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**ELECTRICAL RESISTIVITY SURVEY FOR PREDICTING POTENTIAL
ZONES AND AQUIFER PROTECTIVE CAPACITY IN SAGAMU, OGUN
STATE, NIGERIA.**

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ABSTRACT

In rapidly evolving peri-urban areas, producing aquifers must be evaluated with reference to natural protection afforded by overlying materials as well as identification of water-bearing formations. The groundwater potential zones and aquifer protective areas in the Apaken area of Sagamu, Ogun State, south-western Nigeria have been assessed in this study by the integrated ER approach. Natural electric field (NEF) measurements were supplemented by 12 vertical electrical sounding (VES) profiles with the Schlumberger array and six two-dimensional electrical resistivity survey (ERT) profiles with the Wenner array. VES data were partially curve matched and computer assisted iterated, while ERT data were inverted to form 2D resistivity sections. The aquifer occurrence and the overburden's protecting capacity have been interpreted based on geoelectric parameters and Dar-Zarrouk relationships. The interpreted geoelectric models suggest that there are 3 to 5 layers with the topsoil, lateritic layer, and the sandy clay and overburden layer of ferruginous, medium to coarse-grained sand, ranging from 1.2–24.0 m. The main aquiferous interval is ferruginous fine sand. According to the reported interpretation, the groundwater-yield classes are moderate-to-high at 50% of the VES locations and very low-to-low at 50% of the locations. The results of the longitudinal-conductance assessment suggest that 91.67% of the sites are poorly protected, while the remaining 8.33% are protected poorly. The sites of VES 4, 6 and 11 are all favourable for groundwater and have moderate protection, and were recommended for further drilling investigation. The results of the ERT and NEF are independent and indicative to good groundwater conditions along traverses 3 and 4. The results illustrate that groundwater productivity and aquifer protection are decision variables that are different but complementary. Groundwater-potential assessment alone is not as defensible as the integrated interpretation for borehole siting and groundwater-resource protection in Sagamu.

Key words: electrical resistivity, vertical electrical sounding, electrical resistivity tomography, groundwater potential, aquifer protective capacity.

1. INTRODUCTION

1.1 Background

Groundwater is a key resource for water security as it can offer fairly reliable supplies where surface water sources are seasonal, degraded or sparsely distributed. Urbanisation, industrial activities and population growth in the Southwest of Nigeria make it more important to be able to identify groundwater resources prior to drilling, and also decreases the chances of contaminating groundwater resources. Alabi et al., (2021), Olatinsu & Salawudeen, (2021) and Osumaje et al., (2024) conducted recent studies on NIR in Nigeria which revealed that the methods are still relevant in delineating the geometry of the aquifers, assessing the potential of groundwater and evaluating vulnerability, especially when the interpretations are guided by geology and other supplementary data.

1.2 Groundwater-investigation tools: Electrical resistivity

Electrical resistivity methods take advantage of variations in the electrical characteristics of materials in the subsurface. The apparent resistivity measured in groundwater investigations depends on lithology, porosity, degree of saturation, pore-fluid conductivity, clay content and textural variations. Thus, resistivity does not directly measure groundwater quantity. The utility is in the ability to delineate geoelectric boundaries and to determine thickness-resistivity-geologic setting combinations consistent with occurrence of aquifers. Groundwater targeting decisions have been enhanced by recent studies that have shown that VES, ERT and integrated geophysical techniques can contribute to the improvement of groundwater targeting decisions when appraised within the local geology (Fajana, 2020; Agyemang, 2021; Osumaje et al., 2024).

1.3 Aquifer protective capacity

Potential for groundwater and capacity to protect aquifers are two different hydrogeological answers to different questions. Groundwater potential refers to the probability of an aquifer holding a substantial amount of groundwater that can be utilized and protective capacity refers to the ability of overlying materials to prevent contaminants from migrating down through the overburden. The parameters of Dar-Zarrouk are widely used geoelectrical indicators that can be used to assess the protection offered by overburden. In recent times in Nigeria and similar environments, the importance of integrating aquifer geometry, with protective-capacity analysis, rather than using aquifer prospectivity alone to determine where to drill, has been demonstrated (Alabi et al., 2021; Ademolu et al., 2025).

1.4 Problem statement and research gap

A groundwater-quality risk is possible in a groundwater-quality target that is overlain by a thin, permeable, or poorly-protective sequence. In contrast, an aquifer that is adequately protected might not be sufficiently thick or have adequate hydraulic characteristics to allow its economical abstraction. The central research question is not just where groundwater might be, but where groundwater occurrence and natural aquifer protection converge to a point suitable for responsible development. The groundwater-potential evaluation, protective capacity assessment and independent geophysical corroboration was useful in the Sagamu investigation, combining the three elements in groundwater exploration and is particularly useful in the present investigation of Ogun state.

