

(RESEARCH ARTICLE)



MAPPING OF APPARENT RESISTIVITY VALUES USING THE GEOSTATISTICAL METHOD IN THE GAGNOA REGION

Oscar Zahibo Onétié *, Assoué Kouakou Sylvestre Kouadio, Omer Zephir Delasme and Issouf Coulibaly

Department of Geosciences, Peleforo Gon Coulibaly University, Korhogo, Côte d'Ivoire.

* Corresponding Author

ORCID Details

Onetie Zahibo Oscar: <https://orcid.org/0009-0006-0585-0882>

World Journal of Advanced Research and Reviews, 2026, 32(01), 1396–1404

Publication history: Received on 12 September 2026; revised on 18 October 2026; accepted on 20 October 2026

Article DOI: <https://doi.org/10.30574/wjarr.2026.32.1.2276>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

The study aims to identify areas suitable for the installation of productive hydrogeological wells in the Gagnoa region (Ivory Coast). The objective is to improve the drinking water supply in the crystalline basement. The research is based on the geophysical method of electrical resistivity (electrical towing) using a Schlumberger quadripole arrangement. The authors applied a geostatistical approach to a sample of 42 resistivity data points obtained from 51 transects. This approach included a variographic analysis (fitted to a theoretical exponential model) to define the spatial structure, followed by kriging interpolation to map the entire area. Statistical analysis reveals high heterogeneity in the structures, with resistivity values ranging from 63 to 980 $\Omega \cdot m$ (average of 411.48 $\Omega \cdot m$). The variogram indicates a practical range of 20.4 km, demonstrating good large-scale interconnectivity of the fractures. The interpolation map reveals that 32% of the region (in the northeast and west) exhibits low resistivities (180–240 $\Omega \cdot m$) associated with conductive shale formations, while the central and northern parts show average values (240–420 $\Omega \cdot m$). The geostatistical approach using kriging proves effective in predicting the distribution of apparent resistivity. Areas with low to moderate resistivities are the most promising locations for future drilling, as they coincide with high fracture densities, which are essential for groundwater flow and storage.

Keywords: Mapping, Geophysical, Resistivities, Geostatistics, Variographic, Gagnoa

1 INTRODUCTION

In many parts of the world, access to drinking water is a crucial issue. In Côte d'Ivoire, it remains a priority for the government, as demonstrated by numerous projects to drill water wells, the most recent of which is the 'WATER FOR ALL' project. The Ivorian territory consists of 97.5 per cent crystalline and crystallophylic bedrock. Consequently, groundwater resources represent a highly valuable alternative for supplying drinking water to our populations, particularly those in rural areas. The main groundwater resources are contained in weathered rock and fissure aquifers. These aquifers result, respectively, from the weathering of rocks and the fracturing of the bedrock (1,2,3). Bedrock geological formations are generally characterised by low primary porosity and marked heterogeneity, making the

identification of areas favourable to well productivity a major challenge. Consequently, several approaches have been considered for identifying these areas, such as geomorphology, remote sensing, GIS and, most frequently, geophysics. Geophysics is a highly valuable tool for conducting a hydrogeological research programme, whether to identify new resources or to improve our understanding of an aquifer (4). Furthermore, the application of geophysical methods based on electrical resistivity (drag line and electrical sounding) has yielded conclusive results, with a failure rate of 12 per cent in the UEMOA project (5). This study therefore aims to identify areas suitable for the establishment of productive boreholes by using electrical resistivity values determined at points showing geophysical anomalies, using a geostatistical approach in the Gagnoa region.

