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Exploring the Impact of Cemetery Leachates on Groundwater Quality in Benin City Metropolis, South-South Nigeria

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Abstract

Worldwide, research conducted under various time frames and environmental circumstances consistently identifies leakage from cemeteries as a significant contributor to groundwater contamination. The study evaluated the quality of groundwater from selected boreholes around second cemetery in Benin City metropolis, using electrical resistivity approach and water quality assessment method. Groundwater samples were collected randomly from fifteen (15) different boreholes around second cemetery. The water samples were analyzed in triplicates to obtain the mean value and standard deviation of each water quality test parameters. For the analysis of the water quality data, the average weighted index method was employed to estimate the overall water quality index (WQI) of individual boreholes. Factor analysis was use to analyse the information content of the water quality indicators in order to get reasonable information on the critical water quality parameters that requires adequate attention towards improving the overall groundwater quality around second cemetery. The spatial distribution of the WQIs was determined using Inverse Distance Weighting (IDW) while hydro-geochemical facies were inferred using an adaptation of the Piper-Hill diagram. The profile maps from both traverse obtained from the electrical resistivity data confirmed the cemetery operations as the source of the leachate plume resulting to the contamination of the subsoil. Evaluation of the WQIs indicated that more than 70% of the water samples collected around second cemetery was unsuitable for consumption and the degree of suitability of the borehole water was found to be positively correlated with distance from the cemetery. The outcome of the principal component analysis (PCA) revealed that; calcium, electrical conductivity, iron, dissolved oxygen, nitrite, chloride, pH, nitrate, sodium, zinc, sulphate, copper and carbonate are the parameters mostly affected by necroleachate from human decomposition. Hydrochemical analysis result shows that the origin and geochemical composition of the groundwater varied spatially. The types of water that have been identified include Ca-Cl_2, Mg-Cl_2, Ca-Mg-Cl_2, and Mg-Ca-SO_4

1. Introduction

Groundwater stands as a significant reservoir of water resources [1, 2, 3, 4, 5]. Groundwater refers to water situated beneath the Earth's surface within soil pores and rock fractures. Constituting approximately 30% of the global fresh water supply, it serves the water requirements of roughly 30% of the population [6, 7]. The reliance of groundwater stems from the prevailing issues of pollution and scarcity that is often associated with surface water [8, 9, 10]. Groundwater stands out as the foremost vital element in the hydrological cycle, constituting approximately two-thirds of the world's freshwater resources, including those of Nigeria [2, 11]. Groundwater plays a pivotal role as a primary source of potable water for communities worldwide, presenting several advantages compared to surface water alternatives. It is inherently cleaner due to its effective self-purification and ease of treatment [12, 13, 14].

Despite its resilience, human activities pose significant threats to the purity of groundwater. Urban areas, in particular, face groundwater pollution primarily from leachates seeping from municipal waste dumpsites and cemeteries [14, 15, 16]. Various studies have documented the presence of organic, inorganic, and microbial pollutants in groundwater, prompting extensive efforts toward remediation [17, 18]. The need for sustainable management and protection of groundwater resources is emphasized, with a focus on the development of effective policies and governance arrangements [19, 20]. Despite these challenges associated with groundwater pollution, the significant role of groundwater in supporting human welfare and livelihoods underscores the urgency of addressing these issues [21, 22]. The ingress of pollutants into groundwater aquifers not only compromises water quality but also poses significant health risks to human populations reliant on these resources for drinking and other domestic purposes [23]. Research conducted under various time frames and environmental circumstances consistently identifies leachate from cemeteries as a significant contributor to environmental pollution [2, 14, 15]. Cemeteries are identified as potential origins of soil and groundwater pollution [24, 25, 26]. The elevated precipitation levels characteristic of Nigeria's coastal areas, along with apparent neglect of burial sites, contribute to the rapid dissemination of necroleachate in and around cemetery sites [27].

The movement of detrimental substances like necroleachate in the soil depends on factors such as burial frequency, groundwater depth, soil permeability, including the composition of clay minerals and their ability to exchange particles [28]. Necroleachate resulting from human decomposition serves as significant sources of harmful heavy metals, presenting serious risks to both human health and the environment [12, 29, 30, 31, 32].

Elevated concentrations of heavy metals in soil, regardless of their ionic or organometallic form, can pose threats to human and animal health [33]. For instance, prolonged exposure to cadmium through drinking water can lead to various health complications [34]. Similarly, extended exposure to mercury has been associated with damage to the heart, kidneys, digestive system, as well as the central and autonomic nervous systems [35, 36]. These substances can be carried from burial sites via seepage, penetrating surrounding soils, and potentially leaching into groundwater, posing health hazards to residents reliant on the contaminated water for different purposes. According to studies, the ecology may suffer from the poor placement of cemeteries and a lack of measures to prevent the transfer of contaminants [37]. Aquifer protection depends on how permeable the underlying medium is to the transmission of contaminants into subordinate aquifer units [38, 39]. The rate and amount of leachate intrusion are mostly determined by how easily contaminants can travel through the subsurface strata beneath the cemetery and its surroundings. The consumption of polluted water presents a significant risk of waterborne illnesses, as demonstrated by the prevalence of diseases like typhoid and diarrhea. These health concerns are exacerbated by the absence of access to fundamental water treatment techniques and the lack of awareness among users regarding the dangers associated with drinking such water [40, 41, 42].

This study's uniqueness lies in its examination of the distinct influence of cemetery leachates on the groundwater quality within the Benin City Metropolis in south south Nigeria. While previous research may have addressed groundwater contamination in urban areas or studied various sources of contamination, this study focuses explicitly on the influence of cemetery leachates. By narrowing the scope in this manner, the research can provide targeted insights into the extent and nature of groundwater pollution attributable to cemetery activities. This specialized focus allows for a more thorough understanding of the potential risks posed by cemetery leachates to groundwater quality in the region.