1.5 Aim and objectives

The aim of this study is; to evaluate groundwater potential zones and aquifer protective capacity in Sagamu, Ogun State, using electrical resistivity and complementary geophysical methods. The objectives are;

- i. delineate the subsurface geoelectric layers and infer their lithological significance;
- ii. identify the principal aquiferous formations and their spatial distribution;
- iii. assess groundwater potential using geoelectric and hydrogeophysical indicators;
- iv. evaluate aquifer protective capacity using longitudinal conductance and related Dar-Zarrouk concepts;
- v. compare the independent evidence from VES, ERT and NEF;
- vi. identify locations that merit confirmatory drilling and hydrogeological investigation; and
- vii. discuss implications for groundwater protection and sustainable water-resource management.

Figure 1. Integrated hydrogeophysical workflow

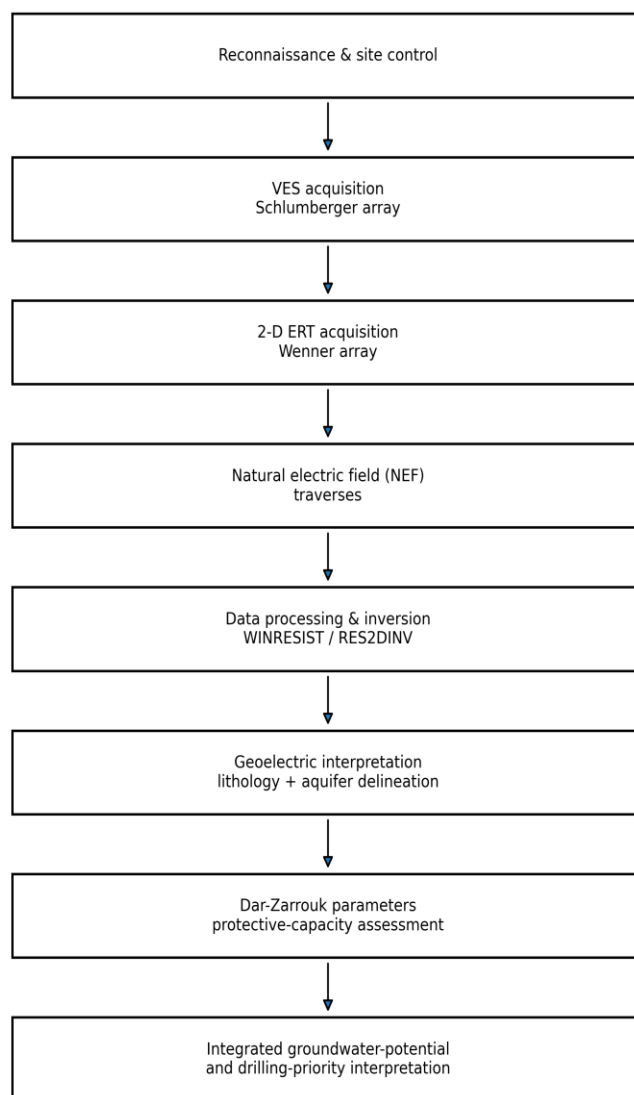


Figure 1. Integrated hydrogeophysical workflow used for groundwater-potential and aquifer-protection assessment.

2. STUDY AREA

2.1 Geographic and environmental setting

The Sagamu area is located in Ogun State of southwest Nigeria which is a critical region for groundwater development for domestic, agricultural and industrial purposes. The Apaken investigation is a local-scale hydrogeophysical study that is being carried out in the Sagamu environment. An exact VES/ERT, administration boundary, roads, drainage and relevant geological contacts must be verified on the location map to accompany the study-area section for final journal submission. Where no coordinates are provided in the source record, the present manuscript does not attempt to provide coordinates.

2.2 Geological and hydrogeological setting

The subsurface sequence that is known where the area of interest is interpreted as unconsolidated to semi consolidated near surface materials and sand rich layers. The geoelectric models reported are the formation of topsoil, laterite, sandy clay and ferruginous sand with the laterite being the main aquiferous layer. The thickness, continuity and hydraulic properties of the sandy units and extent of occurrence of the low-permeable units overlying the sandy units are very important for groundwater occurrence.

2.3 Conceptual hydrogeological model

The conceptual model adopted is a vertically different overburden sequence, consisting of topsoil, lateritic materials, locally sandy clay and ferruginous sand. Particularly for groundwater development, the ferruginous fine sand interval is assumed to be the most significant. The thickness and electrical characteristics of the overlying material(s) are significant to protective effect and cannot be taken for granted; must be quantified.

