

Original Research Article

An Integrated Approach to the Investigation of groundwater potential in parts of Akuku-Toru Local Government Area, Rivers State, Nigeria

ABSTRACT

Aim: This study aims to assess groundwater potential in some parts of Akuku-Toru Local Government Area by integrating the geophysical data from Vertical Electrical Sounding (VES) surveys with geospatial analysis. The research seeks to provide a comprehensive understanding of groundwater availability and its correlation with geophysical and the geospatial parameters.

Study Design: A comprehensive approach was adopted involving the collection of Vertical Electrical Sounding (VES) data at multiple locations within the study area. Geospatial data including elevation, Drainage density, Geology, Apparent resistivity and slope maps information were also incorporated. The collected data were subjected to rigorous processing, correlation analysis and reclassification to explore the potential of freshwater resources in the study area.

Place and Duration of the Study: The research was conducted in four communities (Abonnema, Ekulama, Jacobkiri and Belema) within the Akuku-Toru Local Government Area over a span of 18months. The area's hydrogeological context and topographical features are investigated to determine groundwater potential zones.

Method: The research utilized the Vertical Electrical Sounding (VES) method to obtain aquifer resistivity data, reflecting subsurface Lithological variations. Geospatial analysis involved accessing elevation and drainage density patterns. Correlation analysis was also performed to link the geophysical and geospatial data with qualitative interpretations, facilitating the assignment of numerical values representing groundwater potential zones.

Results: The Correlation analysis revealed insightful patterns. Aquifer resistivity, elevation and slope were identified as influential parameter affecting groundwater potential. The geology of the study area, categorized into dominant formations, exhibited varying degrees of potential for freshwater resources. The Correlation of geophysical and geospatial data provided a comprehensive understanding of groundwater availability across the study region.

Conclusion: The integration of geophysical and geospatial analysis offers a robust approach to groundwater potential assessment. The research findings contribute valuable insights into the spatial distribution of potential freshwater resources in the study area. The correlation between aquifer resistivity, elevation, slope, and geology enhances our understanding of hydrological conditions and provides a foundation for future groundwater studies and management strategies.

Keywords: Groundwater potential assessment, Vertical Electrical Sounding, geospatial analysis, aquifer

resistivity, geological formations, freshwater resources

1. Introduction

Water, a fundamental natural resource, is indispensable for sustaining life and fostering societal progress. Its availability and equitable distribution are pivotal for ensuring the well-being of communities and ecosystems. In the context of water resources, both surface water and groundwater play indispensable roles. While surface water is more conspicuous, groundwater constitutes an essential yet often overlooked reservoir of freshwater. Groundwater resources, accounting for less than 30% of the world's freshwater reserves, contribute significantly to supporting diverse human and environmental needs [1][3]. Over 1.5 billion people globally rely on groundwater for their drinking water requirements, underlining its vital importance [15].

Groundwater's significance is particularly pronounced in regions grappling with sporadic surface water availability. Its inherent resilience to pollution risks, ease of extraction, and potential for long-term storage make it an invaluable asset. However, despite its crucial role, many areas encounter challenges related to groundwater overexploitation and resource management, stemming from inadequate knowledge of subsurface dynamics [2]. Addressing these challenges demands a deeper understanding of hydrogeology, which serves as the foundation for informed groundwater management strategies [7].

In this endeavor, the integration of geophysical techniques, remote sensing, and Geographic Information Systems (GIS) has emerged as a transformative approach. Vertical Electrical Sounding (VES) surveys facilitate the characterization of subsurface lithological variations and potential aquifer zones, contributing to a more comprehensive understanding of groundwater distribution [6][13]. Remote sensing harnesses electromagnetic radiation to analyze surface spectral characteristics, enabling the identification of potential groundwater-rich areas [17][10]. GIS complements these techniques by enabling the creation of accurate groundwater resource maps and modeling of hydrological processes [8].

Within the Akuku Toru Local Government Area of Rivers State, Nigeria, the availability of reliable freshwater resources is a paramount concern for sustainable development. Communities such as Abonnema, Ekulama, Jacobkiri, and Belema heavily depend on groundwater for domestic, industrial, and agricultural needs. However, a dearth of hydrogeological insights hampers effective water resource management and planning [15][11]. Traditional mapping methods fall short in delineating groundwater potential zones with precision [1][4]. To bridge this gap, a multidisciplinary approach integrating electrical resistivity, remote sensing, and GIS techniques is imperative to map and define freshwater potential zones accurately [6].

This research aims to employ a multidisciplinary approach combining VES, remote sensing, and GIS to comprehensively assess groundwater potential in the Akuku Toru Local Government Area. By integrating geophysical and spatial data, the study endeavors to contribute valuable insights into the distribution and characteristics of groundwater resources. Through these efforts, the research seeks to enhance groundwater management practices and promote sustainable water resource utilization within the study region.

In the subsequent sections of this paper, we delve into the methodology, results, and implications of our research findings. By addressing the gaps in hydrogeological knowledge, our study endeavors to provide a foundation for effective water resource management and inform future research endeavors.

2. Study Location

The Akuku-Toru Local Government Area is located in the Niger Delta region of Nigeria and has a complex geological and hydrogeological environment that affects its freshwater resources [5]. The area is part of a large sedimentary basin that covers about 75,000 square kilometers and is influenced by the interaction of geological, hydrological, and environmental factors [12]. The geology of Akuku-Toru is mainly made up of sandstones, shale, and clay deposits, which were formed by sedimentation from the Niger River and its tributaries during the Cretaceous and Tertiary periods. As part of the Niger Delta Basin, the area has rich layers of sediment formed by rivers such as the Niger and Benue [9].

The Niger Delta region is an interesting example of how the hydrology and geology of an area are interconnected [13]. The flow of the Niger River and its tributaries creates a unique hydrogeological environment, with sedimentary rocks that date back to the Eocene period [12]. The communities of Abonnema, Belema, Jacobkiri, and Ekulama, located in the Akuku-Toru Local Government Area, share the same geological and hydrological characteristics as the rest of the Niger Delta region [5][9]. These communities rely on shallow aquifers made up of sand and gravel deposits for their water supply. These aquifers are unconfined and are found along the banks of the Niger River and near the coast of the Atlantic Ocean [5].