2 GEOLOGICAL CONTEXT OF THE GAGNOA REGION

The area of interest is situated in the central-western part of Côte d'Ivoire, within a Proterozoic domain comprising crystalline and crystallophyllic rocks. From a lithological perspective (Figure 1), two major groups can be distinguished: granitoids and volcano-sedimentary rocks (6). The volcano-sedimentary formations consist of fine-grained amphibolites with a distinctly schistose structure, chlorite schists, sericite schists and grey-green tuffs with generally very fine grains. The most significant granitoids are oriented and non-oriented granites and granodiorites (6). These various geological formations have been affected by several tectonic phases, which have led to the development of extensive fracturing. A more detailed analysis of the fractures has revealed two predominant fracture systems: N0-10 and N90-100 (7). From a hydrogeological perspective, three types of aquifers can be distinguished: laterite aquifers, fissure aquifers and major fracture aquifers.

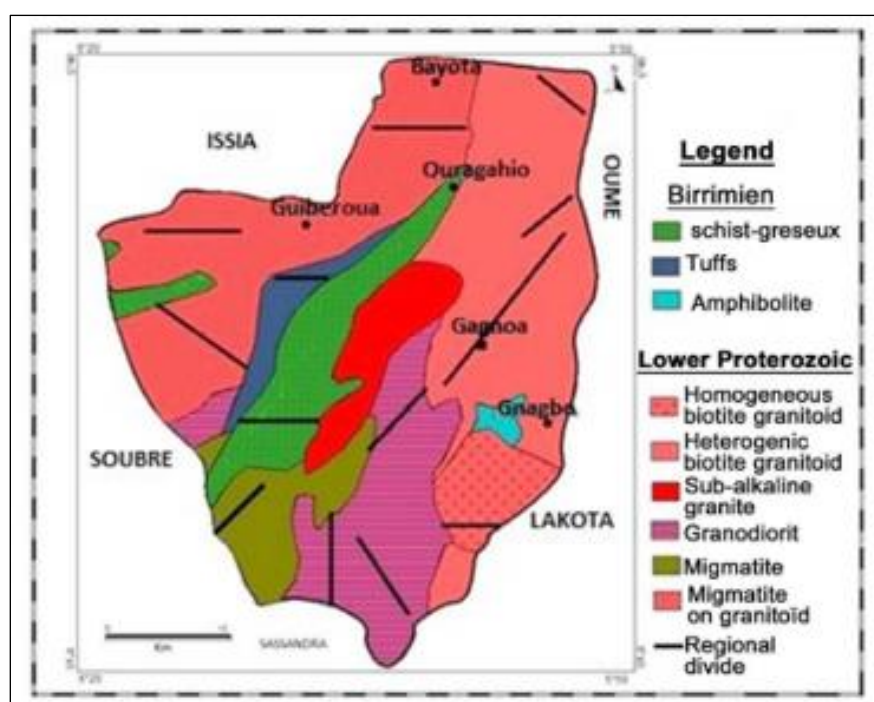


Figure 1: Modified geological map of the Gagnoa region (8)

3 MATERIALS AND METHODS

3.1 Tools

The tools used are part of the Schlumberger quadripol system, which consists of the Syscal Pro resistivity meter, four injection and reception electrodes, coils, hammers, a tape measure, and a compass.

3.2 Data

The data used in this study consist exclusively of 42 sets of electrical resistivity data acquired using the drag-line method. These data were obtained from 51 drag-line transects.

4 METHODOLOGY

4.1 Data Acquisition Method

The methodology, based on Schlumberger's aligned quadripole array, involves injecting a direct current I through two injection electrodes, A and B, and measuring the potential difference (ΔV) using two potential electrodes, M and N (Figure 2). The Syscal Pro reports the value of the electrical resistivity ρ of geological formation. The implementation of the electrical tow is described in greater detail in the work by (8).