Figure 3. Conceptual geoelectric/hydrogeological model for the Sagamu setting

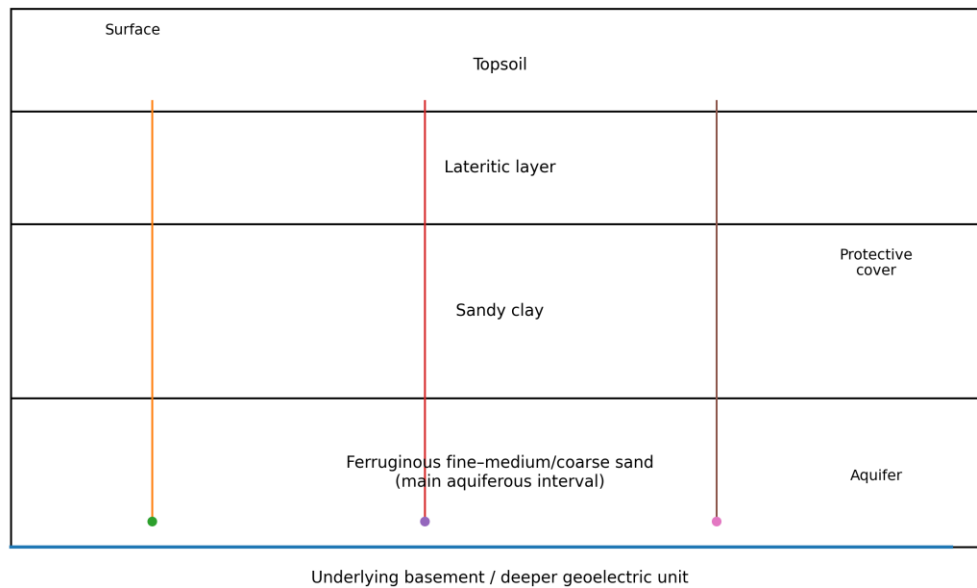


Figure 2. Conceptual geoelectric/hydrogeological model of the interpreted Sagamu setting; schematic and not to scale.

3. MATERIALS AND METHODS

3.1 Survey design and data acquisition

Three complementary geophysical components were used in the reported investigation: 12 VES sites using the Schlumberger array; six 2-D ERT profiles using the Wenner array; and NEF measurements along the ERT traverses. The horizontal information is complemented by the vertical information. The values of the resistivities and thickness of the layered earth, especially, can be estimated by VES; ERT can give two dimensional continuous variation of resistivity in space. NEF was not used as a single indicator of the differences in electrical properties of the sub-surface layers, but rather as an extra tool (Ademolu et al., 2025).

Figure 2. Schematic of Schlumberger VES configuration and conceptual subsurface layers

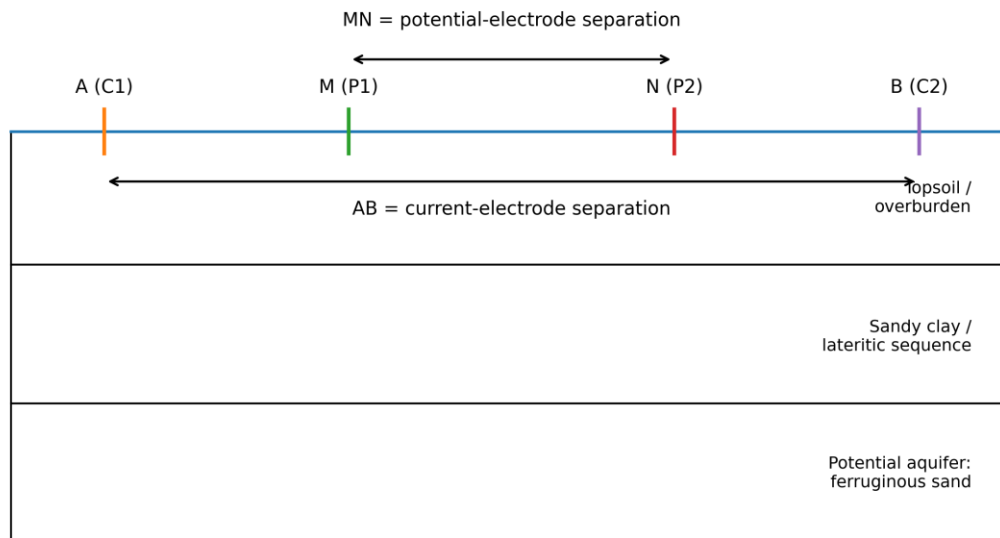


Figure 3. Schematic Schlumberger VES configuration used to resolve vertical geoelectric layering.

