geological map of the study area with soil sampling locations. (Modified after NGSA, 2006).

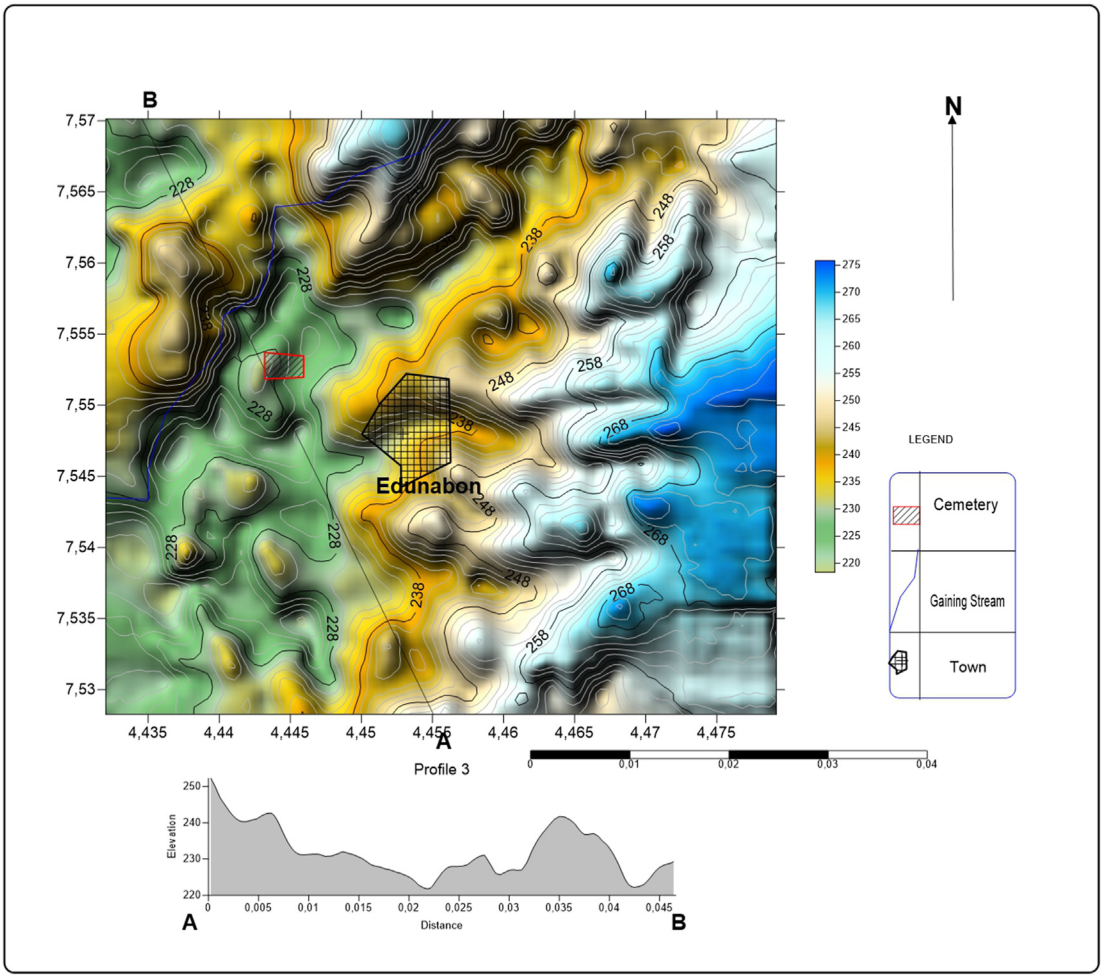

Figure 3. Terrain map of the study area.

investigation using the Schlumberger array technique to determine the depth of contamination, and then a geotechnical test to determine the vulnerability of the soils within the study area.

Ten water samples were randomly taken from wells and rivers around the cemetery and tested for physical, chemical, and biological elements. These were transported to the laboratory within 24 h of collection. The Atomic Absorption Spectrophotometer was used to analyze cations and heavy metals, while the Iron Chromatographic method was utilized to analyze anion analysis and the titrimetric method was used to analyze SO_4 and HCO_3. Biological constituents (Total Coliform, *Faecal streptococci,* and *E. coli)* were analyzed using the enzymatic substrate method (Colilert). Microbiological analysis of the collected samples was carried out within 24 h of sampling.

Sampling points were located using the global positioning system (GPS). A well far away from the cemetery was also sampled as a control. The findings were compared to the World Health Organization's (2016) standard and the Nigerian Standard of Drinking Water Quality (NSDWQ).

The electrical resistivity geophysical method was carried out using eight vertical electrical sounding (VES) surveys. Data obtained were subjected to interpretation using the partial curve matching techniques before iteration using the iterative software. The resistivity values adopted for the determination of the depth of contamination and other layers are after the work of Adeoti et al. (2011) in Murana et al. (2019). See supplementary list.

Six (6) bulk soil samples were taken from two hand-dug pits, one from the upper section of the cemetery (Pit 1) and the other from a water-logged area in the bottom half of the cemetery (Pit 2). The lower part is just about ten meters (10 m) from a river within the vicinity. The coordinates, as well as the elevations of these points, were taken and recorded using the global positioning system. In each of the pits, samples were taken up to about 3 m depth from the surface. They were collected at an interval of about 1 m depth from the other in each pit.