Finding sustainable sources of freshwater is very important in the Akuku-Toru Local Government Area, where underground water and rivers meet. This research aims to discover the potential for groundwater in these communities by using a combination of geophysical and spatial data. By studying the geology and hydrogeology of the Akuku-Toru Local Government Area, we may be able to find hidden sources of freshwater beneath the surface.

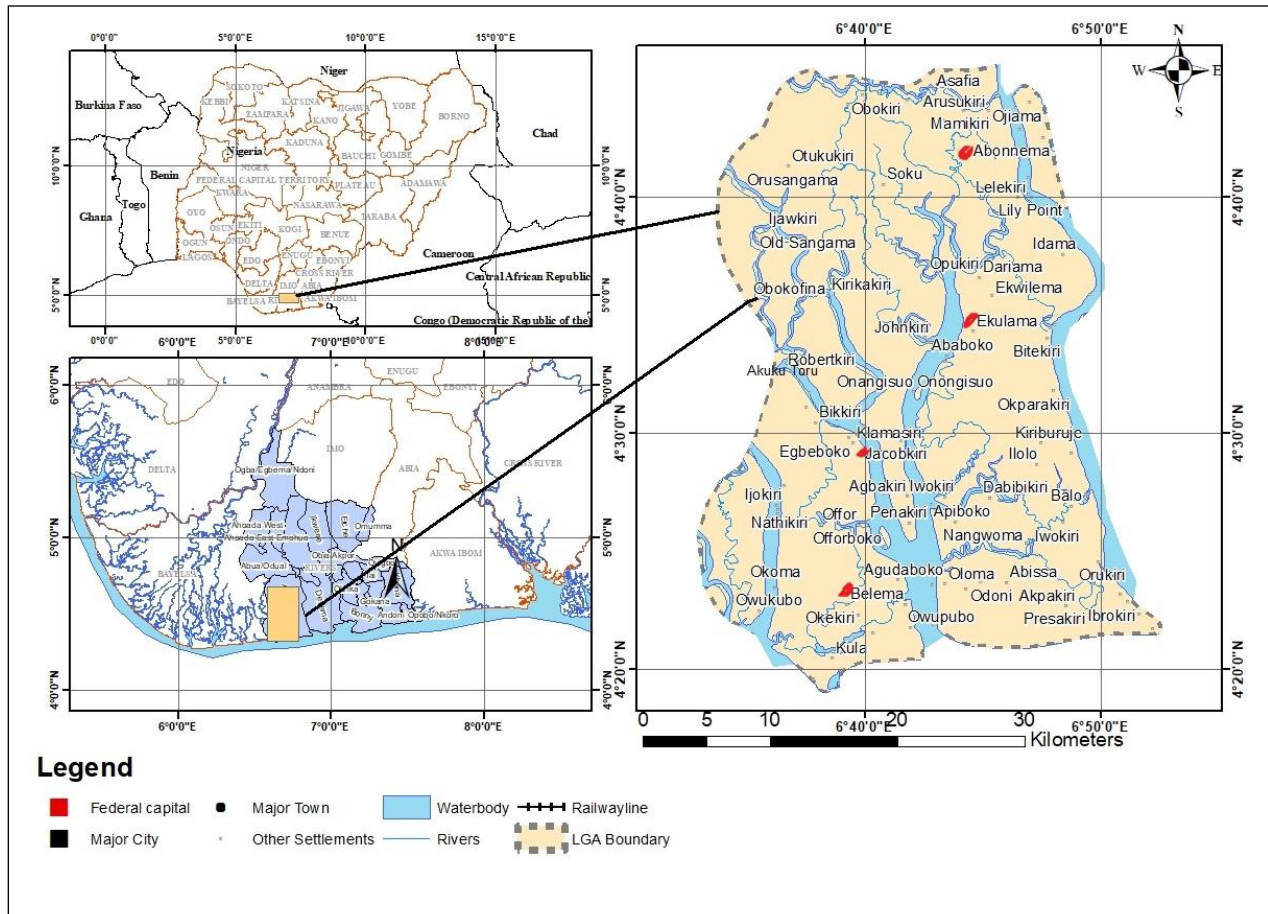


Fig. 1: Location Map of Study Area

3. Materials and Methods

In this study, primary and secondary data were used to comprehensively assess groundwater potential in Akuku-Toru Local Government Area. The materials employed encompassed geophysical data obtained through Vertical Electrical Sounding (VES) surveys, geospatial information acquired through remote sensing techniques, geospatial analyses conducted using Geographic Information Systems (GIS), The integration of these multidisciplinary approaches allowed for a comprehensive exploration of groundwater resources, their distribution and potential zones within the study area [6][16].

3.1 Vertical Electrical Sounding (VES)

For the electrical resistivity analysis, eight VES data were collected from four coastal communities in Akuku-Toru (Abonnama, Belega, Jacobkiri and Ekwilema). Two VES data were acquired from each community using the Abem Terrameter SAS 300B. Four pairs of electrodes were used in the VES measurements. These electrodes help in injecting electrical current into the ground and measuring the resulting voltage to determine the subsurface resistivity. IP2WIN software was also used to interpret the

resistivity data. Stream delineation was done using the GPS to monitor the flow of stream in the study area [3].

To provide a visual representation of the sampling locations, the study area's vertical electrical sounding (VES) sampling points as depicted in Figure 2.0 is presented. This figure highlights the coverage of the data collection. Additionally, table 1.0 showcases the borehole and VES coordinates in the study area, establishing the spatial relationship between the VES points and Borehole data emphasizing their relevance to the study.