3.2 Apparent resistivity

For a homogeneous half-space, apparent resistivity is expressed generally as:

$$\rho_a = K R$$

In this equation, ρ_a is the apparent resistivity, K is a geometric factor that depends upon the configuration of the electrodes, and R is the measured resistance. The apparent resistivity is then analyzed with the layered earth model. Apparent resistivity can not be directly compared to lithological resistivity, because it represents a combination of the volume of the electrodes' field configuration.

3.3 VES interpretation

Partial curve matching and computer-assisted iteration with WINRESIST was used to interpret the VES curves. The process calculates layer resistivities and thicknesses which simulate the apparent-resistivity response observed. The geological setting and the likely electrical character of laterite, clay-rich material, sand and ferruginous sand was used for the interpretation. The number of geoelectric layers which were present at the VES sites was 3-5.

3.4 ERT inversion

RES2DINV was used to process and invert the 2-D ERT data. The intent of the work was to produce resistivity sections that provide a better insight into lateral and vertical variations not provided by a one dimensional interpretation. The following should be reported for each profile for a publication ready publication: inversion RMS error, electrode spacing, profile length, depth of investigation and interpreted geological boundaries. The numerical metadata are not reproduced here since they were not enclosed with the title page supplied.

3.5 Natural electric field measurements

A PQWT system was used to collect NEF measurements along the investigation traverses, which were used as an independent line of evidence. The NEF agreement with resistivity at the two traverses (3 & 4) gave good groundwater conditions, it was reported.

3.6 Dar-Zarrouk parameters

The longitudinal conductance of a geoelectric layer i is given by:

$$S = \Sigma(h_i / \rho_i)$$

where h_i is layer thickness and ρ_i is layer resistivity. Transverse resistance is expressed as:

$$T = \Sigma(h_i \rho_i)$$

Longitudinal conductance in particular is relevant to the estimation of protective capacity because a thick, relatively conductive overburden may be indicative of a low permeability (clayey) material that may hinder the movement of contaminants. But always remember the chemistry of pore fluids can also impact electrical conductivity, as well as various other factors.

3.7 Groundwater-potential classification

Groundwater potential was assessed by integrating aquiferous resistivity, thickness and the aquiferous reflection-coefficient/overburden-thickness interpretation reported. The sites were classified as very low, low, moderate and high potential classes. This method is more preferred than resistivity as there may be multiple interpretations of geology for a resistivity value, which would give rise to multiple groundwater potential values.

3.8 Protective-capacity classification

A parameter for the protective capacity was taken as the overburden's longitudinal conductance. The identified issues in the reported study are poor and weak protective classes. The threshold scheme for each class should be given in a specific table in a final submission and be related to the classification source used by the authors.

3.9 Integrated decision logic

The final interpretation adopts the interpretation of the groundwater potential and protective capacity as two decision axes which are independent. Not all sites with high potential are optimal in terms of drilling conditions; optimal drilling sites are those where productive conditions in the aquifers are fulfilled along with acceptable protection and where geophysical data is at least independent of the drilling site.