Physical properties (colour, texture, and smell) were observed before storing in sealed polythene bags to avoid loss of moisture on exposure to air.

The index and engineering properties testing were conducted at the Osun State University's soil laboratory in Osogbo, Nigeria. They include; natural moisture content, specific gravity grain size analysis, Atterberg limit (liquid limit, plastic limit, plasticity index, and linear shrinkage), and compaction test, while porosity was estimated from the results of the tests.

Major oxides and mineralogical analyses were carried out at the Stonneman analytical facility of the University of Pretoria, Hatfield, South Africa. These include X-ray fluorescence and X-ray diffraction analyses. All the tests were carried out to the British Standard BS 1377(1990) procedures with slight modifications where necessary.

5. Results and discussion

5.1. Hydrogeological condition

Table 1 shows a summary of the in-situ parameters with the geographical location of the sampling points and the proximity of each well to the reference cemetery. Table 2 presents the physicochemical parameters, anions, cations as well as the comparison table of the World Health Organization (WHO) Standard for Drinking water as well as the

Nigerian Standard for Drinking Water Quality (NSDWQ). The regional water level slopes into a gaining stream as illustrated in the diagram showing the positions of the tombs relative to the water level (See S4 in supplementary material). A flowing river, that is the gaining stream is less than 5 m to the cemetery site (see S5 in supplementary material). To understand the environmental impacts of cemeteries, cogent information is needed on the ability of bacteria and viruses as well as the fate of the end product of the decayed human body in soils and groundwater (Üçisik Ahmet and Rushbrook, 1998). The ability of the bacteria and viruses to be retained and to survive in soils and groundwater is a function of the type of the soil in which a cemetery is sited, the type of micro-organisms present, and the prevailing subsurface temperature as well as precipitation. Minute organisms are believed to die off at a double rate as every 10 °C rises in temperature between 5 °C to 30 °C (Reddy et al., 1981). As a result, organisms tend to survive and live longer at lowered temperatures, with a number of microorganisms in the soil surviving at a pH range of 6–7, beyond this; they tend to die off. Where soil and groundwater pH is above 7 or very low below 6, the fraction of bacteria and viruses retained decreases markedly (Üçisik Ahmet and Rushbrook, 1998). In this research, the temperature is about room temperature for most wells especially those that were located around the cemetery; a pointer to the profound influence of effluent from the cemeteries on the surrounding wells. Also, groundwater from sample 1 to sample 7 was observed to exhibit a general pH value that fall between 6.5 and 8.5, an indication of the fact that there is a likelihood that the alkalinity condition in this area would favour the retention of bacteria and viruses. The combined effect of both ends up enhancing the bloom of microbial growth in both the soil and the groundwater within the study area. It was also observed that the electrical conductivity (EC) measured ranged from between 10 to 230 μs/cm with an average value of 132 μs/cm. The conductivity around the cemetery was observed to be higher when compared with those far away from the cemetery. This is an indication of certain levels of pollution from the effect of the cemetery on the groundwater. The results obtained from the analysis of the biological parameters, which is in agreement with the above-described conditions. For instance, the total coliform analysis reveals that most of the groundwater in the vicinity of the cemetery has high total coliform content between 14 and 89 mg/l except in the control well where it was recorded to be less than the permissible limit of 10 mg/l. Analysis showed that the *Faecal streptococci* was near zero except for samples from samples 1 and 2 which are the closest to the cemetery. Earlier studies according to Rodrigues and Pacheco (2003) mentioned the presence of *Faecal streptococci* in cemeteries around Poland and some European countries as well as in the United State of America. This was due to high precipitation and shallow groundwater levels in such areas. This is in complete agreement with the present study with *Faecal streptococci found in wells* closest to the cemetery where the water level occurs at a shallow depth. The total hardness of the selected samples shows a range from 86 mg/l in sample 1 to as high as 380 mg/l in sample 6 with that of the control well about 226 mg/l. Mg^{2+} concentration range from 15.5 mg/l to 52.2 mg/l. These values were observed to be higher than expected when compared with the WHO drinking water standard and the Nigeria drinking water standard. The level of ammonia increase has been linked with the decay of human body. The result of the analysis showed a steady increase in the ammonia concentration in sample 1 to sample 6, and a decline in the level of ammonia in wells 8 and the control well. The relative abundance of the anions was found to be in the following order $NO_3^- > HCO_3^{2-} > Cl^-$. NO^{3-} appears to be the most prevalent with an average concentration of 59.17 mg/l, which is higher than the safe limits of WHO and Nigeria drinking water quality specification of 50 mg/l. This is followed by HCO_3^{2-} (52.8 mg/l) and Cl^- (28.3 mg/l). NH_4^+ concentration value was found to be on the high side with an average value of 2.035 mg/l, a value far above the 1.5 mg/l WHO quality standard. So also, are the concentration of Mg^{2+} (23.459 mg/l), Ca^{2+} (83.98 mg/l) and Na^+ (143.71 mg/l) in that order. Only a few other cations and anions were found to be above the WHO's permissible level. Ca^{2+} levels in potable groundwater should be less than 75 mg/l. The values obtained from the study area are significantly greater than the WHO standard, making them unfit for human or household consumption. The high concentration is most likely due to the presence of leachate from the nearby cemetery, which seeps into the aquiferous strata in the area. All these results aligned with the findings of Neckel et al. (2021) on the effect of heavy metals on groundwater in the City of Carazinho, Brazil.

