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Integrated geophysical investigation of flooding within the campus of Federal College of Education (Technical), Omoku and its environs

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Abstract

This study investigates flooding within the campus of the Federal College of Education (Technical), Omoku, and its environs using integrated geophysical methods. Geo-electric resistivity (VES) and Electrical Resistivity Tomography (ERT) were employed to characterize subsurface properties that influence water retention, drainage, and flooding susceptibility. The VES analysis delineated four geo-electric layers with resistivity values ranging from 57.9 to 32,936.7 Ωm, revealing significant subsurface heterogeneity. The topsoil (layer 1) exhibited variable resistivity (86.7–824.4 Ωm), indicating mixed sandy and clayey materials with poor drainage in low-resistivity zones. The second and third layers demonstrated variable thickness and resistivity, reflecting saturated zones prone to water retention and areas with better drainage properties. The fourth layer, likely compact bedrock, exhibited high resistivity, acting as a barrier to water flow and contributing to surface runoff. Secondary geo-electric parameters including reflection coefficients, transverse resistivity, longitudinal resistivity, and anisotropy, provided additional insights. Low resistivity and high anisotropy zones indicated water-saturated or clay-rich materials associated with flood-prone areas. High resistivity and low anisotropy corresponded to better-draining zones with sandy or gravelly materials. ERT profiles complemented the VES results by mapping lateral and vertical variations in resistivity. Low-resistivity zones in the upper subsurface were linked to water-saturated soils, obstructing drainage and increasing flood risk. High-resistivity regions indicated less permeable materials that could exacerbate runoff and surface water accumulation. The study concludes that the interplay of subsurface heterogeneity, saturated zones, and impermeable layers significantly influences flooding in the area. The findings provide critical data for flood risk management and infrastructural planning, highlighting the need for effective drainage systems and soil stabilization measures in vulnerable regions.

Keywords: *geo-electric, ERT, heterogeneity, transverse resistivity, longitudinal resistivity*

Introduction

Flooding is a major environmental challenge, especially in regions susceptible to heavy rainfall and poor drainage systems. In Nigeria, flooding has become increasingly frequent and destructive, impacting the socio-economic wellbeing of communities, infrastructure, and local economies. The risk of flooding in the coastal region is increasing, this may be attributed to extreme weather phenomena caused by climate change, population growth, increase in infrastructure located in coastal zones, sea level rise, and in some cases subsidence, caused by pumping of groundwater. The rise in sea level contribute to the coastal regions being more vulnerable to climate change disasters, such as flooding (El-Zein et al., 2021; Wu et al., 2020; Narendra et al., 2024). The rise in sea level inundates

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low-lying wetlands and dry land, erodes shorelines, contributes to coastal flooding, and increases the flow of salt water into estuaries and nearby groundwater aquifers. The Federal College of Education (Techni--cal), Omoku, and its environs are not immune to the-se impacts. The coastal city of Omoku is characteri-zed by variable geology, including sands, silts, and clays, and is prone to flooding due to high water tables and frequent rainfall. Recurrent flooding within the campus disrupts academic activities, damages infrastructure, and poses risks to the safety of staff and students and general quality of life. Addressing these flooding challenges requires a comprehensive understanding of both surface and subsurface conditions that influence flood occurrences in the area. Flooding is influenced by a range of factors, including rainfall intensity, surface runoff, and the geological characteristics of the affected area (El-Zein et al., 2021; Obiora and Ibuot, 2023; Srivanit et al., 2024). In regions like Omoku, subsurface features such as soil type, permeability, water tables, and underground structures play a critical role in how floodwaters accumulate and persist. Shallow water tables or impermeable soil layers can increase flood susceptibility, especially during periods of high rainfall. The Niger Delta region, where Omoku is located, is particularly susceptible to flooding due to its low-lying terrain, dense river networks, and prox-imity to the coast. This geographic context increases the complexity of flood management, as it requires a nuanced understanding of both surface and subsur-face interactions. Furthermore, anthropogenic factors, such as uncontrolled urbanization and poor waste disposal practices, exacerbate the problem by clogging drainage systems and reducing the natural infiltration capacity of the soil. To address these issues, an integrated geophysical investigation offers a viable solution. Geophysics, as a multidisciplinary field, provides the tools and methodologies necessary to explore subsurface properties and dynamics that contribute to flooding. These methodologies enable the identification of the causes of flood susceptibility, be it from underground water saturation, poor drainage infrastructure, or geological features like impermeable soil layers. The integration of multiple geophysical techniques allows for a comprehensive analysis, offering data-driven insights into the hydrological and geological conditions of the study area. Electrical Resistivity Methods (ERM is widely used geophysical techniques to investigate subsurface structures by measuring the resistance of materials to electrical current. ERM is particularly useful in hydrological studies, as it helps to detect variations in subsurface moisture content, identify permeable or impermeable layers, and map water-saturated zones (Keller and Frischknecht, 1982; Lowrie 1997; Reynolds, 2011; Ibuot et al., 2017). The electrical method is non-invasive and cost-effective, making it ideal for surveying large areas without disturbing the environment. In flood-prone regions, ERM offers valuable insights into subsurface conditions, which are often not visible through traditional surface investigations. ERM has been successfully applied in flood studies worldwide to investigate groundwater levels, assess soil moisture distribution, and map subsurface features like aquifers and impermeable layers (Adebanija and Oladunjoye, 2014; Kayode et al., 2019; Golebiowski et al., 2020; El-Saadawy et al;, 2020; Obiora and Ibuot, 2023). These studies have shown that ERM is highly effective in identifying areas prone to flooding by detecting water-saturated zones and underlying geological structures that influence flood dynamics. For the Federal College of Education (Technical), Omoku, ERM can help identify key flood-contributing factors, allowing for more informed flood risk assessments and mitigation strategies. Flooding within the campus of the Federal College of Education (Technical), Omoku, has led to substantial disruptions and property damage. Despite surface-level flood control measures, the persistence of flooding suggests that subsurface factors may play a significant role. An integrated geophysical study using electrical resistivity methods offers an oppor-tunity to better understand the subsurface conditions contributing to flooding in this area. The findings will provide critical data for planning long-term flood mitigation strategies, improving the resilience of the campus infrastructure, and enhancing the safety of its occupants. This investigation will integrate electrical resistivity and electrical resistivity tomography (ERT). These techniques will be employed to map subsurface features, including water tables, soil composition, and potential weak zones in the geological structure that may contribute to water accumulation and flooding. This study will focus on the campus of the Federal College of Education (Technical), Omoku, and its immediate surroundings. However, the study may face limitations such as potential access restrictions to certain areas of the campus and environmental conditions that could affect data collection. Additio-nally, while ERM is an effective tool for subsurface investigations, its sensitivity to surface noise and va-