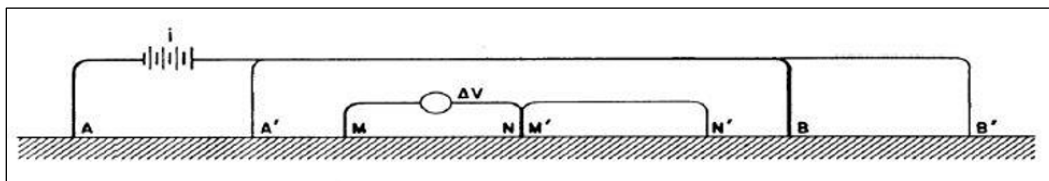


Figure 2: Illustrative diagram of horizontal prospecting (single-wire drag). (7)

4.2 Geostatistical Analysis Method for Electrical Resistivity Values

Geostatistical analysis allows for the study of regionalized phenomena (9). A regionalized phenomenon is a natural phenomenon that unfolds in space and/or time in a structured manner and is well-defined over a bounded domain (domain of validity). Mathéron (9) defines a regionalized variable (VR) as a function Z defined on a surface (S), through which the phenomenon can be satisfactorily described. A variable is said to be regionalized when the values it takes depend on its position in space (10). The study of the random variable makes it possible to identify, when it exists, the spatial structure of the phenomenon under study (11). In the context of this study, the regionalized variable is the value of electrical resistivity obtained at the anomaly point. The geostatistical method is implemented in the following steps:

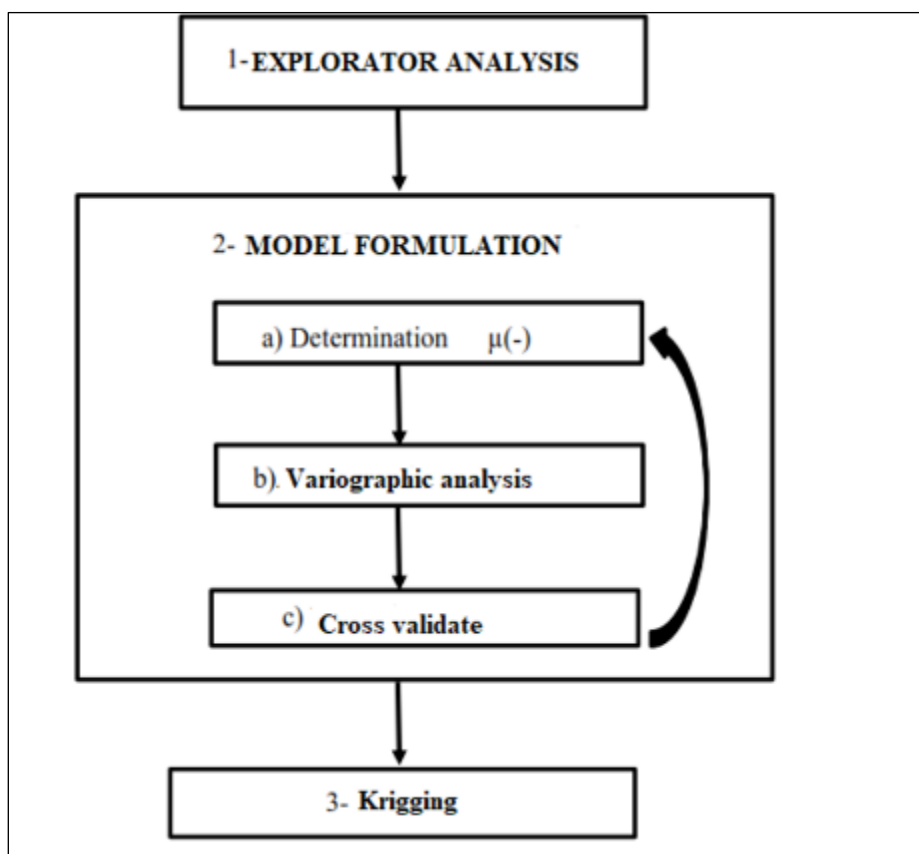


Figure 3: Steps of geostatistical method

4.2.1 Variographic Analysis

The geostatistical analysis tool is called a variogram or “intrinsic random function.” Analyzing it makes it possible to define the characteristics of the spatial structure of the phenomenon under study. The variogram is defined by equation (1)

$$\gamma(h) = \frac{1}{2} \text{VAR}[Z(x+h) - Z(x)]$$

Avec :

- $\text{VAR}[Z(x)]$: variance of the regionalized variable at the point x ;
- h : module vector $(x-x')$;
- $\gamma(h)$ est le semi-variogram.