2. Research Methodology

2.1 Description of study area

The focus of this research is Benin City, chosen due to its significance as the capital of Edo State. Positioned as a nodal town, it stands as one of the largest cities in Nigeria. Situated between latitude 6°20′17″ N and longitude 5°37′32″ E, the city resides in the southern part of the country, boasting an elevation of 88 meters above sea level. Benin City experiences two distinct seasons: the wet season, which extends from March to October, and the dry season, which lasts from October to March. As of the 2006 national census, the city was home to a population of 1.15 million individuals. Mainly populated by the Bini-speaking people of Edo ethnic nationality, Benin City is anticipated to reach a population of 5.5 million by the year 2050. This projection is based on the National Population Commission's urban growth rate of 3.5% per annum. Within the city, there are three main public cemeteries: the 1st Cemetery, 2nd Cemetery, and 3rd Cemetery. The 1st and 3rd Cemeteries are situated in the Ikpoba-Okha local government area, while the 2nd Cemetery is located in the Oredo local government area. Figure 1 provides a 3D-study area map depicting the spatial arrangement of these cemeteries. For this study, the second cemetery was used for data collection

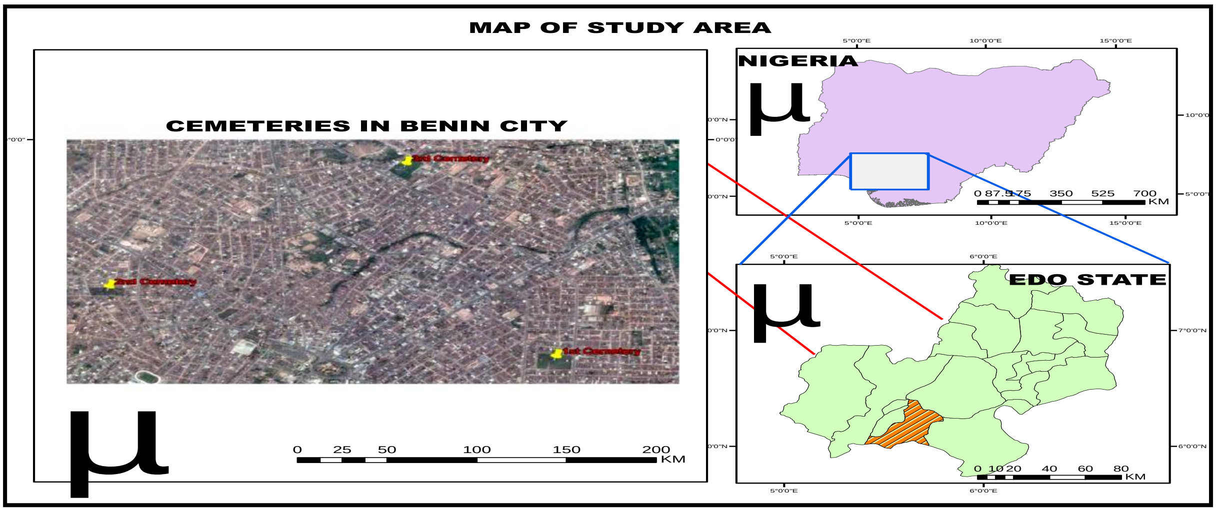

Figure 1: Study area map showing the three cemeteries

2.2 Geophysical Investigation using Dipole-Dipole Approach

The ERT resistivity survey around the second cemetery in Benin City utilized the ABEM Terameter SAS 300C, global positioning systems (GPS) for coordinate and elevation measurements, DIPRO application version 4.01 for 2-D resistivity inversion, and Surfer Software program for contouring.

Geophysical approach was employed to delineate the geological formation of the subsurface soil around the cemetery and map pollution of the subsoil [43, 44, 45]. Two transverse lines (TR1-TR2) running in the NE-SW direction were established along which 2-D imaging was conducted. Data acquisition for the 2-D imaging was performed using the Dipole-Dipole array with a dipole length (a) ranging between 0 and 100m and expansion (n) varying from 1-5m [43, 46, 47]. Four electrodes were employed, driven into the ground to a depth of 1m using a hammer and a steel pin, with a spacing distance of 10m. Insulated wires were used to linked the electrodes to the resistivity meter which was applied for monitoring the current and voltage for each electrode pair [48, 49, 50]. Direct current was sent into the ground through the pair of current electrodes (C_1 and C_2), while the other pair of potential electrodes (P_1 and P_2) measured the potential difference created as observed in Figure 2. During the procedure, the apparent resistance (Ra) of the geological materials penetrated was monitored from the crystal display of the resistivity meter. The geometrical coefficient (G) for the electrode location in a dipole-dipole array was determined using an equation reliant on the distance between the electrodes [51];

$$G = \pi \frac{\left[\left(\frac{C_1C_2}{2}\right)^2 - \left(\frac{P_1P_2}{2}\right)^2\right]}{P_1P_2} \tag{1}$$

The apparent resistivity (ρa) was determined by multiplying the apparent resistance (Ra) with the geometric factor G, as outlined in equation (2) [48, 49, 50].

$$\rho_a = \pi \frac{\left[\left(\frac{C_1C_2}{2}\right)^2 - \left(\frac{P_1P_2}{2}\right)^2\right]}{P_1P_2} R_a \tag{2}$$

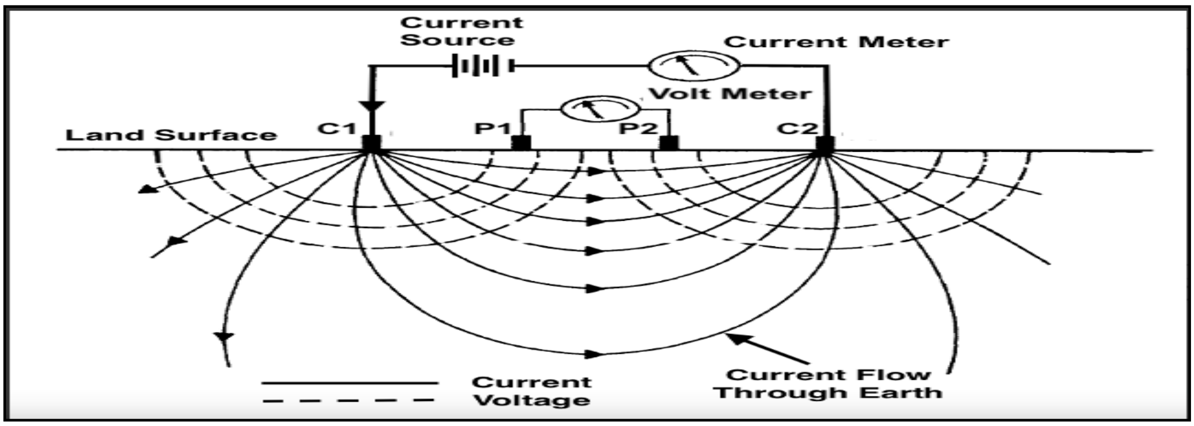

Figure 2: Dipole-Dipole array

2.2 Groundwater Sample Collection

To delineate the boundary of the developed area (land use) within the vicinity of the second cemetery, a digital mapping process was employed, with grids set at 200-meter intervals to establish sampling points, ensuring even coverage. For precise geo-referencing of identified boreholes, Garmin hand-held GPS receivers were utilized to ascertain the geographical coordinates of each borehole. Sampling of water was conducted from fifteen (15) boreholes selected randomly. Prior to collection, air-tight, clean, and dried plastic containers were rinsed thoroughly with water from the respective boreholes, ensuring cleanliness. The collected samples were appropriately labeled and stored in air-tight, clean, and dried plastic containers, then transported to the laboratory for analysis following standard procedures and guidelines recommended by the World Health Organization (WHO). Each water quality parameter was analyzed in triplicates to determine the mean value and standard deviation. To analyze biochemical oxygen demand (BOD), the water samples were kept in opaque bottles to prevent photosynthesis and oxygen generation prior to analysis. Additionally, in-situ parameters including dissolved oxygen (DO), temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured on-site to prevent inaccuracies in measurement values