The Piper plot in Figure 4 shows the sources of dissolved constituents in water. According to the piper diagram, water samples fall within no-dominant to Na–K cations. Similarly, the anion triangle was scarcely distributed HCO_3–Cl type. Generally, the water samples of the study area reflect a mixed type on the diamond-shaped region, this reflects the

Table 1. : Geographic location and in-situ parameters.

WELL NO	Latitude (N)	Longitude (E)	pH	EC (μs/cm)	TDS (mg/l)	Temp (°C)	TBD	DTW (m)	DTB (m)	Elevation (m)	Comment
1	07° 33′.252″	004° 26′.864″	7.25	0.35	0040	26.37	Turbid			231.8	Down stream
2	07° 33′.256″	004° 26′.877″	7.16	0.38	0040	26.8	Turbid			240.9	Up stream
3	07° 33′.174″	004° 26′.946″	6.19	1.44	0170	29.7	Clear	1.5	3.1	231.2	Well inside a filling station
4	07° 33′.136″	004° 26′.946″	6.00	0.96	0110	28.0	Clear	1.3	2.7	227.8	Well directly by the side of the cemetery
5	07° 32′.997″	004° 26′.835″	6.15	1.32	0150	28.3	Clear	1.2	2.4	228.2	Well directly at the back of the cemetery(30m)
6	07° 32′.995″	004° 26′.945″	6.27	1.60	0170	29.2	Clear	3.3	5.3	244.2	Surface well by the side of the cemetery
7	07° 33′.138″	004° 26′.972″	6.13	1.00	0120	29.6	Clear	0.7	2.1	233.2	Surface Well directly in front of the cemetery(20m)
8	07° 33′.033″	004° 27′.021″	6.11	2.76	0310	29.8	Slightly turbid	4.1	4.6	239.1	Surface well close to a tomb, in front of a health center
9	07° 33′.887″	004° 27′.054″	6.10	2.17	0240	29.4	Clear	3.5	4.0	242.2	Surface well in front of a school far away from the cemetery.
10	07° 33′.000″	004° 27′.192″	6.31	2.30	0250	29.9	Slightly turbid	5.8	6.1	253.7	Control.

DTW = Depth to water, DTB = Depth to Bottom, TDS = Total Dissolved Solid, EC = Electrical Conductivity.

Table 2. : Table showing the physico-chemical parameters, cations and anions analyzed in the study area.

S/N	Parameters	Unit	S1 Stream	S2 Stream	S3 Well	S4 Well	S5 Well	S6 Well	S7 Well	S8 Well	S9 Well	S10 Well (C)	WHO	NSDWQ
1	Total Hardness $CaCo_3$	Mg/L	86.0	102	256	172	254	380	230	270	378	226	-	150
2	Calcium Hardness $CaCo_3$	Mg/L	44.0	36.0	124	96.0	156	196	156	194	164	126	-	-
3	Magnesium Hardness $CaCO_3$	Mg/L	42.0	66.0	132	76.0	98.0	34.0	74.0	76.0	214	150	-	-
4	Nitrate (NO_3)	Mg/L	53	64	65	76	86	49	54	71	73	0.7	50	50
5	Iron (Fe)	Mg/L	0.02	0.01	0.03	0.01	0.00	0.01	0.00	0.01	0.02	0.71	0.3	0.3
6	Alkalinity	Mg/L	42.0	30.0	68.0	48.0	60.0	76.0	52.0	58.0	46.0	48.0		
7	Manganese (Mn)	Mg/L	0.06	0.12	0.02	0.02	ND	0.01	0.03	0.02	0.03	0.03	0.4	0.2
8	Calcium (Ca^{2+})	Mg/L	87.6	84.4	89.7	88.5	82.5	88.6	82.5	89.8	75.7	70.5	75	75
9	Magnesium (Mg)	Mg/L	10.2	16.1	32.2	18.5	23.9	8.29	18.1	18.5	52.2	36.6	0.1	0.20
10	Sulphate (SO_4^{2-})	Mg/L	1.00	0.00	0.00	1.00	16.0	1.00	0.00	4.00	10.0	0.00	250	100
11	Chloride (Cl^-)	Mg/L	14.0	15.0	39.9	20.0	48.9	47.9	26.0	98	90.0	67.0	250	250
12	Sodium (Na)	Mg/L	59.10	280.5	225.9	213.0	131.8	231.1	116.9	76.7	58.5	43.6	200	200
13	Bicarbonate (HCO_3)	Mg/L	42.0	30.0	68.0	48.0	60.0	76.0	52.0	58.0	46.0	48.0	250	250
14	Potassium (K^+)	Mg/L	3.41	2.89	5.87	2.11	6.21	5.92	3.04	12.8	10.6	8.87	10	10
15	Chromium(Cr^{6+})	Mg/L	0.21	0.07	0.09	0.05	0.03	0.07	0.09	0.12	0.07	0.07	0.05	0.05
16	Copper (Cu^{2+})	Mg/L	0.02	0.03	0.02	0.01	0.04	0.02	0.03	0.02	0.04	0.05	2	1
17	Flurie (Fl)	Mg/L	0.48	0.53	1.29	0.76	0.13	0.34	0.64	0.48	0.20	0.02	1.5	-
18	Ammonia (NH_3)	Mg/L	4.04	3.03	3.04	2.66	2.21	3.16	1.99	0.04	0.09	0.09	1.5	-
19	Carbonate (CO_3^{-2})	Mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-
20	Faecal *streptococci*	Cfu/100ml	3	4	0	0	0	0	0	0	0	0	-	0
21	Total Coliform	Cfu/100ml	72	89	34	29	53	27	18	22	14	9	10	10
22	E-coli	Cfu/100ml	4	6	3	2	2	3	2	1	0	0	0	0