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riations in data interpretation may introduce uncertainties. Despite these challenges, the study aims to provide valuable insights into the flood mechanisms affecting the campus and contribute to long-term flood management strategies. The objectives of this research include understanding the subsurface characteristics that influence flood occurrence, identifying areas of high flood risk, and proposing sustainable solutions to mitigate the effects of flooding. Ultimately, this study will contribute to a better understanding of flood dynamics in the Federal College of Education (Technical), Omoku, and its environs, while also providing a blueprint for similar flood-prone regions across the Niger Delta. Through an integrated geophysical approach, it is hoped that long-term, sustainable solutions to flooding in the area will be developed, ensuring the safety and functionality of the academic institution and its surrounding communities.

Materials and methods

The study area

Federal College of education (Technical), Omoku is located in the northern part of Rivers State, Nigeria, within the Niger Delta region. It lies approximately 60 km east of Port Harcourt. The geographical coordinates of the study area lies between latitudes 5.33° N and 5.35° N, and longitudes 6.63° E and 6.66° E (Fig. 1). It is situated in a low-lying area that is part of the larger Niger Delta floodplain, which is characterized by a network of rivers, creeks, and wetlands (Tamunobereton-ari et al., 2014; Okoroh and Ibuot, 2023). The area experiences a humid tropical climate with heavy seasonal rainfall, which contributes to flooding in certain parts of the region. The geology of the study area, like much of the Niger Delta, is dominated by sedimentary formations associated with the complex depositional environment of the Delta. The region is underlain by three primary geological formations; the Benin, Agbada, and Akata Formations. The Benin Formation is the most significant geological unit in Omoku and its surroundings. It is a Quaternary to Tertiary-aged formation that is mainly composed of unconsolidated sands, silts, and clays (Ibuot et al., 2017). The formation is highly porous and permeable, which facilitates groundwater movement and storage. Thickness varies, but the formation can reach up to several hundred meters in depth, with alternating layers of sands and clayey interbeds. The Agbada Formation lies beneath the Benin Formation and is made up of alternating layers of sandstones, shales, and siltstones. It is rich in hydrocarbons, contributing to the significant oil and gas reserves in the Niger Delta region. Although not as exposed at the surface as the Benin Formation, it plays a role in the subsurface hydrogeological regime. The Akata Formation forms the base of the Niger Delta geological sequence, consisting predominantly of marine shales and clays. It serves as a source rock for hydrocarbons but is generally deeper and does not directly influence surface or shallow subsurface hydrology in the Omoku area. The geology of Omoku is heavily influenced by the fluvial and deltaic depositional processes that have shaped the Niger Delta over millions of years. The area is composed of allu-