For any distance h separating two support points (a pair of points), the variogram expresses the mean squared half-increase.

The graphical representation of the variogram is fitted to various theoretical models to determine the regionalization parameters. In earth sciences, the exponential and spherical theoretical models are the most use (3,11). These theoretical models will be fitted to the experimental variograms (Equations 2 and 3).

- **exponential model**

$$\gamma(h) = C_0 + C_1 \left(1 - \exp\left(-\frac{h}{a}\right)^3 \right) \quad \text{pour } h \geq 0$$

- **spherical model**

$$\gamma(h) = \left\{ C_0 + C_1 \left(\frac{3h}{2a} - \frac{1}{2} \frac{h^3}{a^3} \right) \right\} \quad \text{pour } 0 \leq h \leq a$$

$$\gamma(h) = C_0 + C_1 \quad \text{pour } h > a$$

The variogram has the following characteristics:

- A plateau or threshold is the value at which the semi-variogram levels cancel each other out.
- A range “ a ” that denotes the distance h at which the plateau is reached. Pairs of points separated by a distance h less than “ a ” are spatially correlated, which is not the case when h is greater than “ a .”
- A nugget effect is the semivariances at a distance $(0,0)$. It also refers to very short-range variation, location errors, analysis errors, and analytical precision.
- The formulation of the model is based on two assumptions or conditions for the application of geostatistics. The two assumptions are:
 - Stationarity or continuity assumption (constant mean and variance)
 - Intrinsic or homogeneous assumption (minimum variance and distance-dependent) of the regionalized variable.
- The appropriate model was selected through cross-validation, which enables the kriging process.

4.2.2 Kriging

Kriging is an optimal interpolation method based on regression of observed measurements around the measurement to be estimated, with the weight of each measurement determined based on its spatial covariance with the other measurements. Kriging is based on the assumption of spatial autocorrelation in the data. Kriging is the only technique that simultaneously provides the estimated value and the associated error, characterized by the kriging standard deviation.

- The mathematical experiment (E) with zero estimation errors (unbiased condition), Equation (4)

$$E(Z^* - Z_0) = 0$$

Avec Z^* : **estimated value**

Z_0 : **initial value**

- The variance (Var) of the estimation errors is minimized (condition of optimality):

$$Var(Z^* - Z_0) \text{ minimum}$$

Ultimately, the interpolation process follows the steps of variographic analysis and modeling, cross-validation to compare the performance of the different models, and kriging, which will generate the interpolation map along with the estimation error map.

5 RESULTS

5.1 Basic Statistics on Apparent Resistivities Determined from Electrical Profiles

Analysis of the results from the various profiles yielded 42 apparent resistivity values for points that were subjected to electrical soundings. These values range from 63 to 980 $\Omega \cdot m$, with an average of 411.48 $\Omega \cdot m$. The wide range of values indicates an extreme contrast between the minimum and maximum values. This indicates a very high degree of heterogeneity in the structures or materials measured in the field. The standard deviation is particularly high. On average, the measurements deviate by nearly 253.86 $\Omega \cdot m$ from the mean, confirming a high degree of data dispersion (Table 1).

Table 1: Basic Statistics of Apparent Resistivities

	Total	Max	Min	Average	Sd	CV
Apparent resistivity values ($\Omega \cdot m$)	42	980	63	411,48	253,86	162%

The coefficient variation of the apparent resistivities recorded along the profiles indicates a dispersion in these values. In other words, the resistivities used to conduct surveys differ from one location to another. Consequently, this value was extrapolated across the entire study area. This extrapolation was performed using a highly valuable tool in earth sciences: geostatistics.