Table 1.0 Borehole and VES Coordinates

S/N	Location	Coordinates		Elevation
		Longitude	Latitude	
1	Abonnema 1	6°46'25'.23'E	4°43'46'.96'N	38 ft
2	Abonnema 2	6°46'25'.99'E	4°43'34'.35'E	40ft
	Ekulama 1	6°41'07'.82'E	4°32'14'.10'N	17ft
	Ekulama 2	6°40'13'.45'E	4°32'40'.28'E	9ft
	Jacobkiri 1	6°40'46'.07'E	4°28'37'.98'N	4ft
3	Jacobkiri 2	6°41'47'.33'E	4°28'40'.57'E	3ft
	Belema 1	6°38'48'.89'E	4°22'55'.09'N	38 ft
4	Belema 2	6°38'53'.74'E	4°22'50'.14'N	40ft

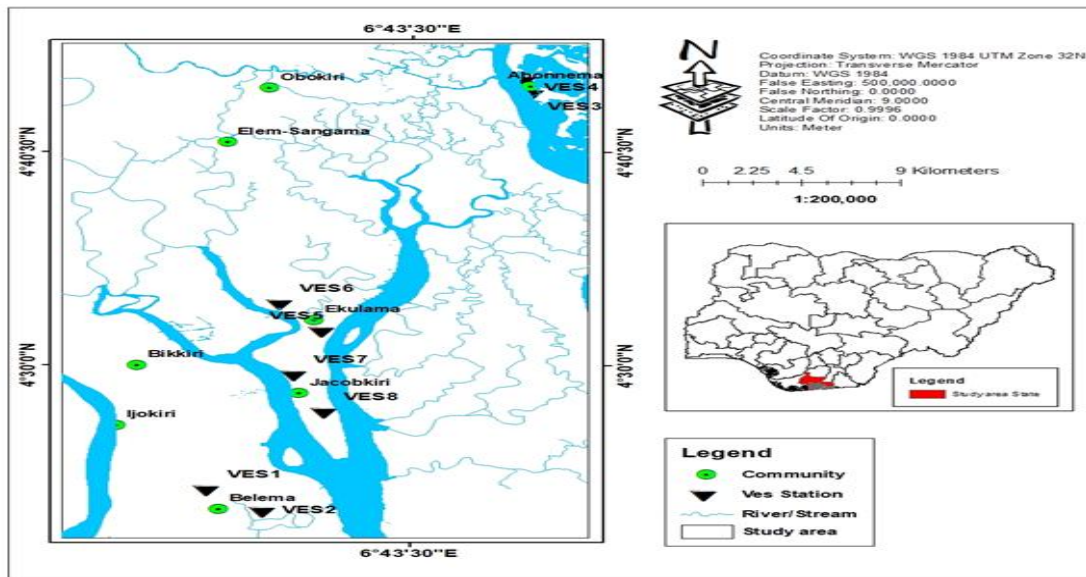


Fig. 2: VES Sampling Location Map

3.2 Remote Sensing Data Acquisition

The remote sensing analysis involved the use of satellite imagery to gather information about the study area's topography and land cover types. ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) data were utilized to obtain topographic information, providing valuable insights into the terrain and elevation variations in the study area. High resolution multispectral satellite images, Landsat 8 OLI data offers multispectral bands with varying resolutions, enabling the analysis of spectral signatures and land cover characteristics [10][8]. These images were used to generate elevation maps, drainage patterns and spectral information. The multispectral data were subjected to preprocessing steps, including atmospheric correction to enhance data quality and suitability for subsequent analysis.

3.3 Geospatial Analysis using Geographic Information Systems (GIS)

Geographic Information Systems (GIS) software was utilized to integrate the VES and remote sensing data with other spatial datasets. The GIS platform enabled the creation of thematic maps depicting groundwater potential zones based on the correlation of geophysical and geospatial parameters. Data layers, including aquifer resistivity, elevation, slope, and drainage density, were overlaid and processed to delineate areas with varying degrees of groundwater potential [6][8][11].

These integrated methodologies allowed for a comprehensive investigation into the hydrogeological characteristics of the study area, offering insights into the spatial distribution of potential groundwater resources in the study area. The workflow presented in Figure 3.0 serves as a guide for executing the methodology, ensuring a systematic and organized approach to the delineation of freshwater potential zones in the study area.

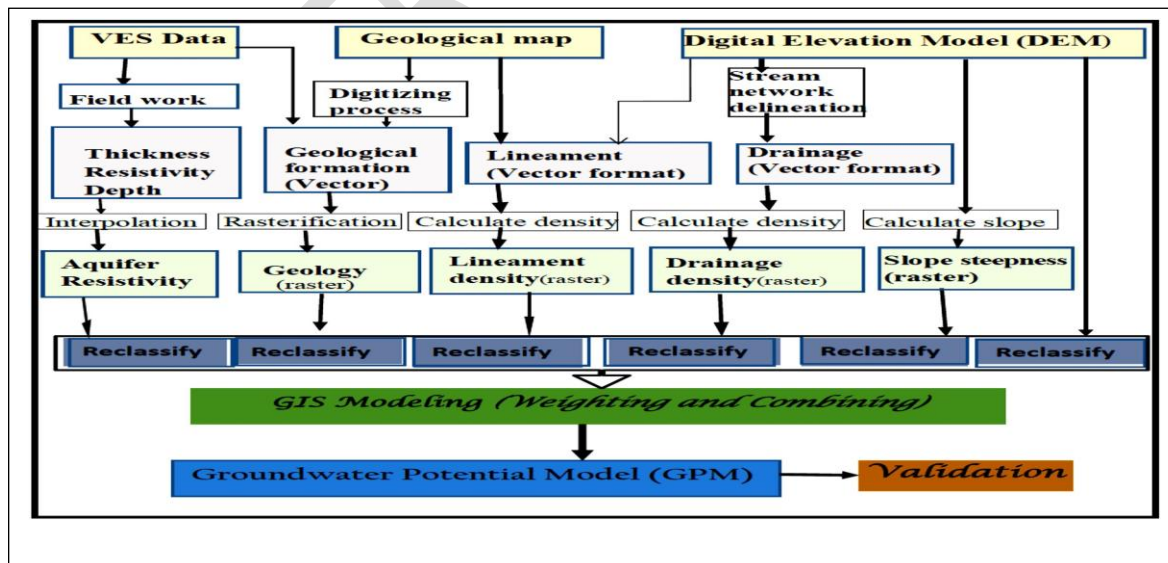


Fig. 4: Workflow of Groundwater Potential Model of Study Area [6]

4. Results

The presented results encapsulate the intricate interplay between geophysical, geospatial and hydrogeological factors, shedding light on the hydrological dynamics that govern the availability of groundwater resources in the study area.