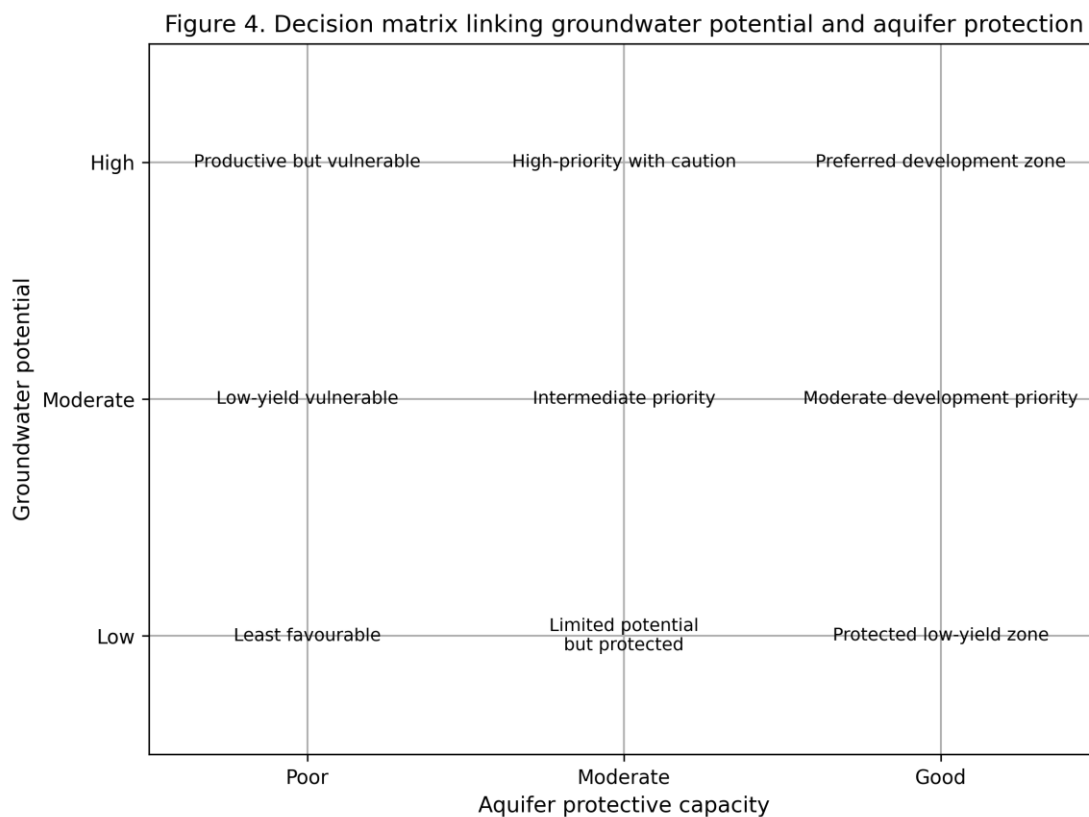


Figure 4. Decision matrix showing why groundwater potential and aquifer protective capacity should be evaluated jointly.

4. RESULTS

4.1 Geoelectric layering

The reported VES interpretation delineated three to five geoelectric layers. The principal units comprise topsoil, lateritic soil, sandy clay and ferruginous medium- to coarse-grained sand. The reported ranges are summarised in Table 1.

Geoelectric unit	Reported resistivity range (Ω m)	Reported thickness range (m)	Interpretation
Topsoil	55.5–747.3	0.4–2.9	Near-surface soil/topsoil
Lateritic layer	225.6–8,985.8	0.8–18.3	Lateritic/ferruginous overburden
Sandy clay	504.3–5,477.8	6.5–34.6	Intermediate sandy-clay unit
Ferruginous medium-coarse sand	603–4,422.8	Not separately stated in abstract	Aquifer-related sand unit
Total overburden	—	1.2–24.0	Combined overburden thickness

As can be seen by the large ranges of resistivity, lithological correlation, and not lithological resistivity thresholds, is important. The interval of the aquiferous-ferruginous sand is not only identified by the resistivity, but also by the geoelectric pattern and the geologic context.

4.2 Groundwater potential

The groundwater-yield interpretation reported is for 50% of VES locations to be in the moderate-to-high groundwater-yield class and 50% of VES locations to be in the very low-to-low groundwater-potential class. This suggests that there is high spatial variability with respect to groundwater prospectivity in the area surveyed.

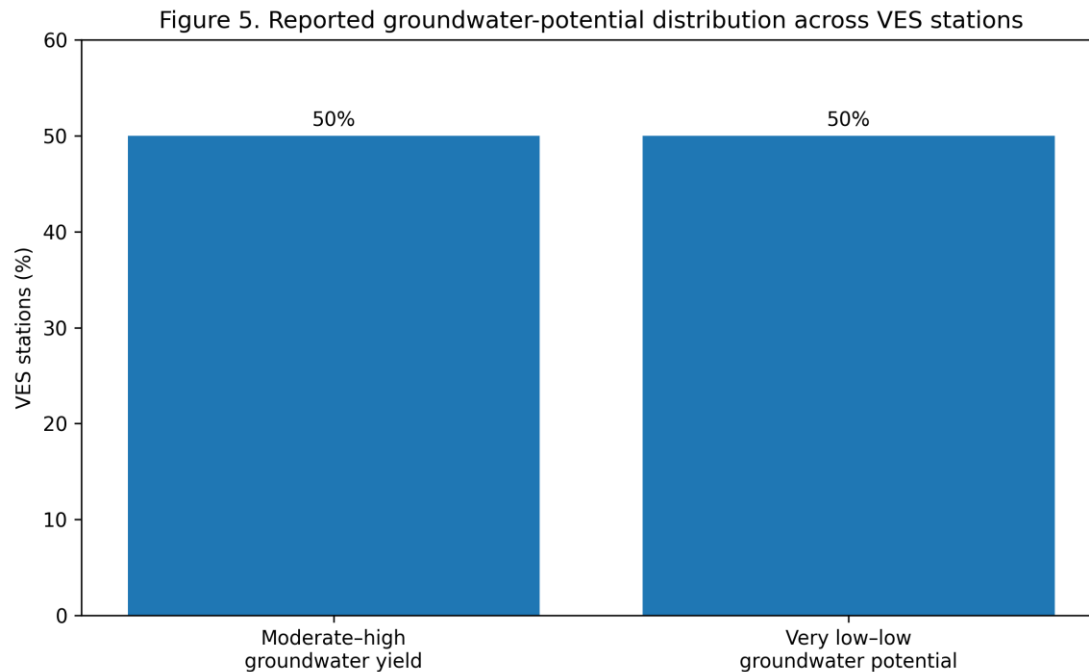


Figure 5. Reported distribution of groundwater-potential/yield classes across the VES stations.