(WHO, World Health Organisation, NSDWQ, Nigerian Standard of Drinking Water Quality).

anthropogenic influence brought about by the interaction from different sources, typically from contaminant loading in the cemetery combined with the chemistry of the local aquifer solids.

The fact that mixed water type prevails in the study area was further supported by the Durov diagram (Figure 5). Most samples plot in the central field of the Durov plot along the dissolution or mixing line. This as

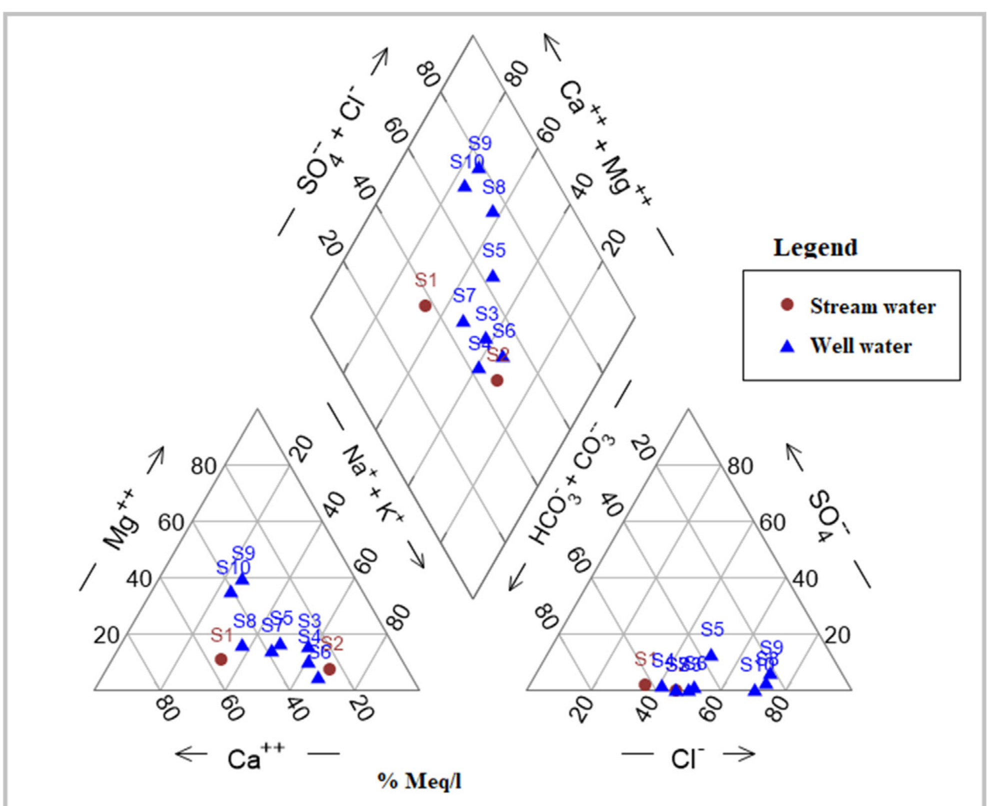

Figure 4. Sources of water according to Piper diagram.

opined by Ravikumar et al. (2015) can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing with no dominant major anion or cation.

5.2. Geophysical investigation and geo-electric sections

The result of the geophysical investigation is shown in Table 3. Eight vertical electrical sounding (VES) surveys were conducted to investigate the depth of the contamination/pollution. From the investigation, the lithology reveals a thin layer of clayey sand to sandy topsoil that ranges in thickness from as low as 0.25 in VES 7 to as high as 1.56 m in VES 4 and resistivities of as low as 46.6 Ωm in VES 4 to as high as 97.72 Ωm in VES 2. This is closely underlain by a clayey sand/clay interval in certain points having high porosity but, in most cases, the second geo-electric layer constitutes the aquiferous layer and exhibited very low resistivity values that range from 3.18 in VES 3 to 37.6 Ωm in VES 5. This is indicative of the fact that there exists a high conductivity anomaly within the aquiferous zone. The depth to contamination varies from 2.1 m around the stream to around 3.9 m in other places, which corresponds to the depth of the aquifer in the study area, as outlined according to geophysical investigation. It is obvious that the leachate from the decaying cadavers has penetrated the aquiferous layer within the subsurface, thereby contaminating the subsurface water. This is evident in the rise of the values of the conductivity (EC) obtained in the sampled groundwater taken in the vicinity of the cemetery with prominent ions such as ammonia, magnesium ion, and nitrate ions shooting above the acceptable WHO and NDWS standards. These values were, however, observed to be different from what is obtained from the control well located about 700 m away from the cemetery.