2.3 Water Quality Analysis

For in-situ parameters, namely; electrical conductivity (EC), total dissolved solids (TDS), pH and temperature portable multi-parameters water quality tester was employed while dissolved oxygen was measured using DO meter (Lutron DO-5509). The concentration of heavy metals presents in the water samples, namely; Fe, Mn, Zn, Cu, Cr, Cd, Ni, Pb, and V was determined using Atomic absorption spectrometer (UNICAM 969) presented in Figure 3 while the UV visible spectrophotometer (Thermo Scientific Spectronic 20D+) presented in Figure 4 was used to analyzed the level of phosphorous (P), Nitrate (NO_3), Nitrite (NO_2) and Sulphate (SO_4).

Figure 3: UNICAM 969 AA Spectrometer

Figure 4: UV Visible Spectrophotometer

2.4 Statistical Analysis of Water Quality Parameters

A metric known as the water quality index was employed to assess the overall quality variation of water samples collected from different boreholes. This index was derived by analyzing approximately twenty-two (22) physico-chemical parameters. The methodology for calculating the water quality index involved several key steps:

1. Estimation of the parameters weightage using the equation proposed by Shweta et al., 2013 as follows;

$$W_n = \frac{1}{S_n} \quad (1)$$

W_n is the unit weight of the different parameters tested
S_n is the standard values of selected parameters (WHO Standard Permissible Limit)

2. Determination of the quality rating or sub index of selected parameters using the modified version of the rating proposed by [43] as follows:

$$q_n = \frac{100(V_n - V_{io})}{(S_n - V_{io})} \quad (2)$$

q_n is the quality rating or sub index
V_n is the laboratory test result for each parameter tested
S_n is the standard value of each parameter tested (WHO standard for drinking water)
V_{io} is the ideal value of selected parameters tested (in pure water V_{io} = 0 for all parameters tested except pH and dissolved oxygen which is 7.0 and 14.6 respectively.

3. Estimation of the Water Quality Index (WQI) using

$$\text{WQI} = \left(\frac{\sum W_n . q_n}{\sum W_n}\right) \quad (3)$$

To glean significant insights into crucial water quality parameters necessitating attention to enhance groundwater quality around the second cemetery, principal component analysis (PCA) was employed. PCA offers a method for identifying the most critical parameters describing the entire dataset while minimizing data loss. The spatial distribution of these critical groundwater quality parameters, as discerned by PCA, was depicted using a geostatistical approach employing the inverse distance weighting method (IDW). For characterizing the hydro-geochemical facies of groundwater near the cemetery, a Piper-Hill diagram was utilized. The placement of an analysis plotted on a Piper diagram allows for preliminary conclusions regarding the water's origin. The initial step in data preparation for generating the Piper plot involved converting the anions and cations from mg/L to Meq/L using:

$$\text{Conc. (Meq/L)} = \frac{\mathit{conc.}\ \text{(Mg/L)} \times \text{Valence}}{\mathit{Atomic}\ \text{Weight}} \quad (4)$$

The conversion from Mg/L to Meq/L account for the balance for ions attached to each primary ion in the water sample. It was important that the data are also normalized to percent of the total ions. The percentage for each ion was calculated relative to the total cations or anions using;

$$\text{Relative Conc. (Meq \%)} = \frac{\mathit{Cation}\ \text{conc. (Meq/L)} \times 100}{\mathit{Sum}\ \text{of all cation concentration (Meq/L)}} \quad (4)$$

3. Results and Discussion

3.1 Dipole-Dipole Investigation

Resistivity data from transverse 1 were employed to generate the 2-D dipole-dipole profile maps presented in Figures 5 and 6. Observations from the profile maps indicate that the surface of the study area has low resistivity (34Ωm to 180Ωm), which increases with depth. Leachate plumes, observed at depths of 5 to 20 meters, have traveled horizontally to approximately 70m to 120 meters in a northeastern (NE) direction. The topsoil in this horizontal distance range is presumed to be heavily contaminated with necroleachate from cemetery activities. Similarly, resistivity data from transverse 2 were also employed to generate the 2-D dipole-dipole profile maps presented in Figures 7 and 8. For transverse 2, resistivity data reveals low values (48.8Ωm to 77.1Ωm) at the surface, increasing with depth. Necroleachate was detected at depths of 0 to 10 meters, having traveled horizontally to approximately 20m to 30 meters with a resistivity range of 7.98Ωm to 26.8Ωm. The 2-D dipole-dipole profile map confirms the northeast (NE) direction of leachate movement. The outcome indicates the presence of a necroleachate plume at depths of 5 to 20 meters and 0 to 10 meters, respectively as illustrated in Figures 5, 6, 7 and 8. The profile maps from both traverse confirmed the cemetery operations as the source of the leachate plume, specifically exposing the activities at a depth of 5 to 20 meters for traverse 1 and the presence of the plume from the surface to a depth of 0 to 10 meters for traverse 2. Necroleachate resulting from the decomposition of dead bodies contains heavy metals and other toxic substances due to the decay of coffin material [15, 28].