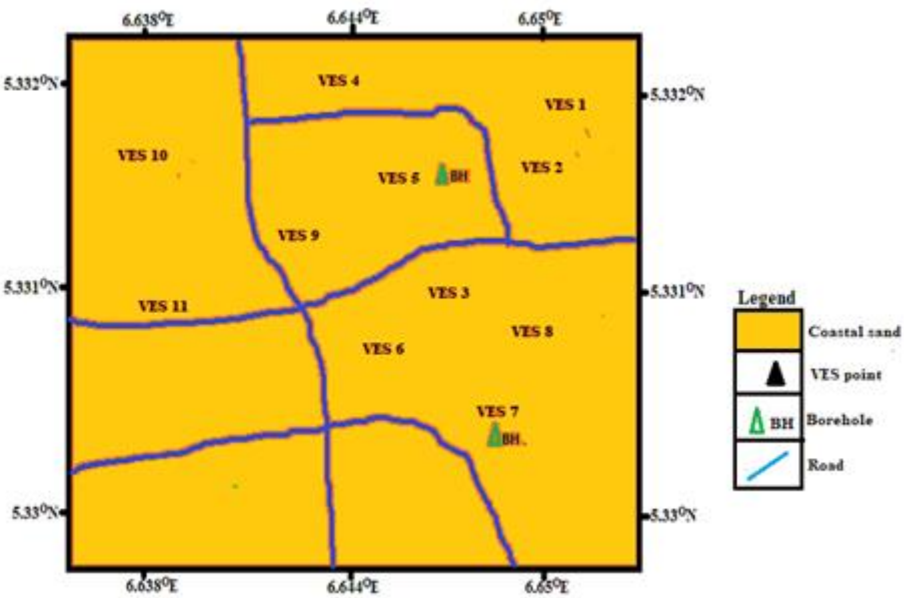

Figure 1
Geologic map of study area showing VES points

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vial deposits, predominantly sandy with interspersed clay layers that influence both the geology and the hydrological characteristics of the region (Reijers et al., 1997u). Omoku's hydrogeology is characterized by the presence of shallow aquifers within the Benin Formation. The aquifers are unconfined to semi-confined and consist of unconsolidated sands and gravels with high permeability, which allow for significant groundwater recharge and storage. These aquifers serve as a major source of water for both domestic and agricultural uses in the region. The aquifers in Omoku are typically shallow, occurring at depths of 5 to 50 m, though deeper aquifers may also be present. Groundwater flow is influenced by the permeability of the sandy layers, while the presence of clayey interbeds may restrict flow in some areas, leading to the formation of perched water tables. Recharge of the aquifers is primarily through rainfall, which is abundant due to the tropical climate. Omoku is part of the Niger Delta floodplain, meaning the groundwater system is closely linked to surface water bodies such as rivers, streams, and swamps. Seasonal flooding from these water bodies can lead to waterlogging and increased groundwater levels during the rainy season. The region's proximity to the Niger River and other smaller rivers, such as the Orashi River, contributes to periodic flooding during the wet season (April to October). Low topography, coupled with high water tables, makes the area prone to seasonal flooding and waterlogging, particularly in poorly drained areas. While the sandy soils facilitate infiltration and groundwater recharge, they also contribute to rapid water saturation during periods of heavy rainfall. The clay layers within the aquifer system act as confining units, which can lead to localized perched water tables and exacerbate flooding conditions when the surface runoff is high.

Data Acquisition

The electrical resistivity technique is a geophysical method used to study subsurface properties by measuring the resistance of materials to the flow of electric current. This technique involves injecting an electrical current into the ground through two current electrodes and measuring the resulting potential difference at other two potential electrodes. The resistivity values obtained give insights into the composition, structure, and moisture content of subsurface materials. The electrical resistivity technique is effective because it provides non-invasive, in-situ measurements that are useful for mapping subsurface features and assessing soil and rock properties. Vertical electrical sounding (VES) and Electrical resistivity tomography (ERT) are used in determining the variations of resistivity. They are used in mapping shallow subsurface lithology based on observed contrast in resistivity between the different lithologic units (Telford et al., 1990; Lowrie, 1997; Ibuot et al., 2022). VES is used in resistivity surveys to determine variations in resistivity with depth. It involves a single line of electrodes, where the spacing between current electrodes (AB) is gradually increased to probe deeper subsurface layers. VES is especially effective in layered structures where resistivity varies significantly with depth. By measuring the resistivity at different depths, VES can determine the presence of water-bearing layers and provide information about their thickness, extent, and properties (Lowrie, 1997; George et al., 2018; Obiora and Ibuot, 2020). The electrical resistivity survey in the study area was performed using the Integrated Geo and Instrument Services (IGIS) signal enhancement resistivity meter, model SSR-MP-ATS, along with its accessories. Data for the 1-D Vertical Electrical Sounding (VES) technique was collected at eleven different locations within the study area, utilizing the Schlumberger electrode configuration. In this configuration, direct current was introduced into the ground via a pair of current electrodes (A and B), while a second pair of potential electrodes (M and N) measured the resulting potential difference. The half current electrode spreads (AB/2) ranged from 1.0 to 200.0 m and half potential electrode spreads (MN/2) ranging from 0.25 to 10.0 m. These configurations were used to obtain resistivity data at different depths. The resistivity meter's crystal display was used to read the apparent resistance (R_a) of the geologic materials penetrated. The apparent resistivity was calculated by multiplying the apparent resistance (R_a) by the geometric factor (K) using the expression in equation [1];

$$\rho_a = \pi \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{MN} R_a \qquad [1]$$

where equation [2] gives the geometric factor K;

$$K = \pi \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{MN} \qquad [2]$$

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The apparent resistivity values were plotted on a bilogarithmic graph, allowing for dynamic range adjustments to smooth and correct outliers identified as noise. The smoothened resistivity curves were then electronically inverted to true resistivity using the WINRESIST software. This program generates VES curves (Figs 2a and 2b) and provides primary parameters, including true resistivity, layer thickness, and depth. The resistivity distribution was further visualized using Origin software, which displays resistivity contrasts through contour segments. ERT is a method that provides detailed 2D images of subsurface resistivity distributions. In ERT, multiple electrodes are placed along a line or grid, and an automated system switches between them to collect numerous resistivity measurements across various depths. This technique yields high-resolution images, making it suitable for complex geological investigations. It is an important tool in the study of floods and can provide valuable insights into flood behaviour, groundwater dynamics, and flood risk assessment. In the 2-D electrical resistivity measurement for ERT, the same Integrated Geo and Instrument Services (IGIS) equipment and accessories were used. Current and potential electrode pairs were progresssively spaced at consistent 5 m intervals throughout the measurement process until the maximum separation distance was reached. This approach involved measurements taken at intervals of 5 m, 10 m, 15 m, 20 m, and so on, until the maximum length of 35 m was exhausted. The measured resistances for different intervals were converted to apparent resistivity using the expression given by equation [3];

$$\rho_a = 2\pi a R_a \qquad [3]$$

where *a* is the electrode separation.

The apparent resistivity are converted into true resistivity values through inversion modelling the RES2DIVN exe software program, which adjusts an initial model to fit the observed data. The resulting resistivity profiles or sections are then interpreted to identify subsurface features, such as geological layers, water-saturated zones, or faults, based on resistivity contrasts. The values of the resistivity and thickness were employed in estimating the secondary geo-electric parameters; reflection coefficient, longitudinal resistivity, transverse resistivity, and anisotropy which help in characterising the subsurface. In addition to the geo-electric (resistivity and thickness) properties, the geohydraulic properties (reflection coefficient, transverse resistivity, longitudinal resistivity, and anisotropy) were estimated using equations 4 – 8. These properties play crucial roles in understanding the characteristics of subsurface geological formations that influence groundwater flow, storage, and the area's vulnerability to flooding.