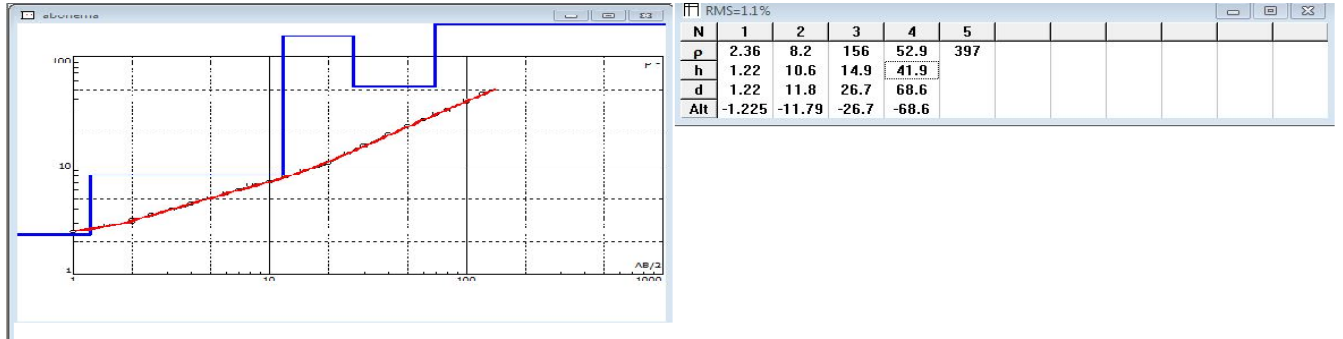


Fig. 5: VES a. Curve type of Abonnema 1 b. Model of Abonnema 1

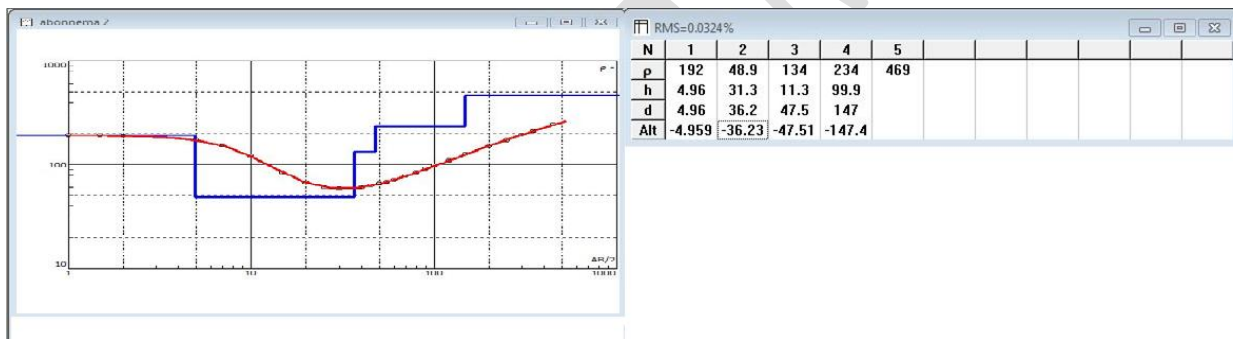


Fig. 6: VES a. Curve type of Abonnema 2 b. Model of Abonnema 2

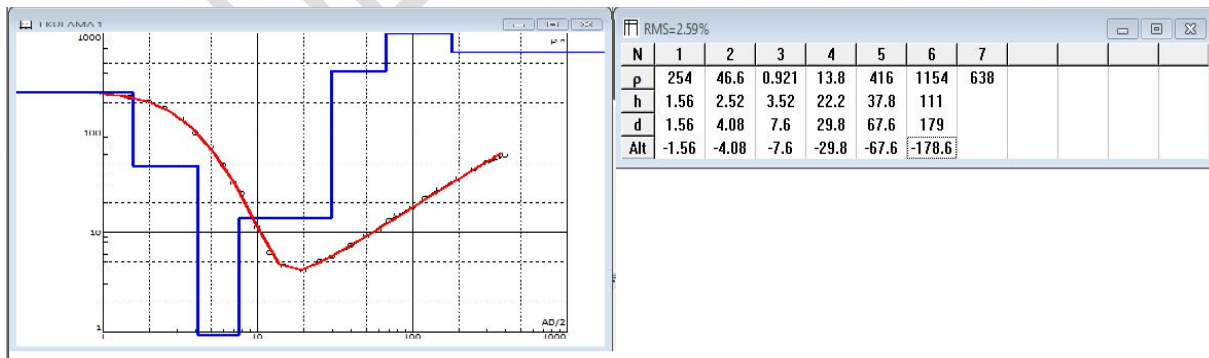


Fig. 7: VES a. Curve type of Ekulama 1 b. Model of Ekulama 1

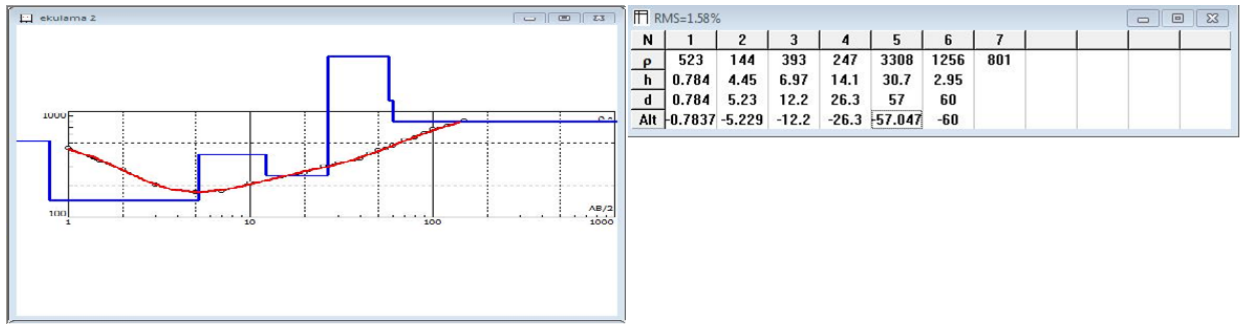