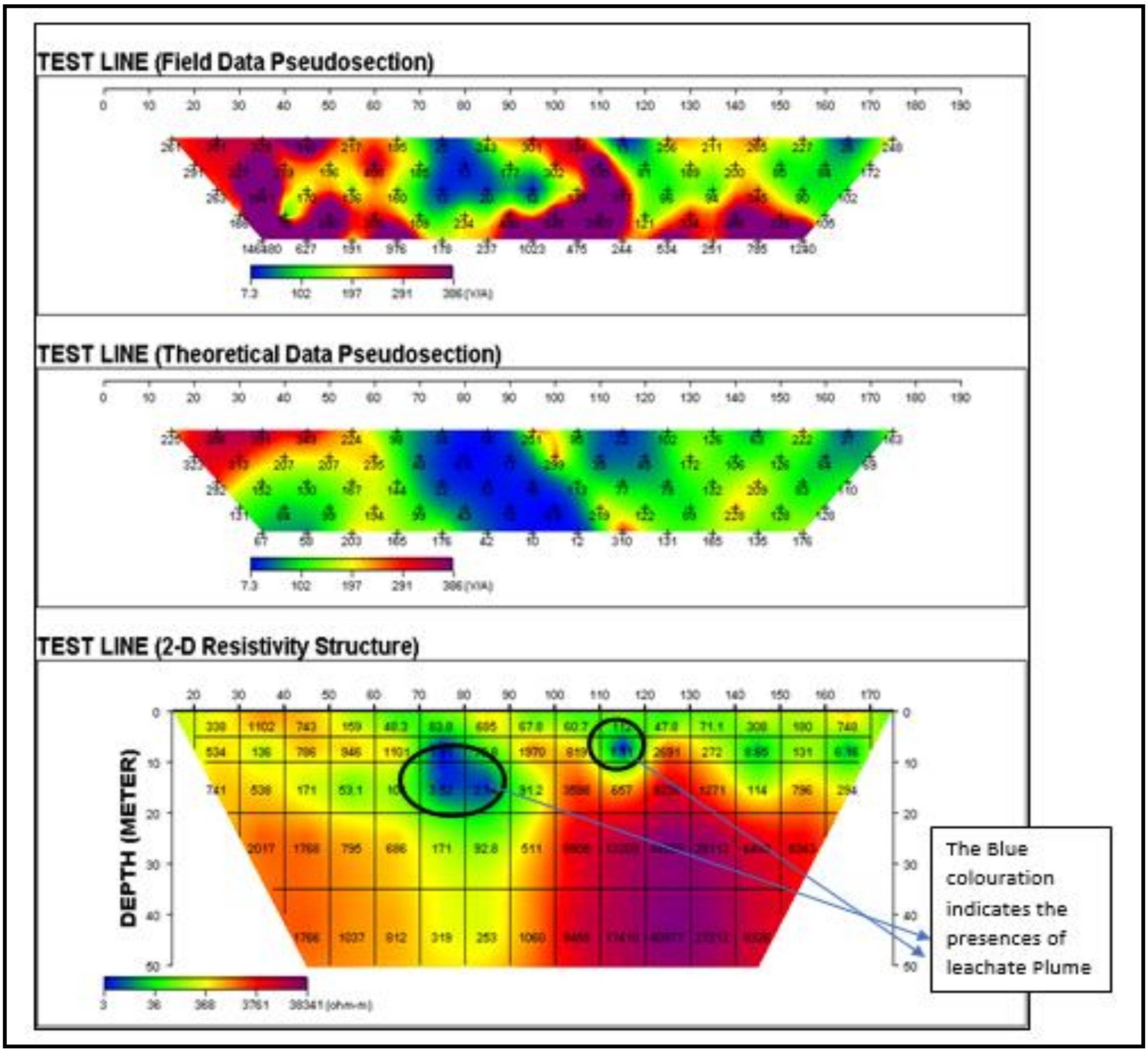

Figure 5: 2-D Resistivity structure based on FEM modeling of transverse 1

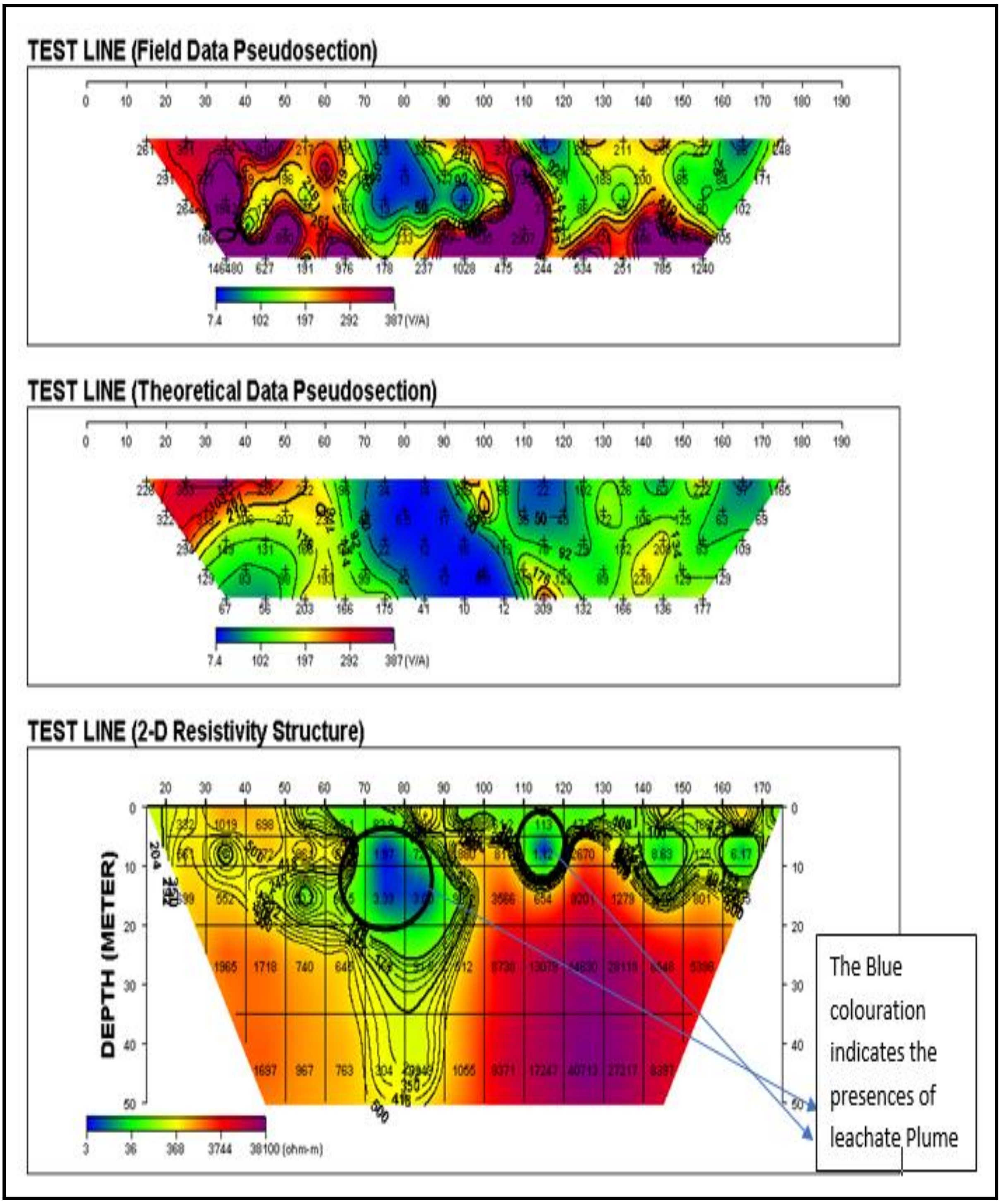

Figure 6: Resistivity structure with contours based on FEM modeling of transverse 1