The geo-electric sections of the study area are presented in the supplementary section (S2 and S3). The geo-electric section reveals that the entire study area is overlain by thin, low resistivity topsoil with values ranging from 52.7 Ω m in VES 8–110.7 Ω m in VES 4 and a thickness of between 0.5 m in VES 1–1.2 m in VES 3. This is followed by a thin clayey layer in VES 1, 2, 3, 4, and 7,a lateritic layer in VES 5, and a weathered layer in VES 6 and 8. Below the thin clayey/weathered layer lies in a region of the fresh basement. From the geo-electric section, it can be seen the level of contamination has gone deep down to the top of the fresh basement, an area that corresponds to the depth of the aquiferous layer. The only exception to the aquifer is in VES 1 where the contamination extends to the top of the weathered layer. The depth of contamination varies from a depth ranging from 0.9 m in VES 4 to 3.18 m in VES 2.

5.3. Soil investigation

a) Index properties of the soils

The WHO (1998) report on impact cemeteries stressed the importance of soil selection and thickness of the unsaturated zone. These two have been found to be an important factor in determining the impact of cemeteries on their immediate environment. Hence the following result gives an overview of the unsaturated zone condition as it relates to soil selection.

The result of the index properties of the soils is summarized in Table 4. Soils within the study area are classified within the well-graded gravel (GW) to well-graded sand with silt (GW-GM) of the unified soil classification (USC) system. By implication, the soils in the area are expected to have poor compaction characteristics, high porosity, and high permeability which translate to poor physical characteristics for cemetery siting (Goodary et al., 2012; Spongberg and Becks, 2000; Hall and Hanbury, 1990). The prevailing soil conditions as reflected in the soil classification will greatly enhance the diffusion and rapid percolation of contaminants in the soil as well as the environment.

According to the particle size distribution curve shown in Figure 6, the coarse fraction which corresponds to sand and gravel particles ranged between 92 and 98% with an average of 95% while the percentage of fine ranged between 0 and 8% with an average of 5%.

Over the years, some limited but valuable recommendations have been given for soils to serve as a suitable material for a safe sitting of the cemetery for example, Boyd 2002, recommended soils of about 5–10 m in clay and 20 m or more in sand. It is clear from the above results that none of the soil samples obtained is in agreement with the specification.

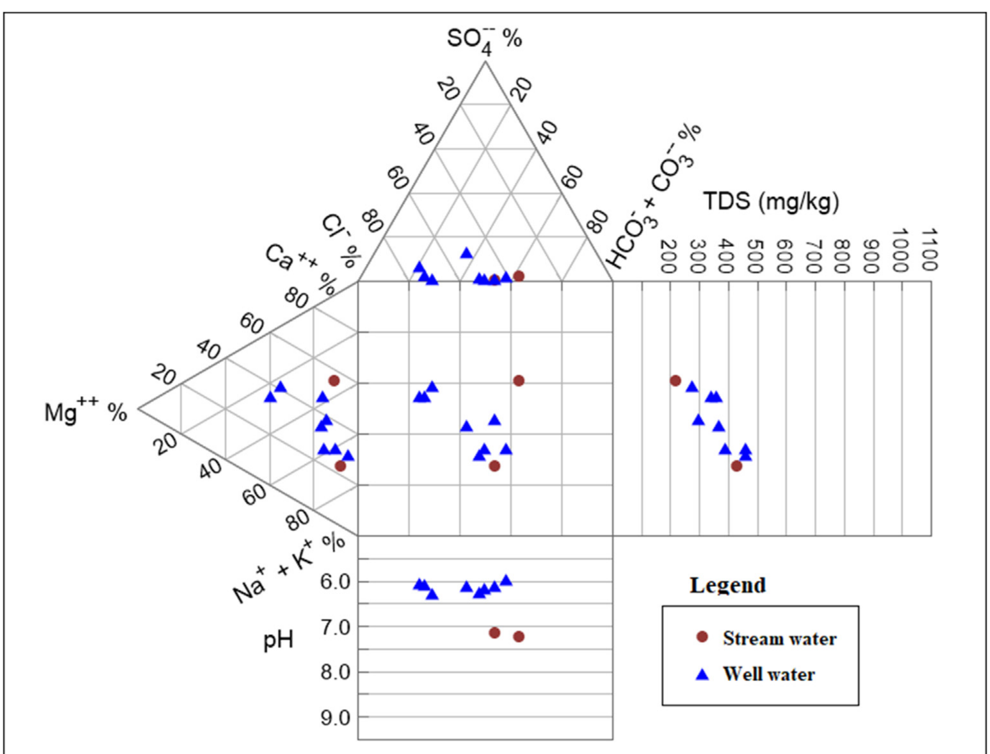

Figure 5. Durov diagram showing zones of hydrogeochemical water types.