5.2 Geostatistical Analysis of Apparent Resistivity Values.

The resistivity values were used to calculate the experimental variogram. The variogram exhibits a distinct structure (Figure 4). The resistivity value thus behaves like a regionalized variable. The parameters derived from the variogram analysis are: the nugget effect (2.104 m), the plateau (3.12×10^4 m), and the range (2.04×10^4 m). This experimental variogram was fitted to an exponential model

$$\gamma = 2.10^4 + 3.12.10^4(1 - \exp(-\frac{h}{2.04.10^4})^3)$$

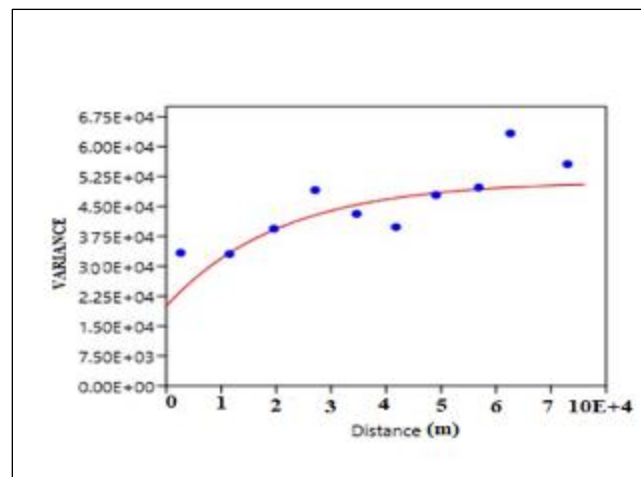


Figure 4: Variogram of apparent resistivity values

This equation helps estimate the resistivity value at a given point within the study area based on the distance between two experimental data points. The variogram indicates that the practical spatial range of the phenomenon should not exceed 2.04×10^4 meters. The resistivity variogram yielded a variable that could be considered a regionalized variable that spreads out in space in a structured manner. It is therefore possible to estimate it using kriging across the entire site. Using Past4.08 software, the resistivity values were krigged. Figure 5 shows the map of estimated resistivity values based on the exponential

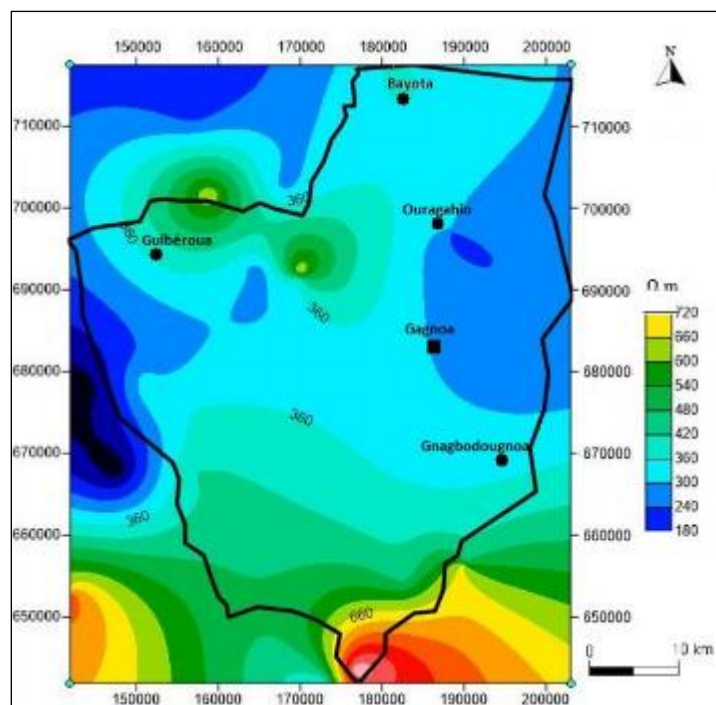


Figure 5: Map showing estimated apparent resistivity values

This figure shows that low resistivities (180–240 $\Omega \cdot m$) are found in the northeast and west of the study area and account for 32% of the study area. Areas of moderate resistivity (240–420 $\Omega \cdot m$) occupy the entire central and northern parts. Areas of high resistivity are located in the south and northwest around Guibéroua. There is a resistivity gradient from the center toward the south.