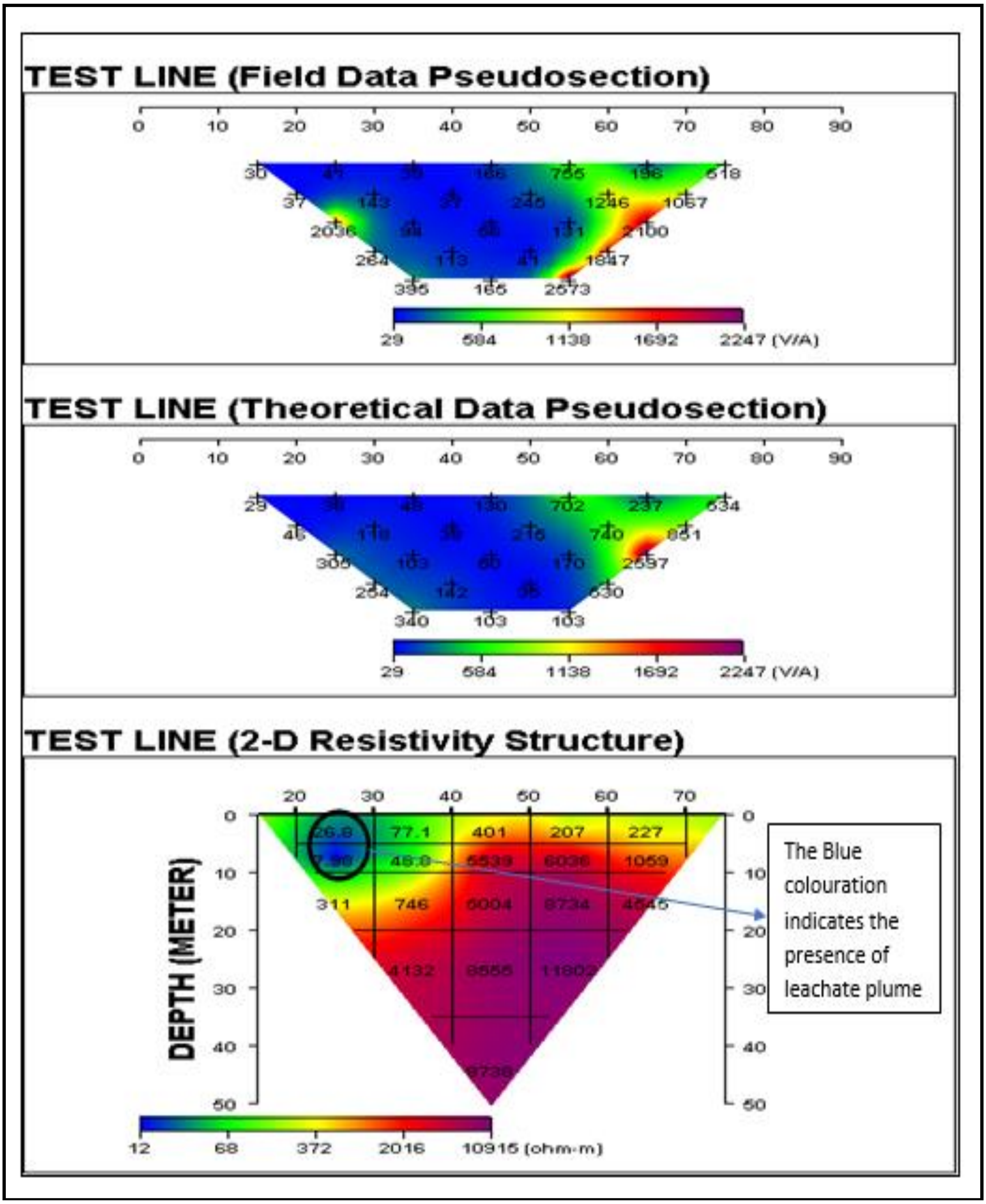

Figure 7: 2-D Resistivity structure based on FEM modeling of transverse 2

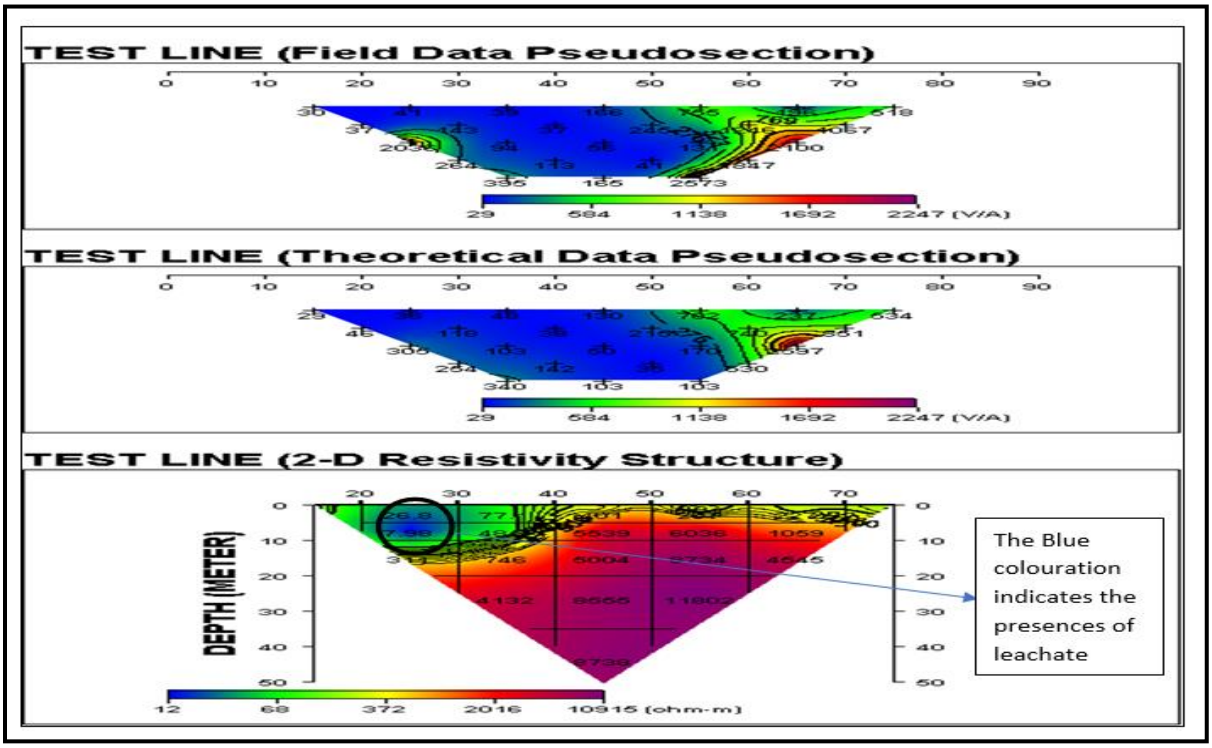

Figure 8: Resistivity structure with contours based on FEM modeling of transverse 2

3.2 Water Quality Index Analysis

Using the average weighted index method; the water quality index of the groundwater samples collected around second cemetery in the month of July, 2022 was determined and presented in Table 1.