Table 3. The summary table of the interpreted resistivity values.

S/N	CURVE TYPE	RES (Ωm)	THICK. (m)	DEPTH (m)	LITHOLOGY
VES 1	KHA	54.6	0.35	0.35	Contaminated sand top soil
		272	0.57	0.92	Contaminated Clayey sand layer
		13.7	1.22	2.14	Contaminated Weathered layer
		462	44.9	47.1	Lateritic layer
		21962			Fresh basement bedrock
VES 2	KA	97.72	0.98	0.98	Contaminated Clayey sand top soil
		27.63	2.73	3.71	Contaminated Weathered layer
		845.1	59.63	63.34	Fresh Basement
		72.89	-	-	Fractured layer
VES 3	QA	97.5	0.49	0.49	Contaminated Clayey sand Top soil
		3.18	0.37	0.86	Contaminated Weathered layer
		865	-	-	Fresh Basement
VES 4	KA	46.6	1.56	1.56	Contaminated sand top soil
		333	11.5	13.1	Lateritic layer
		91849	-	-	Basement rock
VES 5	A	69.6	0.94	0.94	Contaminated clayey sand top Soil
		37.6	3.05	3.99	Contaminated Weathered layer
		13685	4.95	8.94	Basement rock
		62.5	-	-	Fractured layer
VES 6	HA	81.58	1.201	1.201	Topsoil
		12.17	1.201	2.402	Contaminated Weathered layer
		229.5	9.145	11.55	Lateritic layer
		21480	-	-	Basement rock
VES 7	A	56.3	0.25	0.25	Contaminated clayey sand top Soil
		550	0.40	0.65	Contaminated Sandy clayey layer
		13.6	1.60	2.25	Contaminated weathered layer
		8340	-	-	Basement rock
VES 8	A	49.3	1.1	1.1	Contaminated clayey sand top Soil
		8.01	0.727	1.83	Contaminated weathered layer
		2432	-	-	Basement rock

The result of the Atterberg limits as presented in Table 4, shows that the liquid limit of soils ranges from 40 to 54.4% while the plastic limit ranges from 16.02 to 26.31%. Liquid limits of 40.0–60.0% and above are generally of clay soils as outlined by British Standard (BS) 1377 of 1990. The plasticity chart in Figure 7 shows that majority of the soil samples fall within the inorganic clay and silt of medium plasticity and compressibility. Plasticity chart reveals samples ED1A and ED2B plot below the A-line, this by the earlier works of Huang et al. (2009) could suggest the possibility of increased organic content in the soils. With a reasonable amount of organic content in the soil, the soil is expected to have high porosity and permeability due to the weak structure of the resulting soil. The low specific gravity (peculiar to organic soils) of the soils in the study area is expected to result in an increase in the soil porosity and permeability and a decrease in the compaction strength of the soil. Thus, this condition will enhance the diffusion of contaminants through seepage to the surrounding environment causing pollution.

The topographical slope of the area under study indicates that fluid is expected to move from Pit 1 to Pit 2 with a higher coarse grain fraction, as indicated by the grain size results, allowing contaminants to diffuse into the environment, as evidenced by the increased moisture content of soils in Pit 2. The results of the index properties of the soil in the study area are generally such that can cause major contamination to the environment and are thus unsuitable for a safe cemetery sitting. The result of soil porosity ranges between 93.4 and 95.2%. Porosity results confirmed the earlier suspicion that the higher coarse fraction will be responsible for high porosity thereby exposing the area to pollution due

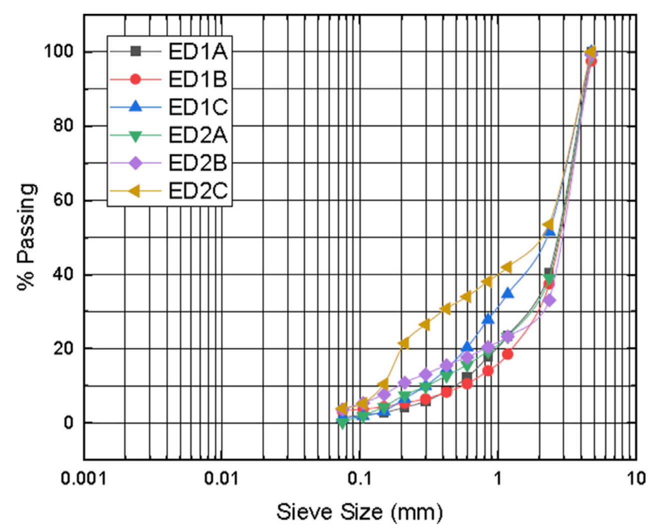

Figure 6. Grain size particle distribution curve.

Table 4. Index properties of the soils in the study are.