Reflection coefficient (k)

The reflection coefficient is an indicator of changes in subsurface properties at different layers with different resistivities, primarily in terms of impedance contrasts. It helps to identify boundaries between permeable and impermeable layers. Distinguish layers that may either allow or restrict groundwater movement. Assess the extent of aquifers or confining layers, impacting flood potential by indicating zones where water might accumulate or flow more freely. This study considers resistivity values of three layers (layers 1, 2, and 3) and the values were used in equations [4] and [5] to estimate the reflection coefficients (k_1 and k_2).

$$k_1 = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad [4] \qquad k_2 = \frac{\rho_3 - \rho_2}{\rho_3 + \rho_2} \quad [5]$$

where ρ_1 is resistivity of layer 1, ρ_2 is resistivity of layer 2, and ρ_3 is resistivity of layer 3. The values of the reflection coefficient should fall between +1 and -1. A positive reflection coefficient occurs when the resistivity of the lower layer is greater than that of the upper layer. This signifies that the lower layer is less conductive (more resistive) compared to the upper layer. A negative reflection coefficient occurs when resistivity of the lower layer is less than that of the upper layer. This signifies that the lower layer is more conductive than the upper layer. (Ibuot et al., 2019; Obiora and Ibuot, 2023).

Longitudinal resistivity, transverse resistivity and anisotropy

These are key parameters used to understand subsurface water flow and soil saturation characteristics, which are crucial for predicting and managing flood risks. Longitudinal resistivity (ρ_l): this parameter measures the resistivity along the direction of current flow, which is typically parallel to the layering of materials in the subsurface and is expressed in equation 6 according to Henriet (1976). In flood studies, low longitudinal resistivity can indicate high water saturation or clay-rich layers, which may affect drainage and increase flood risk due to reduced permeability. It provides information about the resistivity of the subsurface layers along the vertical

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profile (Obiora and Ibuot, 2023). Low values of longitudinal resistivity indicate highly conductive geo-materials, such as saturated sediments or clay-rich soils, which can signal waterlogged or flooded areas. Conversely, high longitudinal resistivity values may point to low-conductivity formations, like bedrock or dry, unconsolidated materials with minimal water content.

$$\rho_l = \frac{\sum_{1=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\rho_i}} \quad [6]$$

Transverse resistivity (ρ_t): It is measured perpendicular to the direction of current flow, across layers and is expressed according to Henriet (1976) in equation [7]. It reflects the average resistivity of materials across multiple layers and is often higher in sandy, permeable materials. High transverse resistivity zones may indicate potential pathways for water infiltration, which can help assess areas prone to groundwater recharge and potential flooding. It provides information about the lateral variations in subsurface resistivity and made possible to detect areas of contrasting subsurface materials or structures that can influence the movement and accumulation of water during flooding events. (Obiora and Ibuot, 2023). In a non-uniform medium, transverse resistivity is consistently higher than longitudinal resistivity, with an anisotropy coefficient greater than one. In a uniform medium, transverse resistivity equals longitudinal resistivity, and the anisotropy coefficient is one (Flathe, 1955; Gernez et al., 2019). Insights from longitudinal and transverse resistivity measurements are valuable for assessing hydrogeological characteristics, identifying flood-prone areas, and developing effective flood management strategies.

$$\rho_t = \frac{\sum_{i=1}^{n} h_i \rho_i}{\sum_{i=1}^{n} h_i} \quad [7]$$

Anisotropy: This property measures the directional variability in subsurface properties. It is the ratio of transverse to longitudinal resistivity and reflects variations in resistivity due to differences in material composition or layering. A high anisotropy ratio suggests significant heterogeneity in the subsurface, such as variations between sand and clay layers. In flood studies, high anisotropy can indicate areas with contrasting drainage characteristics, influencing water retention and flow, and highlighting zones more susceptible to surface water build up and flooding (Maillet, 1947; Ekanem, 2020, Obiora and Ibuot, 2023). The coefficient of anisotropy (λ) is defined as the square root of the ratio between the resistivity measured perpendicular to the bedding and the resistivity measured parallel to the bedding, as shown in equation [8].

$$\lambda = \sqrt{\frac{\rho_t}{\rho_l}} \quad [8]$$

Research has shown that the coefficient of anisotropy is typically 1.0 in isotropic media and seldom exceeds 2.0 in most geological settings (Zohdy et al., 1974; Shailaja et al., 2016; Ekanem, 2020; Asfahani and Al-Fares, 2021).

Results and Discussion

Geo-electric resistivity

The interpretation of VES data obtained from resistivity measurements provides the electrical resistivity, thickness, and depth of the geo-electrical layers as presented in Table 1. The results provide insights into the subsurface material properties, which help to characterize the soil, rock, and groundwater distribution. The study identified four geo-electric layers (layers 1, 2, 3, and 4) within the maximum depth reached by the current electrode spread. The first geo-electric layer has resistivity values ranging from 86.7 - 824.4 Ωm, with thickness and depth ranging from 0.6 - 4.4 m. This layer corresponds to the topsoil, which is near the surface and exhibits a mix of sandy, clayey, or silty materials. The lower resistivity values (~86.7 Ωm) indicate higher clay content or moisture saturation, which might retain water, contributing to flooding risks, while higher resistivity values (~824.4 Ωm) suggest sandy or less conductive material, which may allow for better drainage. The shallow thickness and depth of this layer indicate it may act as a temporary storage zone for surface water during rainfall, contributing to waterlogging and potential flooding. The second geo-electric layer have values of resistivity, thickness, and depth ranging from 57.9 - 5104.5 Ωm, 2.1 - 12.0 m, and 3.5 - 14.5 m respectively. This layer represents a transition zone with a mix of clay, sandy clay, and possibly sandy materials or gravels between the topsoil and deeper subsurface layers. Low resistivity region is associated with saturated clays or silts, increasing flooding susceptibility, while high resistivity regions suggests dry sands, gravels, or rocks. Its thickness (2.1 - 12.0 m) and depth range suggest this layer could influence groundwater flow and may act as an aquifer in some locations. The third layer exhi-