Table 1: Summary of estimated water quality index around second cemetery

S/N	Sample Number	WQI	Overall Status
1	Sample One	286.24	Very poor water
2	Sample Two	77.44	Good water
3	Sample Three	51.92	Good water
4	Sample Four	371.72	Very poor water
5	Sample Five	100.47	Poor Water
6	Sample Six	520.48	Very poor water
7	Sample Seven	216.39	Very poor water
8	Sample Eight	116.69	Poor water
9	Sample Nine	42.36	Excellent water
10	Sample Ten	52.78	Good water
11	Sample One	29.74	Excellent water
12	Sample Two	55.91	Good water
13	Sample Three	109.20	Poor water
14	Sample Four	188.93	Poor water
15	Sample Five	103.16	Poor water

Evaluation of the WQIs indicates that more than70% of the water samples collected around second cemetery was unsuitable for consumption. Although, the study found variations in the degree of groundwater contamination among the sampled boreholes, it was also observed that groundwater quality improves as you go further away from the necroleachate flow direction. This suggests that factors such as burial practices, soil characteristics, and hydrogeological conditions may influence the extent of contamination. The observed deterioration in groundwater quality can be primarily attributed to the infiltration of necroleachate resulting from the decomposition of human remains in the cemeteries. Necroleachate is a complex mixture of organic and inorganic compounds released during the decomposition process, including nutrients, heavy metals, and microbial pathogens. As human remains decompose, fluids containing these compounds percolate through the soil and eventually reach the groundwater, leading to contamination. Heavy metals, including lead, cadmium, and manganese, were identified as significant contributors to groundwater contamination. These metals can persist in the environment for extended periods and pose serious health risks, even at low concentrations. The elevated levels of heavy metals detected in the groundwater samples indicate the potential for long-term adverse effects on human health, including neurological disorders, organ damage, and developmental abnormalities. The findings of this investigation highlight the pressing need for effective management strategies to mitigate groundwater contamination around cemeteries. Measures such as improving burial practices, implementing proper drainage systems, and monitoring groundwater quality regularly are essential to safeguard public health and protect the environment.

3.3 Principal Component Analysis

Principal component analysis (PCA) was conducted to pinpoint the key water quality parameters that had a significant impact on the overall groundwater quality around the second cemetery in Benin City. The aim of PCA was to condense the correlated observable variables into smaller sets of crucial independent composite variables. These smaller sets of independent variables were presumed to be accountable for the subpar groundwater quality near the cemetery. To evaluate the effectiveness of the principal component method for this specific task, the Kaiser-Meyer-Olkin measure of sampling adequacy was utilized. The statistical estimates derived from the Kaiser-Meyer-Olkin measure of sampling adequacy are detailed in Table 2.

Table 2: Testing the suitability of principal component analysis

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.657
Bartlett's Test of Sphericity	Approx. Chi-Square	1.113E3
	Df	171
	Sig.	.000

The computed KMO is indicative of the entire correlation. A value of 0.657 is good according to Kaiser, 1974. The value indicates that PCA is a useful technique to be employed for the analysis. The Barttlet test value was employed to test if the sphericity test is statistically significant. For statistically significant value, the computed Barttlet test should be less than 0.05 and a value of 0.000 as observed in the KMO result shows that the sphericity test is statistically significant.

In the extraction phase, it's crucial to assess communalities. Communalities indicate the total sum of squared loadings for a variable across factors. They can vary between 0 and 1, with a value of 1 suggesting that the component factor explains all the variation in groundwater quality. The extracted communalities are outlined in Table 3.

Table 3; Computed communalities of groundwater quality parameters

S/N	Parameters	**Initial Communalities**	**Extracted Communalities**
1	pH	1.000	.761
2	Nitrate	1.000	.981
3	E.C	1.000	.931
4	DO	1.000	.794
5	TDS	1.000	.912
6	Sodium	1.000	.836
7	Lead	1.000	.745
8	Sulphate	1.000	.937
9	Zinc	1.000	.941
10	Copper	1.000	.976
11	Chloride	1.000	.913
12	Iron	1.000	.874
13	Carbonate	1.000	.874
14	Nitrite	1.000	.739
15	Cadmium	1.000	.716
16	Magnesium	1.000	.875
17	Phosphate	1.000	.921

The communalities signify the percentage of variance elucidated by the extracted components, reflecting the R-squared of the regression conducted using these components. A low communality for an item suggests limited commonality with the extracted components, indicating a lack of association with other items in the set. Initially, communalities are typically 1.000, but focus should be on the extracted communalities, ideally surpassing 0.5. Extraction communalities estimate the variance in each variable accounted for by the factors. High extraction suggests that the extracted components represent the variables effectively. Any extraction below 0.3 may necessitate extracting another component. However, as observed in Table 3, none of the extractions are below 0.3, suggesting that the extracted components sufficiently explain the variation in groundwater quality near the second cemetery.

To ascertain the number of components grouping groundwater quality parameters, total variance explained was considered. This metric indicates how much of the data's variable has been modeled by the extracted factors. Typically, in PCA, only the first few components, accounting for the majority of total variance, are retained for interpretation. The initial eigenvalue, representing the amount of variance each component accounts for and its contribution to the total variance percentage, is crucial. An eigenvalue less than 1 implies that the component explains less variance than a single variable would, thus shouldn't be retained. The extraction analysis assesses how well the component factors explain the variation in overall groundwater quality, employing the total variance explained. Factors with eigenvalues exceeding one indicate the number of component factors necessary to describe the underlying variation in groundwater quality effectively. Conversely, factors with eigenvalues below one lack positive influence on overall groundwater quality. To identify groundwater quality parameters within each component factor, a component matrix was generated. This matrix elucidates the correlation between groundwater quality parameters in each component group. Higher factor loadings indicate closer association with the component factor. Horizontal decentralization of the component matrix was conducted to determine the most highly correlated water quality parameters with the component factors. The best-favored parameters were selected as members of each particular component factor. Results of the horizontal decentralization of the component matrix are presented in Table 4.