Sample Number	Specific Gravity	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Amount of Fines (%)	Amount of Coarse (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	NMC	USCS
ED1A	2.38	66	30	3	1	4	96	46.0	22.53	23.47	19.90	GW
ED1B	2.52	70	24	4	2	6	94	40.0	23.33	16.67	16.96	GW-GM
ED1C	2.26	54	43	2	1	3	97	48.0	19.91	28.69	14.63	GW
ED2A	2.14	67	31	2	0	2	98	45.3	16.02	29.28	20.0	GW
ED2B	2.10	71	21	6	2	8	92	54.4	26.31	28.09	24.4	GW-GM
ED2C	-	52	41	5	2	7	93	44.1	19.99	24.11	25.0	GW-GM

GW–Well graded gravel, GW–GM- Well graded sand with silt.

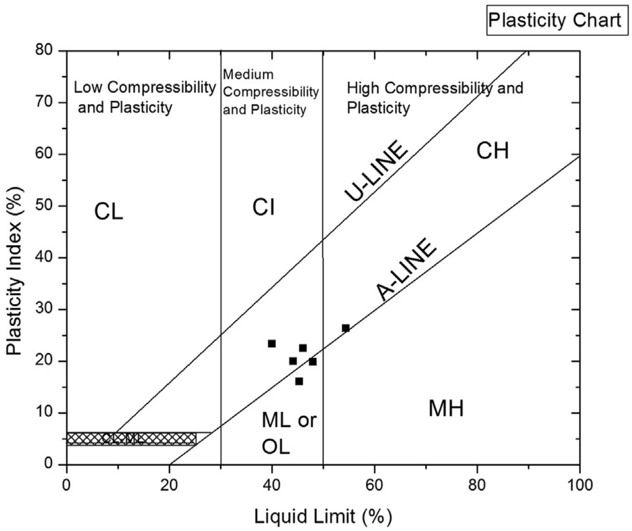

Figure 7. Plasticity charts of soil samples.

to rapid percolation of fluid with reduced duration of fluid movement. This condition affects the rate of natural attenuation of leachates thereby enhancing the free flow of contaminants into the groundwater. According to Kemerich (2012), Neckel et al. (2017 and 2021), and Silva et al. (2020) the increase in mortality rates due to global pandemics, especially the recent COVID-19, and the need to create urban cemeteries hastily has significantly worsen soil contamination in cemeteries, compromising the quality of life of the surrounding population. This is further compounded if the soil does not contain the appropriate clay size fractions that would have held the grains together.

b) Engineering properties of the soils

Table 5 presents the results of the engineering properties of the soil. The compaction test shows that the maximum dry unit weight (MDD) of the soil ranges between 0.98 and 1.53 (Mg/m^3) while the optimum moisture content (OMC) ranges from 3.45 to 26.32 %. These soils are capable of achieving low compaction densities and a higher optimum moisture content. Low MDD and high OMC show that the soil has a low amount of clay because, the presence of a reasonable amount of clay would have caused the soil to achieve significant MDD. Due to the reduced quantity of clay, the percentage of the soil porosity may be high coupled with the established high coarse soil fraction which can encourage the diffusion of contaminants.

Porosity is closely related to permeability, high porosity in sand grains will lead to high permeability, hence the permeability result ranges between 0.027 and 0.432 cm/s (Table 5). Such a high permeability rate aligns with the initial works of Fineza et al. (2014), and is not suitable for the safe sitting of a cemetery because of the immediate environment. Fisher (1994) recommended that for a safe sitting of a cemetery, the underlying soils should have low permeability (10^{-5}–10^{-6} cm/sec) to prevent groundwater contamination. However, it is seen from the above that the result falls within (10^{-1}–10^{-2} cm/sec) which reflects its non-suitability for safe sitting of a cemetery. In recent times, burial practices have been attributed to an outbreak of deadly viral diseases especially the highly contagious haemorrhagic diseases like Lassa fever and Ebola disease (www.punchng.com, accessed 03-08-2018). This has been confirmed by the recent findings of Toscan et al. (2021) and Neckel et al. (2021). There is an urgent need to prioritise standard regulations in siting cemeteries and general burial practices around countries in Africa.

c) Mineral and Chemical Properties

The result of the XRF analysis indicates the major elements present in the soil sample. These are highlighted in Table 6. In order of abundance, it includes Si, Al, Fe, Ti, K, Mg, and Ca. Other minor elements include; Cr, Cu, V, and P. The result reveals a significant reduction in the amount of Si, Al, and Fe from Pit 1 to Pit 2 due to the topography and drainage conditions of the area. As the fluid move from higher topography to the lower one (Pit 2), there seems to be more dissolution of elements and increase in the amount of clay. The significant proportions of oxides of calcium and phosphorus prove that the calcitic and apatitic minerals occur in reasonable quantity. XRD results as shown in Table 6 reveals major minerals common in the soil samples are microcline, quartz, and kaolinite. These minerals occur in variable quantities because of the prevailing conditions of the area.