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bits the widest resistivity range (66.4 - 32936.7 Ωm), indicating significant spatial heterogeneity. Its thickness and depth ranged from 6.2 - 31.8 m, and 13.2 - 40.6 m respectively. This layer may likely indicates saturated sands or silts at the lower range, transitionning to consolidated sands, gravels, or fractured bedrock at higher resistivity values. Its significant thickness and depth variability imply heterogeneous subsurface conditions with potential zones of water storage and flow. This saturated layer could contribute to rising water tables during extended rainfall, influencing flooding in low-lying areas. The variability in thickness suggests uneven subsurface drainage, leading to localized flooding in areas where water accumulates. The fourth layer is likely deep bedrock or compact sedimentary material, with high resistivity values (111.3 - 12651.0 Ωm) indicating low permeability. The thickness and depth were undefined within the maximum current electrode spread. Low resistivity (~111.3 Ωm) suggests possible fracture zones containing water, while high resistivity (~12651.0 Ωm) represents compact, impermeable rock, acting as a barrier to water flow. The presence of fractures (low resistivity zones) could provide pathways for groundwater movement, potentially exacerbating flooding when connected to shallower saturated zones. Impermeable regions may prevent water infiltration, causing surface runoff to accumulate. Figures 2a, 2b and 2c show the variations of resistivity in layers 1, 2, and 3 which show similar variation trends, where high resistivity was observed in the southeastern part and spread towards the northeastrn part. The variations of thicknesses of layers 1, 2, and 3 are displayed in Figures 3a, 3b, and 3c. The primary geo-electric parameters (resistivity and thickness) were employed in estimating the secondary geo-electric parameters (reflection coefficients, longitudinal resistivity, transverse resistivity, and anisotropy) tabulated in Table 2. These properties are crucial as they help characterize the subsurface materials, identify areas of high permeability, water storage potential, and flow pathways, which are essential for predicting and managing flood risks. The reflection coefficients (k_1 and k_2) have values ranging from -0.8114 – 0.7219 and -0.5114 – 0.9519 respectively. The negative values of reflection coefficient indicates transition to a more conductive medium, such as a clay layer, a water-saturated zone, or a mineralized zone beneath a resistive layer like dry soil or rock. Also, positive reflection coefficient indicates a transition to a layer

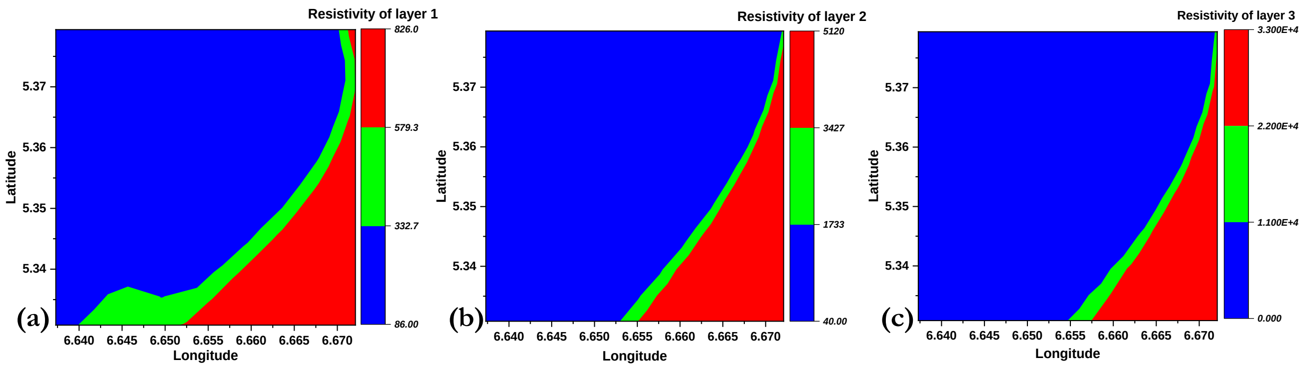

Figure 2. *Contour maps of resistivity (a) layer 1 (b) layer 2 (c) layer 3*

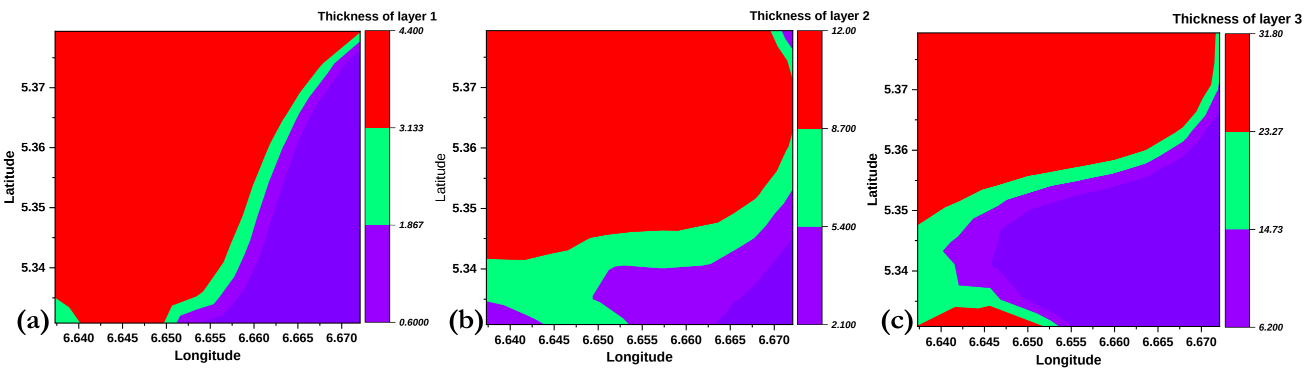

Figure 3. *Contour maps of thickness* (a) *layer 1* (b) *layer 2* (c) *layer 3*

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Table 1. *Summary of electrical resistivity survey in the study area*