Fig. 8: VES a. Curve type of Ekulama 2 b. Model of Ekulama 2

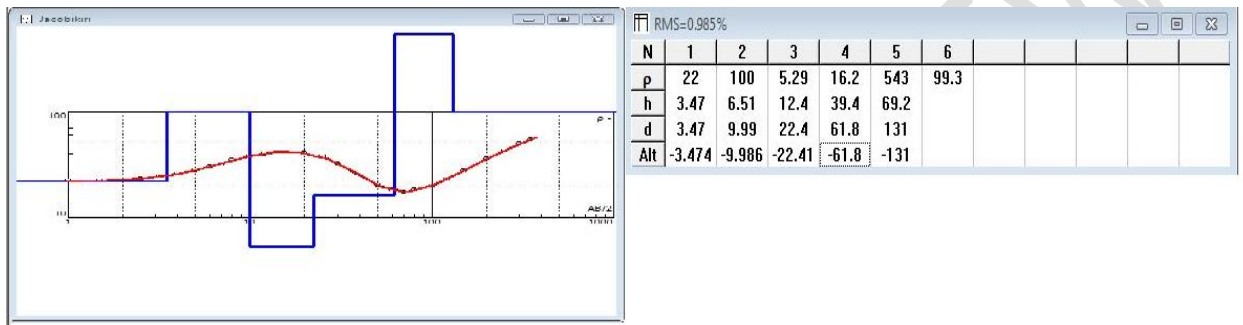


Fig. 9: VES a. Curve type of Jacobkiri 1 b. Model of Jacobkiri 1

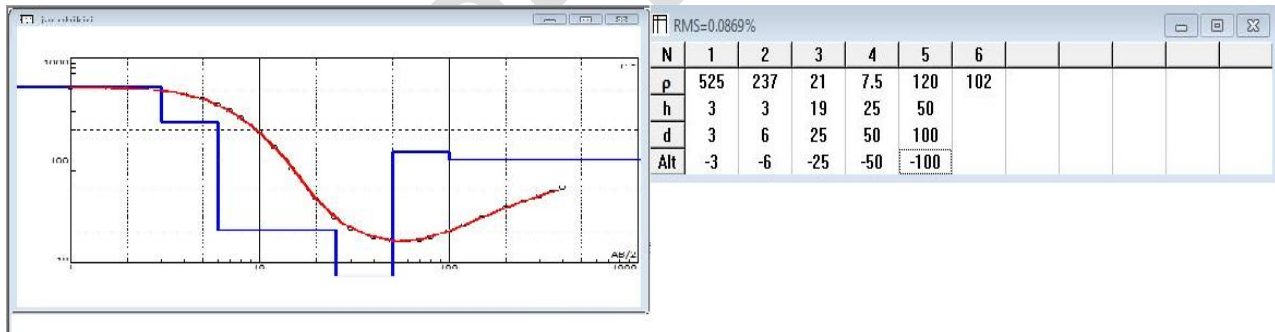


Fig. 10: VES a. Curve type of Jacobkiri 2 b. Model of Jacobkiri 2

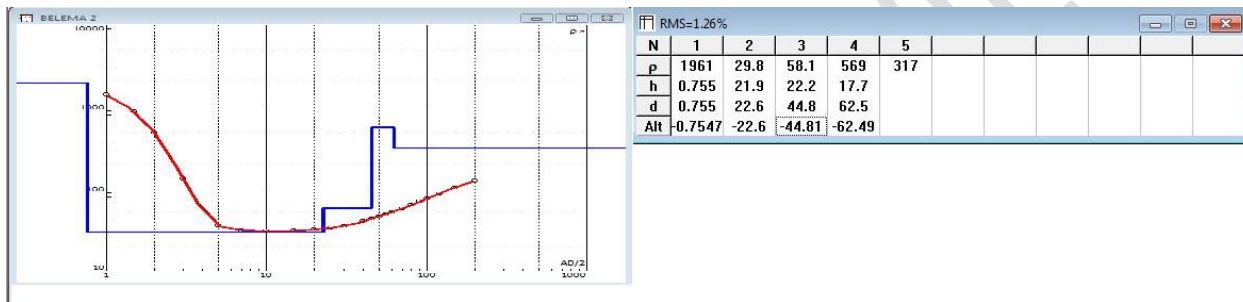
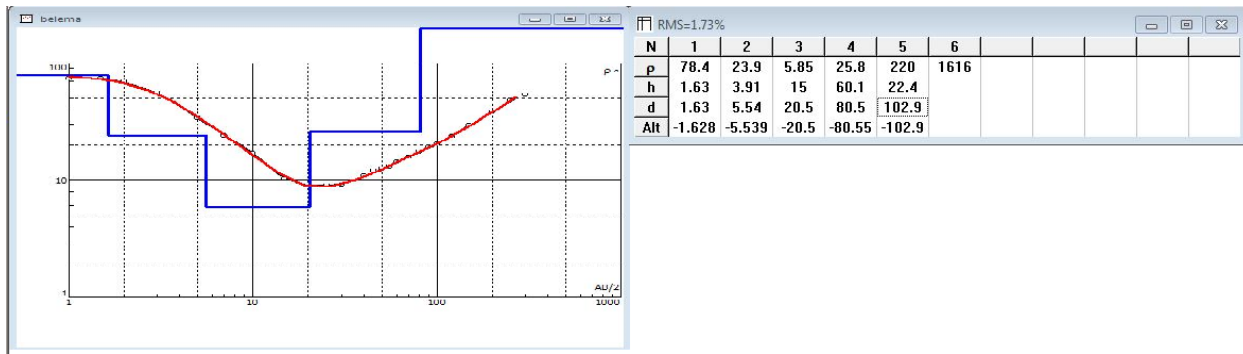