4.3 Aquifer protective capacity

Longitudinal-conductance analysis indicates the aquifer is poorly protected, with the main protection occurring being the shale and clay of the lagoon. 91.67% are poor and 8.33% are weak protective capacity. Thus, a productive sand-rich aquifer doesn't mean that there will be a natural barrier to surface derived contaminants.

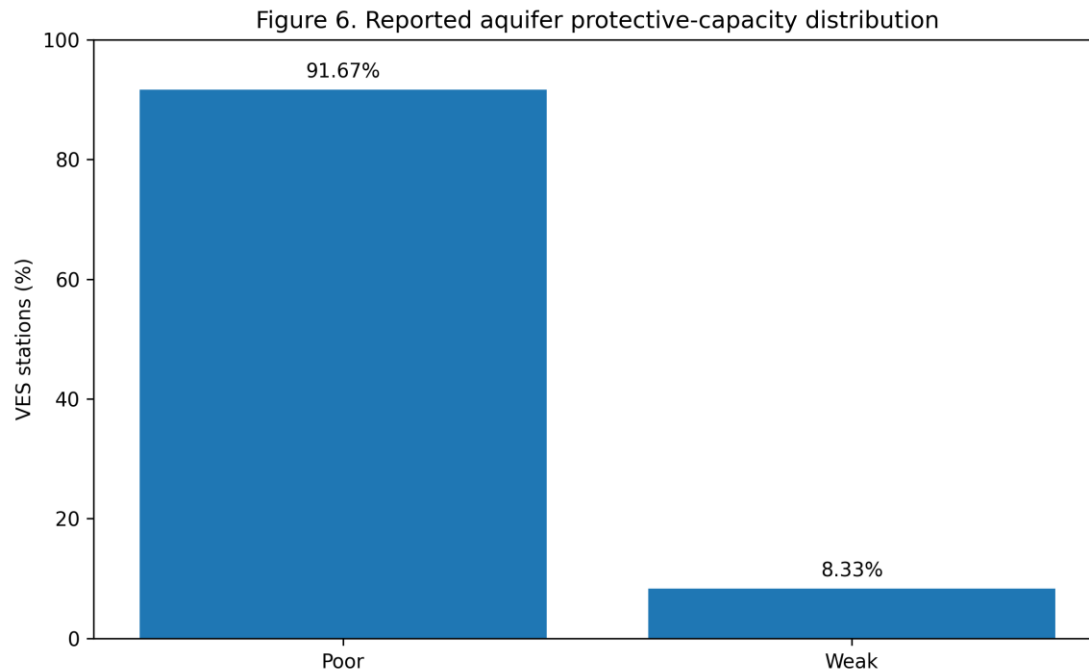


Figure 6. Reported distribution of aquifer protective-capacity classes.

4.4 Priority drilling locations

The VES stations (4, 6 and 11) were reported moderate groundwater-yield and moderate protective capability. These stations are found towards the western and north west end of the study area and are recommended to be suitable sites for drilling. The reported ERT and NEF results also fall within each other's range of values at traverses 3 and 4, which is a confirmation of favourable groundwater conditions.

Target	Reported interpretation	Management implication
VES 4	Moderate-high groundwater yield; moderate protection	Priority for confirmatory drilling
VES 6	Moderate-high groundwater yield; moderate protection	Priority for confirmatory drilling
VES 11	Moderate-high groundwater yield; moderate protection	Priority for confirmatory drilling
Traverses 3 and 4	ERT and NEF agreement for favourable groundwater	Independent geophysical corroboration

5. DISCUSSION

5.1 Hydrogeophysical meaning of the interpreted sequence

The identified sequence is a typical type of mixed near surface profile with lateritic and sandy-clay combined overlying the sand rich sequences. The geoelectric interval of fine sand is mainly ferruginous and is the main groundwater geoelectric indicator. But the differences in thickness and resistivity are great and this does not necessarily mean any lateral continuity of the productive conditions. The synergy of VES and ERT is useful here; VES will help to delineate vertical layering and ERT will be able to help with the identification of lateral changes.