VES No.	Longitude (°E)	Latitude (°N)	Elevation (m)	Layer Resistivity (Ωm)				Layer thickness (m)			Layer depth (m)		
				ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3	d_1	d_2	d_3
1	6.6506	5.3326	18	86.7	57.9	2350.9	6076.8	2.9	5.0	7.9	2.9	14.5	22.4
2	6.6529	5.3320	18	570.8	1136.0	1455.5	267.5	1.9	5.0	6.2	1.9	7.0	13.2
3	6.6512	5.3308	17	469.0	624.6	551.7	944.4	0.9	6.5	31.8	0.9	7.4	39.2
4	6.6713	5.3756	15	411.4	1137.3	2948.7	198.7	0.6	8.9	28.4	0.6	9.5	37.9
5	6.6721	5.3778	13	824.4	5104.5	32936.7	230.6	1.4	2.1	10.4	1.4	3.5	13.9
6	6.6716	5.3794	21	632.8	65.9	1496.6	274.8	3.9	3.9	26.9	3.9	7.8	34.7
7	6.6495	5.3327	15	555.0	549.3	177.6	2645.4	3.5	7.0	22.5	3.5	10.5	33.0
8	6.6494	5.3322	13	547.0	643.5	1023.3	12651.0	1.6	12.0	27.0	1.6	13.6	40.6
9	6.6506	5.3326	15	120.3	114.7	269.1	176.2	2.0	5.0	22.6	2.0	7.0	29.6
10	6.6373	5.3318	19	170.8	83.2	66.4	111.3	2.0	4.1	21.7	2.0	6.1	27.8
11	6.6492	5.3314	13	376.7	113.6	209.9	263.4	4.4	6.5	30.9	4.4	10.9	41,8

VES points	Long. (°E)	Lat. (°N)	Reflection coefficient		ρ_t (Ωm)	ρ_l (Ωm)	λ
			k_1	k_2			
1	6.6506	5.3326	-0.1992	0.9519	128.28	1209.69	3.07
2	6.6529	5.3320	0.3312	0.1233	1092.60	1205.24	1.05
3	6.6512	5.3308	0.1423	-0.0630	560.28	561.89	1.00
4	6.6713	5.3756	0.4687	0.4433	2003.66	2483.16	1.11
5	6.6721	5.3778	0.7219	0.7316	5731.10	25497.50	2.11
6	6.6716	5.3794	-0.8114	0.9157	416.48	1238.72	1.73
7	6.6495	5.3327	-0.0052	-0.5114	226.43	296.47	1.14
8	6.6494	5.3322	0.0811	0.2279	846.57	892.27	1.03
9	6.6506	5.3326	-0.0238	0.4023	205.27	232.97	1.07
10	6.6373	5.3318	-0.3449	-0.1123	71.69	76.39	1.03
11	6.6492	5.3314	0.6593	0.2977	2418.87	8487.33	1.87

Table 2
Estimated geo-hydrodynamic properties

with higher resistivity (less conductive layer), such as dry, compact rocks or soils beneath a more conductive layer. It could be inferred that negative reflection coefficients highlight zones of poor drainage and high flood risk due to water-saturated or impermeable layers, while positive reflection coefficients suggest areas with better drainage and lower flood susceptibility, unless resistive bedrock is near the surface, which could promote runoff. Figures 4a and 4b show the variations of k_1 and k_2 across the study area where highly conductive regions are observed in the western-northern regions and southern region respectively.