Fig. 12: VES a. Curve type of Belema 2 b. Model of Belema 2

Table 2.0: Summary of VES Results for Sounding Locations

VES Location	Coordinate		Layer Resistivities						Layer thickness						Error %	Curve Types
	Northings	Easting	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h1	h2	h3	h4	h5	h6		
Abonnema 1	6°46'25'.23'E	4°43'46'.96'N	2.36	8.2	156	52.9	397		1.22	10.6	14.9	41.9			1.1	A
Abonnema 2	6°46'25'.99'E	4°43'34'.35'E	192	48.9	134	234	469		4.96	31.3	11.3	99.9			0.0324	HA
Ekulama 1	6°41'07'.82'E	4°32'14'.10'N	254	46.6	0.921	13.8	416	1154	1.56	2.52	3.52	22.2	37.8	111	2.59	QA
Ekulama 2	6°40'13'.45'E	4°32'40'.28'E	523	1441	393	247	3308	1256	0.784	5.23	12.2	26.3	57	60	1.58	HHQ
Jacobkiri 1	6°40'46'.07'E	4°28'37'.98'N	22	100	5.29	16.2	543	99.3	3.47	9.99	22.4	61.8	131		0.985	KA
Jacobkiri 2	6°41'47'.33'E	4°28'40'.57'E	525	237	21	7.5	120	102	3	3	19	25	50		0.869	HA
Belema 1	6°38'48'.89'E	4°22'55'.09'N	78.4	23.9	5.85	25.8	220	1616	1.63	3.91	15	6.01	22.4		1.73	HA
Belema 2	6°38'53'.74'E	4°22'50'.14'N	1961	29.8	58.1	569	317		0.755	22.6	44.8	62.5			1.26	HA

Geospatial Results

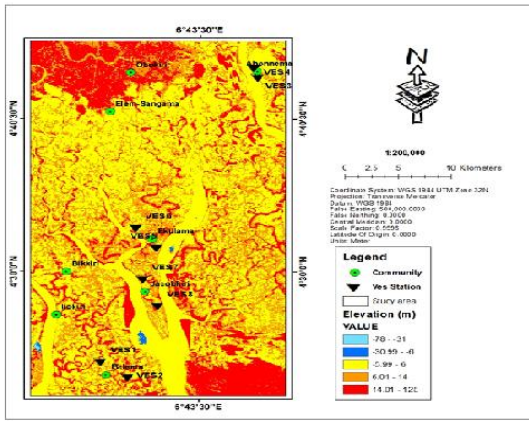


Fig. 13: Elevation map of study area

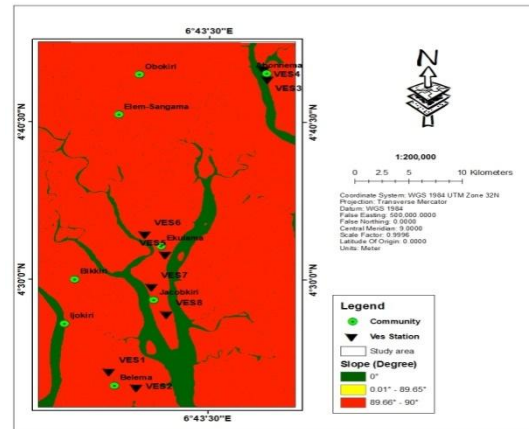


Fig. 14: Slope map of study area

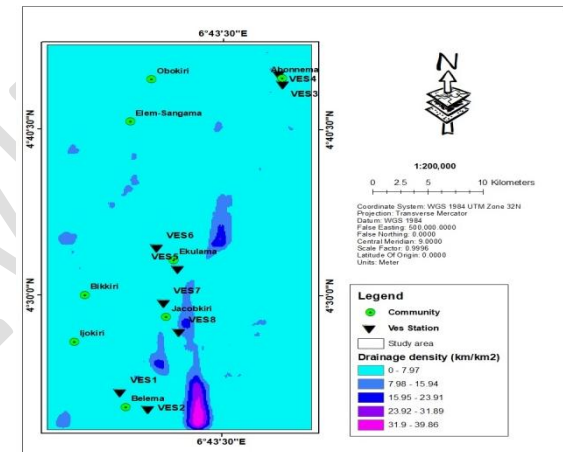


Fig. 15: Drainage density map of study area

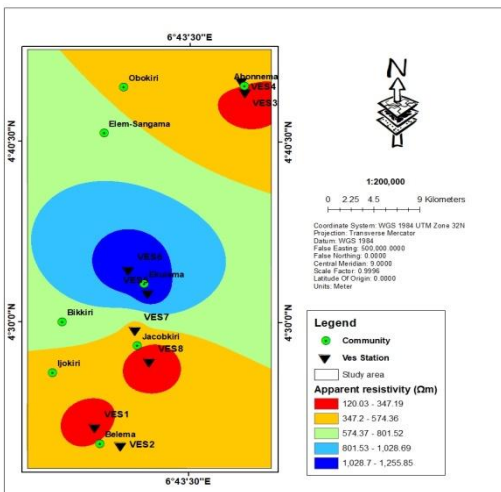


Fig.16: Apparent Resistivity map of study area

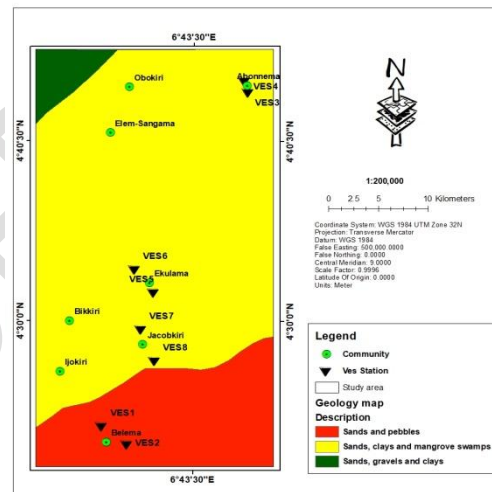


Fig.17: Geology map of study area

Table 3: Summary of Reclassification Results

Community	Apparent Resistivity	Elevation	Slope	Geology	Drainage Density	Remarks
Abonnema	Very High, High, moderate, low	Very low, Low, Moderate High, Very High	Flat, gentle, moderate, Steep, very steep	Clay, Sand Gravel	Very Low, Low, Moderate,	Highest Groundwater Prospect
Ekulama	Very high, High, Moderate, low	Very low, low, moderate, high, very high	Flat, gentle, moderate, steep, very steep	Clay, Sand Gravel	Very low, low, moderate, high, very high	Lower groundwater prospect compared to Abonnema, Belema, and Jacobkiri
Jacobkiri	Very high, high, moderate, low	Very low, low, moderate, high, very high	Flat, gentle, moderate, steep, very steep	Clay, Sand Gravel	Very low, low, moderate, high, very high	Moderate groundwater prospect
Belema	Very high, high, moderate, low	Very low, low, moderate, high, very high	Flat, gentle, moderate, steep, very steep	Clay, Sand Gravel	Very low, low, moderate, high, very high	Higher groundwater prospect compared to Ekulama, lower than Abonnema