The resistivity isovalue map was combined with an estimation error map (Figure 6). This map provides information on the quality of the estimate. On this map, areas of low estimation error cover the study area. The resistivity estimate obtained using kriging techniques is satisfactory for the study area.

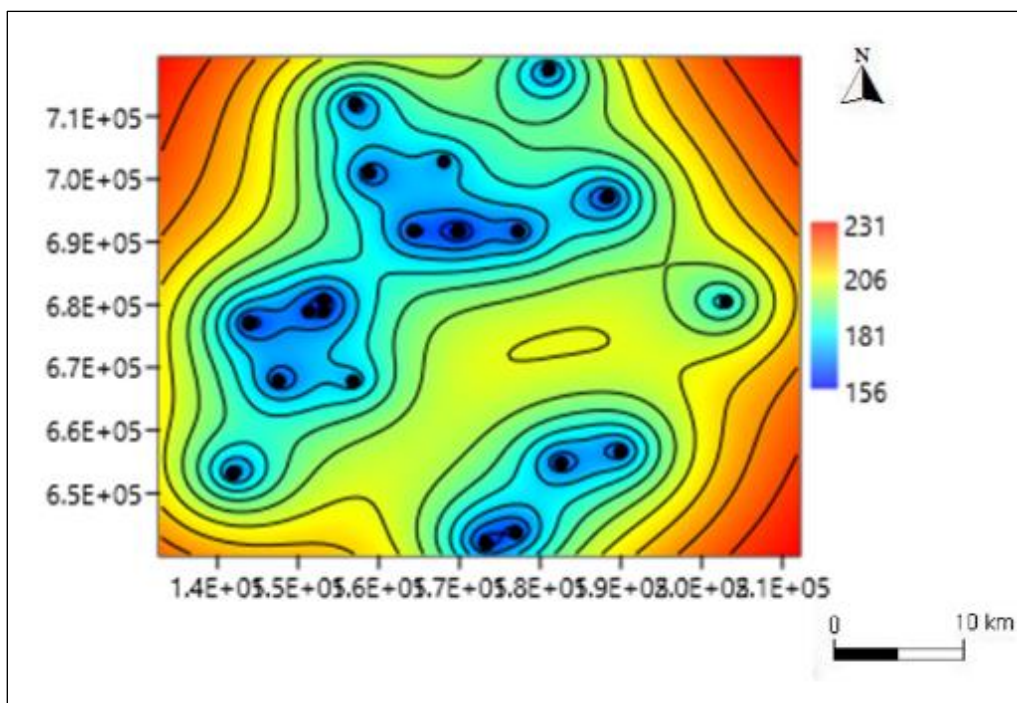


Figure 6: estimation error map

Figure 7 shows the superimposition of the isoresistivity map onto the map of the various geological formations encountered in the area. The relationship between apparent resistivity and geological formations is not clear-cut. However, areas of high resistivity are found in zones where migmatites and granodiorites are present. Low resistivities in the west are found in schistose formations, and in the east in biotite granites. (Figure 7)