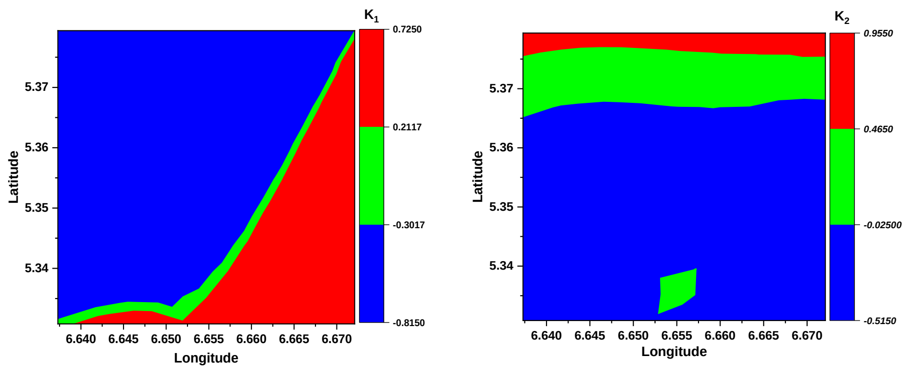

Figure 4. (a) *Reflection coefficient* K_1 (b) *Reflection coefficient* K_2

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The values of transverse resistivity (ρ_t) range from 71.69 – 5731.1 Ωm, the lower values of ρ_t suggest conductive materials such as clay, silt, or water-saturated zones. These areas are prone to flooding because of their high water retention capacity and slow drainage. The higher values reflect resistive materials like sands, gravels, or compacted rocks, which typically allow for better drainage and may be less prone to waterlogging or flooding. Thus, zones with lower transverse resistivity may act as flood-prone regions due to their reduced permeability and high water retention. The longitudinal resistivity (ρ_l) range from 76.39 – 25497.5 Ωm. The lower values of ρ_l suggest the presence of water-saturated or fine-grained materials, often linked to aquitards or flood-prone zones, while higher values suggest the presence of coarse-grained materials like sand or gravel, which have higher permeability and could facilitate groundwater recharge and drainage. Thus, areas with low longitudinal resistivity may indicate regions where water stagnates, while higher values signify better drainage and less flood susceptibility. The values of anisotropy range from 1.00 – 3.07. The low anisotropy (1.00) indicates uniform subsurface materials, which may have predictable water flow and drainage characteristics, while high anisotropy (up to 3.07) suggests heterogeneity in the subsurface, with alternating layers of conductive and resistive materials. This could lead to localized zones of water accumulation and potential flooding. Thus, higher anisotropy indicates potential complexity in subsurface water movement, leading to challenges in flood management and prediction. It can be inferred from this result that areas with low transverse and longitudinal resistivity combined with high anisotropy may be particularly vulnerable to flooding. The variations of transverse resistivity, longitudinal resistivity, and anisotropy are shown in Figures 5a, 5b, and 5c respectively. The transverse and longitudinal resistivity show similar variation trends where high values are observe in the southeastern and northeastern part and correspond to that of layers resistivity in Figures 1a, 1b, and 1c.

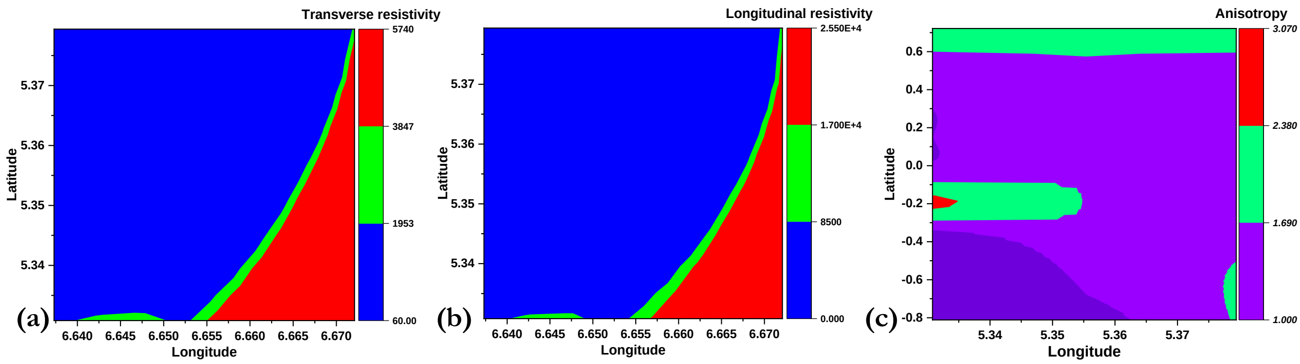

Figure 5. *Contour showing the distribution of* (a) *transverse resistivity,* (b) *longitudinal resistivity, and* (c) *anisotropy*

Electrical resistivity tomography

ERT is used to characterize the subsurface by mapping variations in electrical resistivity, which can provide critical insights into factors contributing to flooding. This study considers three profiles (Figures 6, 7, and 8), which help to demonstrate the resistivity variations within the study area. Profile 1 (Figure 6) delineates low resistivity at the top and shallow layers which spread laterally across the study area. The shallow low-resistivity zones (Blue) dominate the upper subsurface, suggesting water-saturated soils, likely due to clayey materials or high groundwater le-

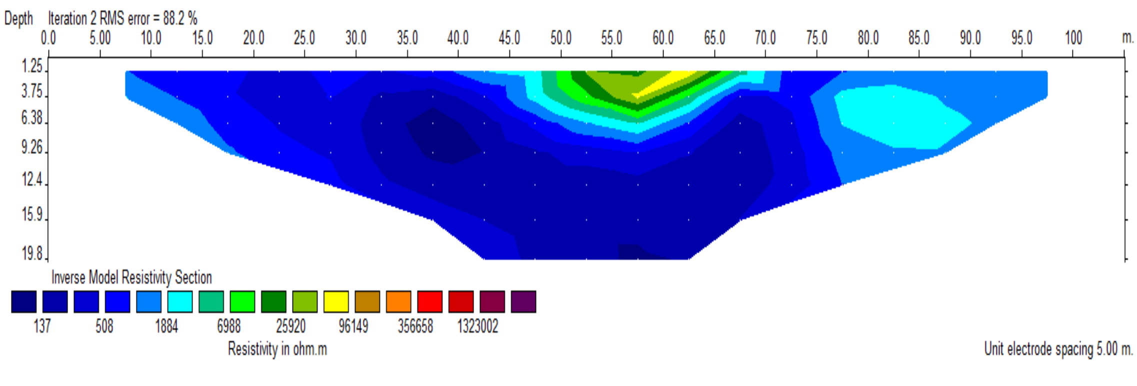

Figure 6
ERT profile 1

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vels. These areas are significant contributors to flooding as they hinder natural drainage. The moderate resistivity zones (Green to Yellow) are localized around the middle of the profile and suggest sandy or silty materials with better drainage properties. However, their presence may only provide limited relief for floodwaters. The dominance of low-resistivity zones reflects high susceptibility to flooding due to poor drainage and water retention in the soil. Flood-prone areas in Omoku are likely linked to these saturated subsurface layers, which prevent efficient infiltration or runoff. Profile 2 (Figure 7) has similar trend as profile 1 where the low-resistivity zones (Blue) dominate the entire subsurface, signifying water-saturated soils, attributed to clayey materials or high groundwater levels. These areas enhances flooding by obstructing natural drainage. The moderate resistivity zones (Green to Yellow) suggest sandy or silty materials with better subsurface drainage properties.