5.2 Findings Of Recent Studies In Nigeria

The Sagamu interpretation is fairly consistent with recent Nigerian study results that indicate the potential of electrical resistivity to delineate water bearing formations and offer valuable geologic aquifer protection proxies. Alabi et al. (2021) used integrated VLF-EM and VES in Moloko-Asipa, Ogun State and obtained the Dar-Zarrouk parameters which were useful in the evaluation of the protective capacity in the area. Likewise, Olatinsu and Salawudeen (2021) showed improved groundwater potential evaluation and subsurface structure delineation using geophysical technique. It has since evolved and more recent literature brings together VES/ERT and vulnerability assessment: poor protection of productive aquifers (Obiadi et al., 2024).

The present Sagamu results are an important one because the groundwater is generally without protective capacity, despite the good groundwater targets. The overall pattern observed in Nigeria is, that aquifer productivity and vulnerability do not always go hand-in-hand. The need for resource availability and resource security analysis as separate but related issues was however deemed appropriate in the north of Akwa Ibom, where good groundwater potential was reported but mostly poor to weak aquifer protection.

5.3. The Aquifer Protection Versus Groundwater Potential

The most important interpretation is that of groundwater potential vs. natural protection, which is incompatibility. When productive sand-rich sections occur within poorly protective overburden, it may be possible to achieve water drilling and the resource may be more susceptible to contamination. Hence, these should be subjected to intensive sanitary measures, proper disposal of waste materials and frequent testing of the quality of water in the ground.

Areas that have high protection standards and thin aquifer may not be suitable for groundwater development. The integrated matrix in Figure 4 offers a practical plan for

decision-making, with the following priorities: Drilling priority is highest in high groundwater potential and acceptable protection zones, whereas drilling is not recommended in poorly protected zones, even in the case of a high groundwater potential.

5.4 Agreements and learning from the VES, ERT and NEF.

Further, the claimed ERT and NEF overpasses 3 and 4 in agreement, which further supports the interpretation as it minimizes the use of only one geophysical modality. In areas where the electrical resistivity may be confused by the presence of clay, pore-water conductivity and lithological equivalence, multi-method agreement may be useful. This comprehensive approach has been emerging in recent groundwater studies to increase the confidence of groundwater potential mapping and drilling decisions (Osumeje et al., 2024; Omachoko et al., 2026).

5.5 Groundwater management plan for the Sagamu area

The poor protective capacity reported implies that groundwater management should not be stopped at the stage of locating productive borehole locations. Significance of land-use planning (effect of bringing contaminants to the surface can cause contaminants to travel through relatively permeable overburden) and controls and monitoring at abstraction points for sanitation. The results thus support a management approach of targeted drilling and groundwater protection zoning.

The study also provides an example of the advantages of geophysical screening before drilling. To assist in the assessment of aquifer depth and thickness, aquifer lithology and aquifer yield, confirmatory boreholes should be used to validate the interpretations. Water quality should then be part of the validation process as electrical resistivity cannot determine water quality.

6. INTEGRATED CONCEPTUAL INTERPRETATION

The groundwater interpretation can be summarised as follows: (i) the subsurface is a heterogenous sequence of topsoil, lateritic material, sandy clay and ferruginous sand; (ii) the ferruginous fine sand is the major aquiferous interval; (iii) groundwater potential is also spatially variable (50% of the locations are rated as moderate-to-high yield and 50% as very low-to-low potential); (iv) the groundwater drilling targets are largely good at VES 4, 6 and 11; and (vi) independent ERT and NEF information indicates favourable groundwater conditions at traverses 3 and 4. The results indicate that the most fragile development option is uniform groundwater use.