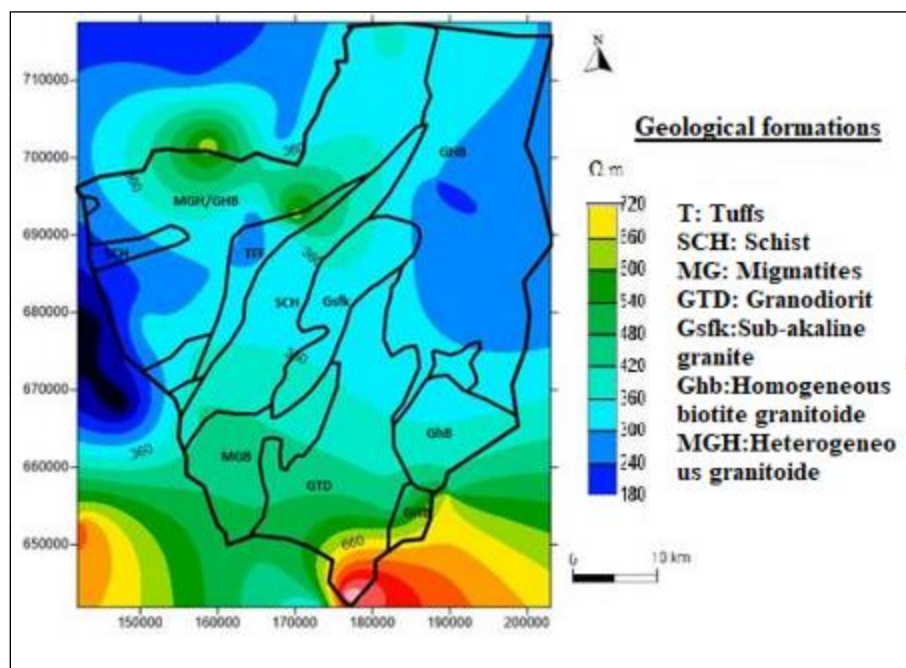


Figure 7: shows the superimposition of the isoresistivity map onto the map of the various geological formations

6 DISCUSSION

The coefficient of variation for the measured resistivity values indicates significant dispersion around the mean value. This reflects a certain degree of heterogeneity in the study area. The spatial variation in resistivity is indicative of fracturing. Indeed, the conductive zones coincide with areas of high fracture density (Onetie; 2016). This highlights the importance of fracturing in groundwater flow. The classification established by (12) confirms the conductive nature of

volcano-sedimentary formations in general and shale in particular. The isoresistivity map also highlights areas of average resistivity ranging from 240 to 420 $\Omega\cdot\text{m}$. This zone is indeed conducive to groundwater exploration because it has the advantage of being porous and permeable (12).

Spatial interpolation of hydrodynamic parameters using geostatistical methods has been conducted by several authors (3; 13; 14). The well-defined spatial distribution of these parameters allows for their estimation across the entire study area. The discontinuity initially reported is a phenomenon commonly encountered in the literature (3; 15; 16). Unlike the work by 13 in the Oumé region, the eigenvalues of resistivity exhibit a structured pattern.

The structural complexity in this region of Côte d'Ivoire is undoubtedly due to the good interconnectivity of the faults.

The “nugget effect” observed in the variogram analysis is due to the combined effect of two (2) main factors (3):

- the presence of micro-regionalization.
- the presence of measurement uncertainties.

7 CONCLUSION

The assessment of groundwater resources in the Gagnoa region, characterized by a heterogeneous crystalline and crystallophyllic basement, was successfully carried out through the combined application of geophysical prospecting (Schlumberger electrical towing) and the geostatistical kriging method.

The main findings highlight:

- Significant heterogeneity in geological structures, reflected in a wide range of apparent resistivity values, which vary between 63 and 980 $\Omega\cdot\text{m}$ with an average of 411.48 $\Omega\cdot\text{m}$.
- Good large-scale connectivity of the fracture network, confirmed by variographic analysis (fitted to a theoretical exponential model), which reveals a practical range of 20.4 km.
- Precise mapping identifying 32% of the region (northeastern and western sectors) as areas of low resistivity (180 to 240 $\Omega\cdot\text{m}$) associated with conductive shale formations, while the central and northern areas exhibit moderate values (240 to 420 $\Omega\cdot\text{m}$).
- The relevance of this study lies in its ability to optimize the siting of future water infrastructure projects in a region where the failure rate of boreholes remains a challenge. By demonstrating the effectiveness of kriging in extrapolating and spatially predicting the electrical properties of the subsurface, this work provides a robust decision-support tool. The areas of low to moderate resistivity thus mapped coincide with high fracture densities, which are essential for water storage and flow.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper.