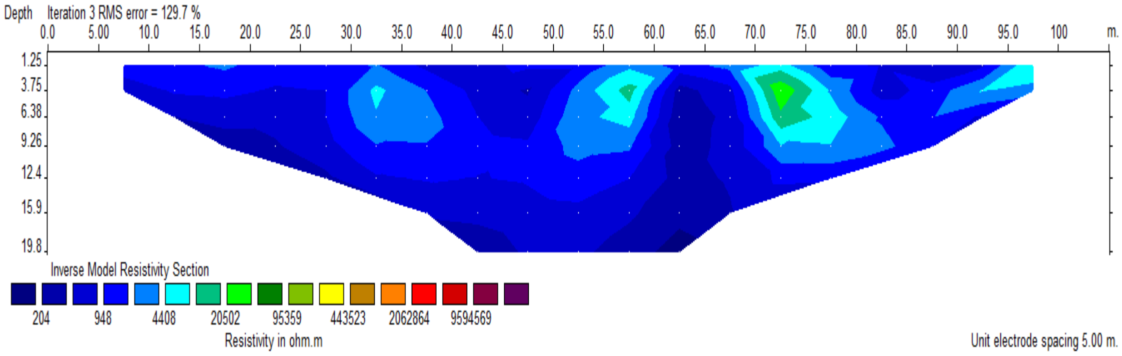

Figure 7
ERT profile 2

Profile 3 (Figure 8) delineates regions of high, moderate, and low resistivity, where low resistivity region is sandwiched between moderate and high resistivity regions. The high resistivity region may correspond to less permeable or unsaturated materials like rocks, compact soils, or sandy layers with low moisture content. The low resistivity region may likely indicates zone of high water saturation, this could represent an aquifer, a clayey layer with significant water retention, or a water-saturated zone prone to flooding. A low resistivity region sandwiched between high and moderate resistivity zones suggests a saturated or clayey layer that can act as a reservoir or pathway for water, potentially contributing to waterlogging or flooding. This configuration may also indicate limited vertical water flow, where impermeable or semi-permeable layers trap water, exacerbating flood risk in the area.

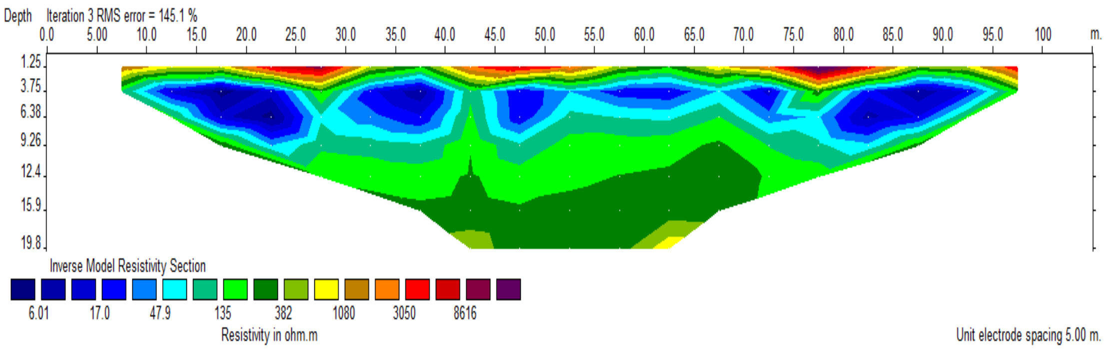

Figure 8
ERT profile 3

Conclusions

The integrated geophysical investigation at the Federal College of Education (Technical), Omoku, and its environs provides detailed insights into subsurface properties and their influence on flooding. The study utilized geo-electric resistivity and electrical resistivity tomography (ERT) to identify key subsurface characteristics that influence water storage, drainage, and flood risks. Four geo-electric layers were identified, each with distinct resistivity, thickness, and depth ranges. The shallow top layer with variable composition (sandy, clayey, or silty materials), its low

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resistivity zones indicate high moisture or clay content, increasing flood risk due to poor drainage. The second layer with variable resistivity, the low resistivity zones signify saturated materials prone to flooding. The third layer was delineated as highly heterogeneous, with zones of saturated sands and silts as well as consolidated materials. The fourth layer with high resistivity, though fracture zones could facilitate groundwater flow, indirectly affecting surface flooding. The Negative reflection coefficients correspond to highly conductive layers (saturated or clay-rich zones) and highlight areas prone to water retention and poor drainage. The Low transverse and longitudinal resistivity values correlate with flood-prone areas due to the presence of fine-grained, water-saturated materials. The ERT Profiles revealed low-resistivity zones in shallow subsurface layers, indicating water-saturated soils and poor drainage, which are significant contributors to flooding. Moderate and high resistivity zones correspond to materials with better drainage, although their influence may be limited by the dominance of low-resistivity regions. The low-resistivity regions mapped in ERT profiles are primary indicators of areas with high flooding susceptibility, particularly due to the presence of clayey, water-retaining soils and saturated layers. The study identifies zones of poor drainage, high water retention, and limited vertical water flow as primary contributors to flooding within the campus and surrounding areas. Subsurface heterogeneity, with alternating conductive and resistive materials, complicates water movement and increases localized flooding risks. The presence of impermeable or semi-permeable layers trapping water exacerbates flood risks during heavy rainfall or high groundwater conditions. This study recommend improve surface drainage systems to mitigate waterlogging in areas with low transverse and longitudinal resistivity, and also enhance groundwater recharge zones in areas with higher resistivity values (indicative of sandy or gravelly materials) to facilitate better drainage. This integrated geophysical approach demonstrates the effectiveness of combining resistivity methods to understand and address flooding challenges in the study area.

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