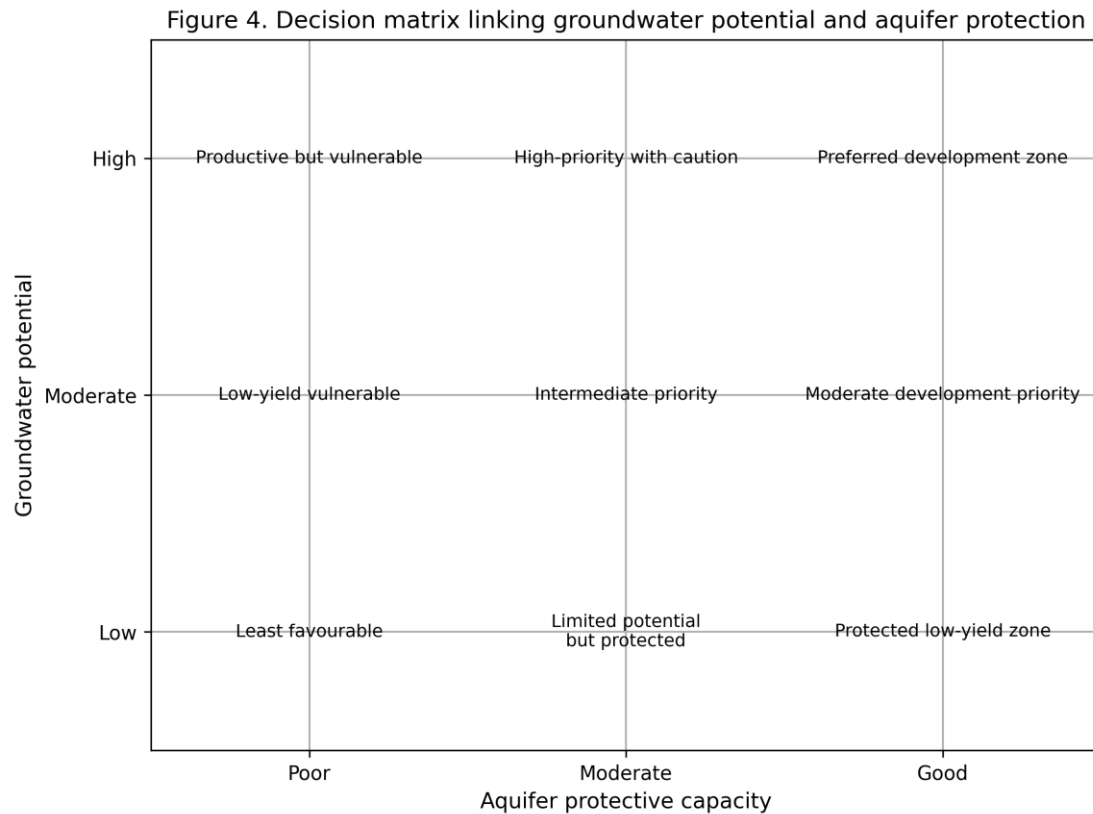


Figure 7. Integrated groundwater-potential/protective-capacity decision framework for prioritising groundwater development and protection.

7. LIMITATIONS AND UNCERTAINTY

The interpretation of electrical resistivity is not unique, that is, a similar resistivity response can be caused by various lithologies and pore-fluid conditions.

The influence of equivalence and suppression on interpretation of Layered-earth VES is important, particularly when conductive (layer) layers are present in the same formation as resistive layers.

Protective capacity estimated using longitudinal conductance is a geoelectrical estimate and should be confirmed using lithological, hydraulic and water quality data.

The quality of the data, electrode geometry, the regularisation and smoothness which is assumed for the subsurface model are critical for the ERT inversion.

Only a limited number of quantitative reproductions of this document are possible because no station by station coordinates are given, no raw apparent-resistivity curve is given, and no inversion statistics or borehole logs are given.

Potential should not be taken as a true indicator of the sustainable borehole yield without the assistance of borehole drilling and pumping test data.

8. CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

The integrated electrical-resistivity investigation is a good model for groundwater potential determination and aquifer protection in the study area, Apaken area of Sagamu (Ogun state). From the interpretation of the VES, three to five geoelectric layers were reported with the top soil, lateritic material, sandy clay and ferruginous sand layers between 1.2m and 24.0m thick. The major aquiferous zone is the ferruginous fine sand interval. The groundwater-potential interpretation suggests that 50% of the VES sites investigated are moderate to high groundwater yield and the other half range from very low to low yield. Protective capacity assessment is less favorable: 91.67% is protected at a poor level, 8.33% is protected at a weak level. Thus, the results suggest that there is no direct correlation between productive groundwater and good natural aquifer protection.

The VES stations 4, 6 and 11 are the priority locations reported in this survey as the groundwater potential is favourable and the protection is moderate. Furthermore, favourable conditions for groundwater are furthered supported by independent ERT and NEF agreements at traverses 3 and 4 respectively. The principal scientific and practical finding is that productivity should not be the only factor when evaluating Sagamu's groundwater development but also consider aquifer geometry and protection.

8.2. Recommendations

To target VES (4, 6 and 11) for confirmatory borehole drilling – where field verified and land access was not a limiting factor.

Use borehole lithological logs and pumping tests to verify the aquifer depth, thickness, transmissivity and sustainable yield interpreted from the borehole logs.

Monitor groundwater quality at areas that are productive but less protected where high groundwater potential is present with potential for contamination.

Control potentially contaminating land uses and waste disposal and septic system siting in recharge areas over the identified aquifer system.

Use VES in combination with ERT and borehole logging and hydrochemical analysis, where future drilling is not certain, instead of using one geophysical tool.

Create a GIS-based groundwater-protection framework that incorporates aquifer productivity, protective capacity and land use and contamination sources.

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