Table 4: Descriptive Statistics of Study Area

Community	Variable	Min	Max	Mean	Standard Deviation
Abonnema	Aquifer Resistivity	2.36	397	141.08	171.42
	Elevation	0	40	19	16.43
	Slope	0	15	7.5	6.46
	Geology (Saturated Sand)	1.22	41.9	18.24	17.71
	Geology (Clay)	10.6	41.9	26.2	11.6

	Geology (Fine Sands)	14.9	68.6	36.76	23.54
	Drainage Density	1	1	1	0
Ekulama	Aquifer Resistivity	0.921	144	528.86	623.28
	Elevation	2.52	37.8	15.39	131.16
	Slope	0	37.8	10.98	13.54
	Geology (Coastal flood plain)	2.59	111	39.43	44.69
	Geology (Shallow marine deposit)	3.52	111	39.43	44.69
	Geology (Clay)	22.2	111	44.8	43.65
	Geology (Sand)	37.8	111	57.9	32.37
	Drainage Density	1	1	1	0
	Jacobkiri	Aquifer Resistivity	5.29	543	156.14
Elevation		3	131	39.28	51.17
Slope		0	25	9.65	11.75
Geology (Coastal plain Sands)		0.869	3	1.75	1.29
Geology (Clay)		3	19	12.33	7.95
Geology (sand)		19	25	22	2.83
Drainage Density		1	1	1	0
Belema	Aquifer Resistivity	23.9	1961	448.96	688.67
	Elevation	1,63	1616	326.38	548.61

Slope	0	22	6.58	9.71
Geology (Coastal plain Sands)	1.26	1961	695.3	748.91
Geology (Shallow marine Deposits)	29.8	317	163.9	124.64
Drainage Density	1	1	1	0

Table 5 Results of Groundwater Potential Zone Prediction

S/N	Rating	Class	Area (km ²)	Percentage area (%)
1	2	Low	4.56	0.4
2	3	Moderate	233.97	21.7
4	4	High	797.31	74.1
5	5	Very high	40.5	3.8

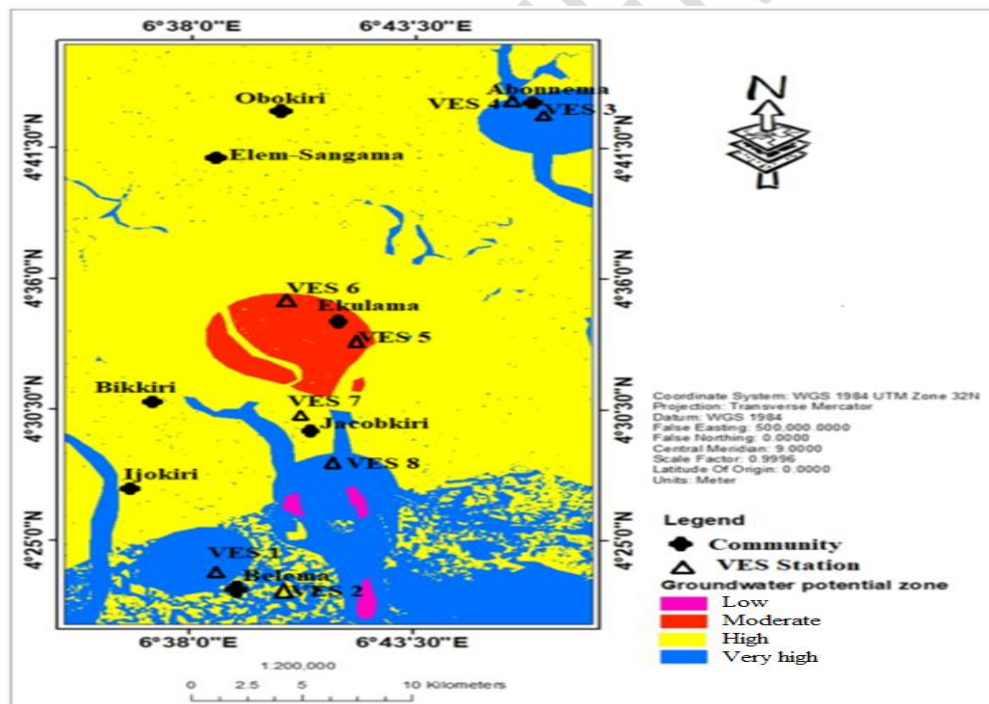


Fig. 18: Groundwater Potential map of study area

Table 6: Correlation between Apparent Resistivity and Inferred Lithology/Remarks

Community	Apparent Resistivity	Lithology	Remarks
Abonnema 1 (VES 3)	High	Topsoil	Non-potential
		Clay	Non-Potential
		Fine Sand	High Potential
		Sand	Medium Potential
Abonnema 2 (VES 4)	High	Fine Sand	Highly Potential
		Topsoil	Highly Potential
		Silty Clay	Medium Potential
		Fine Sand	Potential Zone
Ekulama 1 (VES 5)	Relatively Uniform	Coarse Sand	Medium Potential
		Topsoil	Non-Potential
		Clay	Non-Potential
		Peat	Non-Potential
Ekulama 2 (VES 6)	Low to Moderate	Medium Sand	Potential
		Gravel	Potential
		Coarse Sand	Potential
		Topsoil	Non Potential
Jacobkiri 1 (VES 7)	Low to Moderate	Fine Sand	Non Potential
		Medium Sand	Non-Potential
		Gravel	Potential
		Coarse Sand	Potential
		Clay	Non-Potential
		Fine	Non-Potential
Jacobkiri 2 (VES 8)	Low-Moderate	Peat	Non-Potential
		Clay	Non-Potential
		Coarse Sand	Potential
		Silty Sand	Potential
		Topsoil	Non-Potential
		Fine-Medium Sand	Non-Potential
Belema 1 (VES 1)	Moderate	Clay	Non-Potential
		Peaty Sand	Non-Potential
		Fine Sand	Potential
		Fine Sand	Potential
		Silty-Sand	Moderate
Belema 2 (VES 2)	Varied	Clay	Non-Potential
		Peat	Non-Potential
		Clay	Non-Potential
		Fine Sand	Potential
		Topsoil	Non-Potential
		Clay	Non-Potential
		Silty-Clay	Non-Potential
		Coarse Sand	Potential
		Medium-Sand	Potential