This further strengthens the earlier claim that topography and drainage conditions are responsible for variations. Mobile elements (Ca, Mg and Na) seem to be enriched while common elements (Si, Al, and Fe) deplete as one moves from Pit 1 to Pit 2. Clay minerals such as smectite and sepiolite are present in pit 2 in the study area. This mineral increases the plasticity of the soil materials, while smectite because of its swelling properties could act as a blind or potential seal, other clay minerals like kaolinite and sepiolite are non-swelling clays (Oyelami and Van Rooy, 2018).

The absence of some mineral species in one site compared to another could be explained by the topographical gradient. Additional minerals such as actinolite, smectite, sepiolite, and plagioclase were detected in pit 2, which has a shallow water level depth, although they were lacking in pit 1. It is expected that oxides of Fe^{3+} will be abundant in an oxygen-rich environment, particularly where the water level is at a distance from the

Table 5. Engineering properties of the soils in the study area.

Sample Number	OMC (%)	MDD (Mg/m^3)	Porosity	Permeability (cm/sec)
ED1A	3.45	1.53	93.4	0.363
ED1B	13.36	1.05	95.7	0.432
ED1C	21.26	1.03	95.3	0.115
ED2A	18.81	0.98	95.2	0.108
ED2B				0.043
ED2C	26.32	0.99	95.2	0.027
RANGE	3.45–26.32	0.98–1.53	93.4–95.7	0.027–0.432
AVERAGE	16.64	1.12		0.181

Table 6. Major oxides and Mineralogy of the soils.

Major Elements			Minerals		
	Pit 1 (%)	Pit 2 (%)		Pit 1 (%)	Pit 2 (%)
S_iO_2	51.10	49.76	Hematite	0.54	–
T_iO_2	1.21	1.98	Kaolinite	49.49	12.88
Al_2O_3	22.12	20.01	Muscovite	11.19	–
Fe_2O_3	11.22	9.56	Quartz	20.57	7.69
MnO	<0.01	<0.01	Actinolite	–	4.5
M_g O	0.89	2.37	Microcline	18.21	6.81
CaO	0.65	3.73	Smectite	–	34.8
Na_2O	0.11	1.96	Sepiolite	–	9.72
K_2O	3.07	1.85	Plagioclase	–	23.55
CrO_3	0.04	0.03	–	–	–
P_2O_5	0.04	0.51	–	–	–
NiO	0.01	<0.01	–	–	–
V_2O_5	0.04	0.04	–	–	–
ZrO_2	0.07	0.02	–	–	–
CuO	<0.01	<0.01	–	–	–
LOI	9.46	7.81	–	–	–
Total	100.03	99.63	–	–	–

surface, as opposed to those where the water level is close to the surface. Thus, in pit 1, we have Fe_2O_3 of 11.22 % whereas in Pit 2 it is 9.56 %, kaolinite reduced from 49.49 to 12.88%, muscovite from 11.19 to 0%. Equally, in regions where we have shallow water levels, it is also expected that oxides of Ca and Mg should be of significant quantity in solution. Thus, in Pit 2 where the water level is close to the surface, we have CaO and MgO occurring at 3.73 and 2.37% respectively compared to pit 1 where they occur at 0.65 and 0.89% respectively. In terms of cemetery safety, these findings have a negative rather than beneficial impact. The only benefit it provides is when smectite is present, a swelling clay that has the capacity to prevent leachates from decomposing bodies from entering the groundwater. Near-surface water levels, which operate as a transport medium for leachates in solution and expedite the interaction between leachates and groundwater, vastly outweigh this advantage. Although it might be argued that moving leachate is neutralized by water, this depends on the load and type of leachate.

6. Conclusions

In this research, an attempt was made to characterize the unsaturated zone around St. Peter's cemetery in Edunabon, southwestern Nigeria, and its environment via an approach that integrates the use of hydrogeological, hydro-geophysical, and geotechnical techniques. The unsaturated zone has been shown to be one of the most essential variables in environmental protection in this study.

The findings suggest that the thickness of the unsaturated zone, or lack thereof, determines the rate and impact of contaminants and leachates on the immediate environment to a great extent. The presence and ability of swell clay minerals (e.g. smectite) to attenuate contaminants is largely dependent on the thickness of this zone. The unsaturated zone is where most of the biodegradation of organic components takes place, and a thicker zone enhances the chances of leachate attenuation while thin zones of the subsurface increase the potential of leachate to move into the surrounding rocks.

The rate of percolation and movement of leachates from the decomposing body is controlled by the index properties of soils in the vicinity of cemeteries. Coarse soil fractions are inherently porous and permeable for the most part (except in a few cases). For the safe sitting of cemeteries, soil stabilization through the introduction of soils rich in clay content/mineral (smectite, for example) is recommended.

Common practice (especially in Africa) of siting cemeteries close to river channels and natural drainages should be discouraged. This practice is responsible for incessant outbreaks of communicable diseases, especially during the peak periods of the wet season.

More attention should be given to standards and regulations of sitting cemetery in and around residential areas. It is finally recommended that the effect of burial practice on the quality of air be investigated to ascertain the presence of contaminants on UFPs.

Declarations

Author contribution statement

Olabanji A. Ojo & Charles A. Oyelami: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mutiu A. Fakunle, Ayodeji K. Ogundana, Oluwole E. Ajayi & Tochukwu E. Uche: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

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