Table 4; Result of horizontal decentralization of the component matrix

Variables			**Component Factors**			
S/No	**Variable Code**	**Variable Name**	**1**	**2**	**3**	**4**
1	X_1	pH	0.191			
2	X_2	Nitrate	0.968			
3	X_3	EC		0.854		
4	X_4	DO				0.457
5	X_5	TDS		0.853		
6	X_6	Sodium	0.888			
7	X_7	Lead			0.301	
8	X_8	Sulphate	0.956			
9	X_9	Zinc	0.968			
10	X_{10}	Copper	0.970			
11	X_{11}	Chloride		0.277		
12	X_{12}	Iron			0.692	
13	X_{13}	Carbonate	0.829			
14	X_{14}	Nitrite		0.728		
15	X_{15}	Cadmium				
16	X_{16}	Magnesium	0.925			
17	X_{17}	Phosphate	0.939			
18	X_{18}	Alkalinity	0.914			
19	X_{19}	Calcium	0.982			

Examining Table 4 reveals that the first component factor exhibits the strongest correlation with pH, nitrate, sodium, sulfate, zinc, copper, carbonate, magnesium, phosphate, alkalinity, and calcium. The second component factor is primarily associated with electrical conductivity, total dissolved solids (TDS), chloride, and nitrite. In contrast, the third component factor shows a high correlation with lead concentration and iron concentration, while the fourth component factor is most strongly correlated with dissolved oxygen levels. The rotated component matrix highlights the factors that warrant closer attention to improve groundwater quality in any given location. To discern the most critical factors contributing to poor water quality around the second cemetery, a vertical decentralization of the rotated matrix was conducted, with the results presented in Table 5.

Table 5: Result of vertical decentralization of the rotated component matrix

Variables			Component Factors			
S/No	**Variable Code**	**Variable Name**	**1**	**2**	**3**	**4**
1	X_1	pH				
2	X_2	Nitrate				
3	X_3	EC		0.940		
4	X_4	DO				0.843
5	X_5	TDS				
6	X_6	Sodium				
7	X_7	Lead				
8	X_8	Sulphate				
9	X_9	Zinc				
10	X_{10}	Copper				
11	X_{11}	Chloride				
12	X_{12}	Iron			0.906	
13	X_{13}	Carbonate				
14	X_{14}	Nitrite				
15	X_{15}	Cadmium				
16	X_{16}	Magnesium				
17	X_{17}	Phosphate				
18	X_{18}	Alkalinity				
19	X_{19}	Calcium	0.993			

Upon examining Table 5, it became evident that calcium, electrical conductivity, iron concentration, and dissolved oxygen were the most influential variables impacting the quality of groundwater around the second cemetery. To identify additional variables that are spatially correlated with these critical factors and can also influence overall groundwater quality, a component plot in rotated space was generated and is presented in Figure 9.

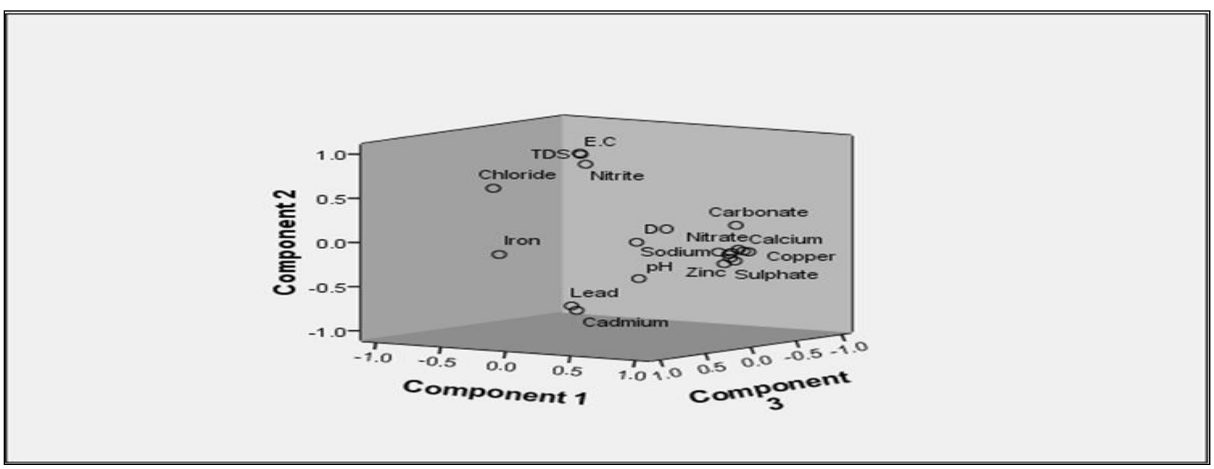

Figure 9: Component plot in rotated space

Observations from the component plot depicted in Figure 9 indicate that electrical conductivity and total dissolved solids exhibit spatial correlation with nitrite and chloride. Conversely, calcium and dissolved oxygen demonstrate spatial correlation with pH, nitrate, sodium, zinc, sulfate, copper, and carbonate. In summary, it is concluded that parameters contributing to poor water quality around the second cemetery comprise calcium, electrical conductivity, iron, dissolved oxygen, nitrite, and chloride. Additionally, pH, nitrate, sodium, zinc, sulfate, copper, and carbonate are identified as other influential factors.

3.4 Hydrochemical Facies

Hydro-geochemical facies were inferred using an adaptation of the Piper-Hill diagram and Durov plot presented in Figures 10 and 11.

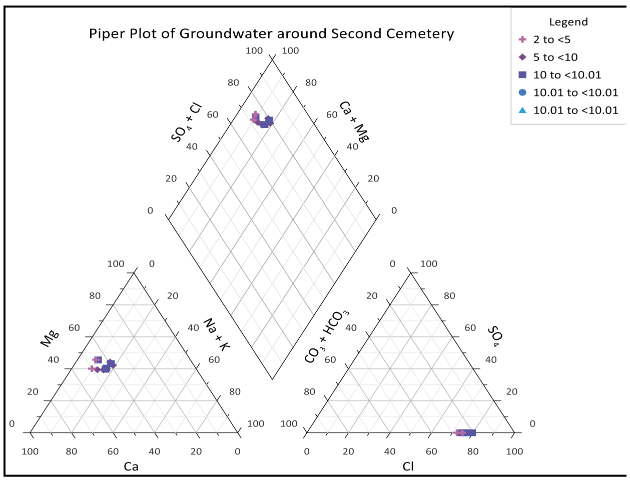

Figure 10: Piper-Hill diagram of second cemetery

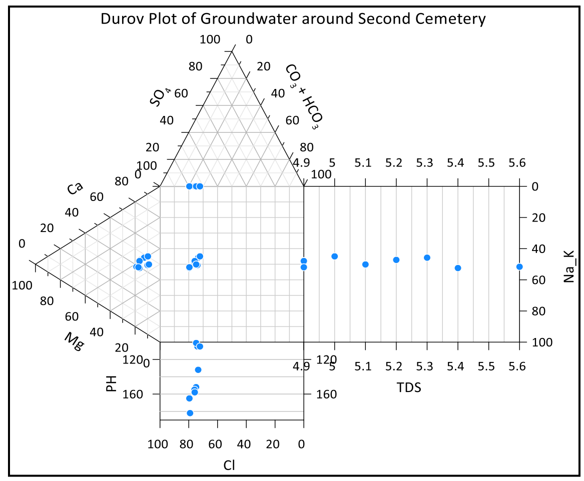

Figure 10: Durov plot of second cemetery

In terms of cation, the bulk of the water samples fell in no dominant cation field, whereas anions fell in the chloride field according to the Piper trilinear diagram plot of the chemical analysis data presented in Figure 10. Magnesium chloride and Magnesium sulphate were identified as the primary groundwater type around second cemetery in Benin City. Owing to the geologic differences which led to geographical variability of the hydrochemical parameters, the hydrochemical analysis results show that the origin and geochemical composition of the groundwater in the area are spatially varied. The types of water that have been identified include Ca-Cl_2, Mg-Cl_2, Ca-Mg-Cl_2, and Mg-Ca-SO_4. In addition to the information from the Piper-Hill diagram, the Durov plot also revealed the presence of high concentration of total dissolved solids in groundwater around second cemetery.