Table 7: Correlation between Slope/Lithology and Inferred Lithology/Remarks

Community	Slope	Elevation	Lithology	Remarks
Abonnema 1 (VES 3)	Gentle	Low	Topsoil	Non-potential
			Clay	Non-Potential
			Sand	High Potential
			Sand	Medium Potential
Abonnema 2 (VES 4)	Gentle	Low	Sand	Highly Potential
			Topsoil	Highly Potential
			Silty Clay	Medium Potential
			Fine Sand	Potential Zone
Ekulama 1 (VES 5)	Moderate to Steep	Low to Moderate	Coarse Sand	Medium Potential
			Topsoil	Non-Potential
			Clay	Non-Potential
			Peat	Non-Potential
Ekulama 2 (VES 6)	Gentle to Moderate	Low to Moderate	Medium Sand	Potential
			Gravel	Potential
			Coarse Sand	Potential
			Topsoil	Non Potential
Jacobkiri 1 (VES 7)	Gentle to Moderate	Low to Moderate	Fine Sand	Non Potential
			Medium Sand	Non-Potential
			Gravel	Potential
			Coarse Sand	Potential
Jacobkiri 2 (VES 8)	Gentle to Moderate	Low to Moderate	Clay	Non-Potential
			Fine	Non-Potential
			Peat	Non-Potential
			Clay	Non-Potential
Belema 1 (VES 1)	Gentle Moderate	Low	Coarse Sand	Potential
			Silty Sand	Potential
			Topsoil	Non-Potential
			Fine-Medium Sand	Non-Potential
Belema 2 (VES 2)	Moderate	Low	Clay	Non-Potential
			Peaty Sand	Non-Potential
			Fine Sand	Potential
			Fine Sand	Potential
Belema 1 (VES 1)	Gentle Moderate	Low	Silty-Sand	Moderate
			Clay	Non-Potential
			Peat	Non-Potential
			Clay	Non-Potential
Belema 2 (VES 2)	Moderate	Low	Fine Sand	Potential
			Topsoil	Non-Potential
			Clay	Non-Potential
			Silty-Clay	Non-Potential
Belema 2 (VES 2)	Moderate	Low	Coarse Sand	Potential
			Medium-Sand	Potential
			Medium-Sand	Potential

5. Discussion

By combining geophysical data, remote sensing observations, and geospatial analyses, the study aims to understand the intricate hydrogeological processes in the Akuku Toru Local Government Area. This

research adds to the larger conversation on evaluating and managing groundwater potential in tropical areas.

Integration of Multidisciplinary Techniques for Groundwater Assessment

The study has demonstrated that combining Vertical Electrical Sounding (VES) surveys, remote sensing, and Geographic Information Systems (GIS) is a powerful and successful method for evaluating groundwater potential. By merging these different datasets, the study takes advantage of their combined strengths and overcomes the limitations of each individual method. This combination not only improves the identification of potential zones but also provides a thorough understanding of the factors that affect groundwater occurrences. This integrated approach enables comprehensive groundwater management and promotes sustainable resource allocation strategies.

Implications of Geophysical Parameters on Groundwater Potential

The connection between the resistivity of an aquifer, its elevation, slope, and potential groundwater zones highlights their combined impact on the availability of water below the surface. The resistivity of an aquifer is a crucial sign of changes in rock types and the paths that groundwater takes, allowing for precise identification of potential aquifer areas. The patterns of elevation and slope offer information on how groundwater is recharged and how it flows, further improving the identification of appropriate locations for extracting groundwater. The complex interplay between these factors reveals the hydrogeological complexities of the area being studied, guiding the development of targeted strategies for managing resources [6].

Hydrogeological Significance of Geology and Remote Sensing

By combining geology and remote sensing data, the study reveals the geological formations that contain potential groundwater reservoirs. The study's categorization of the main formations in relation to potential groundwater zones provides a useful structure for evaluating resources. Remote sensing, using spectral analysis, enhances the identification of potential zones by detecting surface characteristics that suggest the presence of water below the surface. Combining this information with geophysical data improves our overall understanding of hydrogeological structures and provides direction for managing water resources in an informed manner [7][16][13].

Spatial and Temporal Considerations for Groundwater Management

The location of the study area is within the Niger Delta region, which has a complex hydrogeological system, emphasizes the significance of considering space and time in managing groundwater [13][17]. The interaction between surface water and groundwater recharge requires a comprehensive approach

that takes into account changes in seasons and the possibility of contamination. The connection between aquifer systems and water-related elements underlines the necessity for flexible management strategies that can adapt to changing circumstances to protect freshwater resources for future generations.

Limitations and Future Directions

This study improves our knowledge of evaluating groundwater potential in the Akuku Toru Local Government Area, but there are some limitations that need to be taken into account. Using secondary data for some factors may result in some uncertainty in the results. Furthermore, the complicated hydrogeological characteristics of the Niger Delta region necessitate additional investigation to improve the precision of identifying potential zones. Future research could include real-time monitoring, the use of climate data, and predictive modeling to improve the ability to predict groundwater assessments.

Conclusion

In conclusion, the integrated approach of this study, utilizing geophysical, remote sensing, and geospatial analyses, has provided a comprehensive insight into groundwater potential assessment. The findings shed light on the intricate hydrogeological dynamics within the Akuku Toru Local Government Area and offer a valuable foundation for sustainable groundwater management. The holistic synthesis of diverse datasets enhances our understanding of groundwater occurrences, fosters informed decision-making, and serves as a vital tool for policymakers, water resource managers, and researchers in tropical regions and beyond.

The thorough examination of groundwater occurrences in the Akuku Toru Local Government Area is not the end, but rather a starting point for further exploration. Our study serves as both a foundation and a springboard for future research. As we look to the future, we are encouraged to dig deeper, improve our understanding, and go beyond the limits of what we currently know. We urge future researchers to take up this challenge and use our findings as a guide towards developing predictive models, flexible management strategies, and real-time monitoring.

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