3.5 Spatial Analysis

The spatial distribution maps of some selected groundwater quality parameters identified by the PCA analysis is presented in Figures 11 to 14

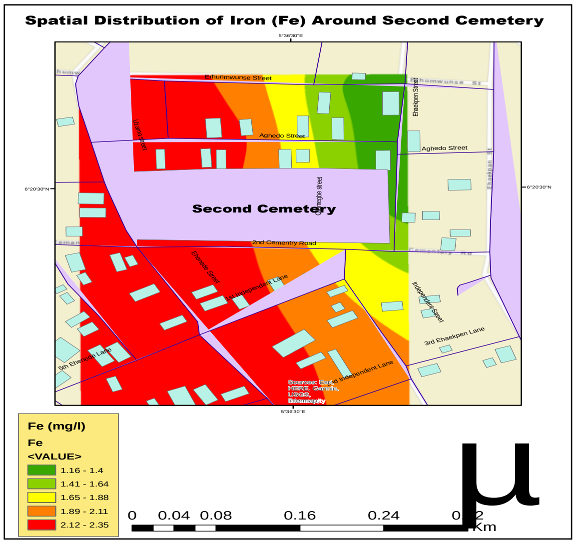

Figure 11: Spatial distribution map of iron

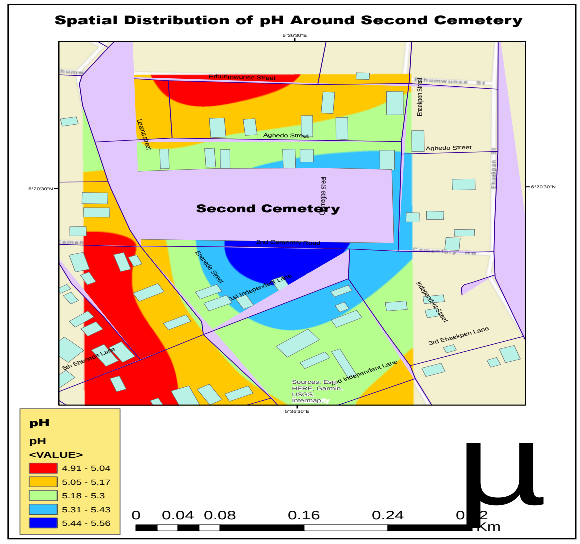

Figure 12: Spatial distribution map of pH

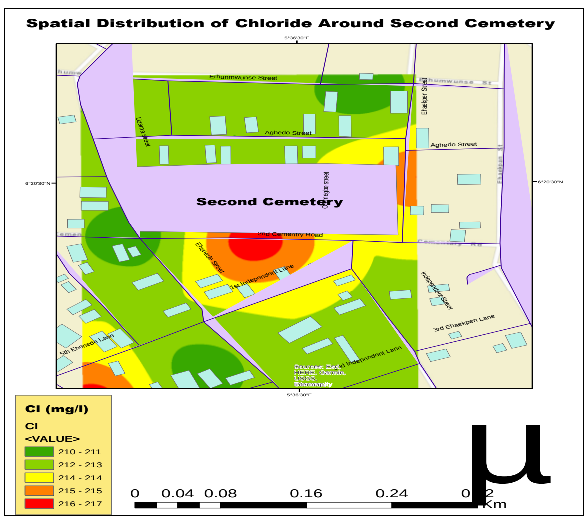

Figure 13: Spatial distribution map of chloride

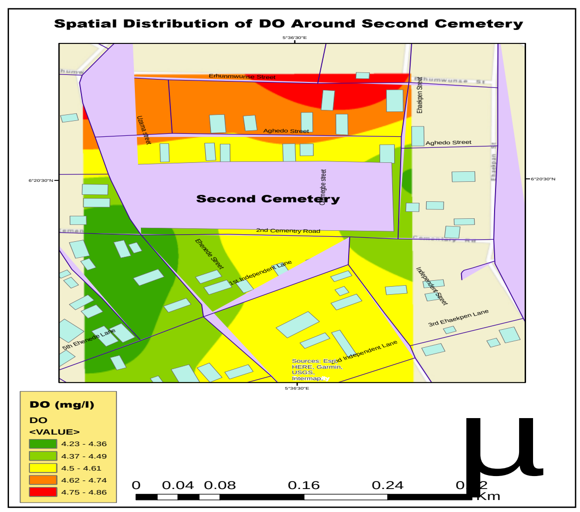

Figure 14: Spatial distribution map of DO

The spatial distribution maps of groundwater quality were employed to identify areas that are within regions of deteriorating groundwater quality. Areas marked red in the spatial distribution maps are classified as high risk areas.

4. Conclusion

The outcome of the reconnaissance survey conducted around second cemetery in Benin City during sample collection revealed that most of the boreholes are not in compliance with the environmental law which recommends a distance of 250m from cemetery for the siting of boreholes. The profile maps from both traverse obtained from the electrical resistivity data confirmed the cemetery operations as the source of the leachate plume resulting to the contamination of the subsoil and, specifically exposing the activities at a depth of 5 to 20 meters for traverse 1 and the presence of the plume from the surface to a depth of 0 to 10 meters for traverse 2. WQIs results indicated that more than 70% of the water samples collected around second cemetery was unsuitable for consumption and the degree of suitability of the borehole water was found to be positively correlated with distance from the cemetery. The outcome of the principal component analysis (PCA) revealed that; calcium, electrical conductivity, iron, dissolved oxygen, nitrite, chloride, pH, nitrate, sodium, zinc, sulphate, copper and carbonate are the parameters mostly affected by necroleachate from human decomposition. Hydrochemical analysis result shows that the origin and geochemical composition of the groundwater varied spatially. The types of water that have been identified include $Ca\text{-}Cl_2$, $Mg\text{-}Cl_2$, $Ca\text{-}Mg\text{-}Cl_2$, and $Mg\text{-}Ca\text{-}SO_4$.

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