REFERENCES

- [1] Biemi, J. (1992) Contribution to the Geological, Hydrogeological, and Remote Sensing Study of the Sub-Sahelian Watersheds of the Precambrian Basement of West Africa: Hydrostructural, Hydrodynamic, Hydrochemistry and Isotopy of the Discontinuous Aquifers of Furrows and Granitic Areas of the Upper Marahoué (Côte d'Ivoire). Doctoral Thesis, University of Abidjan.
- [2] Kouame, F. (1999) Hydrogeology of Discontinuous Aquifers in the Semi-Mountainous Region of Man-Danané (Western Côte d'Ivoire) Contribution of Satellite Image Data and Statistical and Fractal Methods to the Development of a Spatially Referenced Hydrogeological Information System. 3rd Cycle thesis, University of Cocody.
- [3] Lasm, T. (2000) Hydrogeology of Fractured Basement Reservoirs: Statistical Analysis of Fracturing and Hydrodynamic Properties. Application to the Region of the Mountains of Côte d'Ivoire (Archean Domain). Unique Doctoral Thesis, University of Poitiers.
- [4] Dabas, M., Duval, O., Bruand, A. and Verbeque, B. (1995) Continuous Electrical Mapping: Contribution to the Knowledge of a Soil Cover Developed on Deltaic Materials. *Étude et Gestion des Sols*, 2, 257-268.

- [5] Kouadio, A. (2021) Productivity of Water Boreholes by the Method of Electrical Resistivity in the Middle of the Basement (N'zi Comoé zone; Côte d'Ivoire) Single Doctoral Thesis, Nangui Abogoa University
- [6] Géomines (1982). Hydrogeological inventory applied to village water supply. Ministry of Public Works and Transportation, Central Directorate of Water Resources, Republic of Côte d'Ivoire, map of Gagnoa. 31 p.
- [7] Onetie, Z. (2016) Contribution of GIS and Multicriteria Analysis to the Hydrogeological Prospecting of the Precambrian Basement of West Africa (The Case of the Gagnoa Region in the Centre-West of Côte d'Ivoire), Doctoral Thesis, Université Félix Houphouët-Boigny.
- [8] Onetie, O.Z., Kouadio, A.K.S., Orou, K.R. and Abe, M.A. (2024) Characterization of Aquifers in Crystalline and Crystallophyll Basement Zones Using the Electrical Resistivity Method (Trails and Electrical Soundings) in the Gagnoa Region, (Central-Western Côte d'Ivoire). International Journal of Geosciences, 15, 511-523.
- [9] Matheron, G. (1962). Treatise on Applied Geostatistics, Volume I. Proceedings of the Bureau of Geological and Mining Research. Editions Technip, Paris.
- [10] Narboni, P. (1979). Application of the regionalized variables method to data from Gabon. C.T.F.T., Nogent-sur-Marne, Vol. Statistical Note No. 18,
- [11] Razack, M. (1984). Application of numerical and statistical methods to the identification of fractured carbonate reservoirs in hydrogeology. PhD Thesis, University of Languedoc, France, 384 pp.
- [12] Chapellier, D. (2000). Surface Electrical Prospecting. In Online Geophysics Course at the University of Lausanne - IFP (<http://www-ig.unil.ch/cours/>). University of Lausanne, Switzerland.
- [13] Baka, D. (2012) Geometry, Hydrodynamics, and Modelling of Fractured Reservoirs of the Proterozoic Basement of the Oumé Region (Centre-West Côte d'Ivoire), Doctoral Thesis, University Félix Houphouët-Boigny.
- [14] De Lasme O. Z. (2013) Contribution to a Better Understanding of Fractured Aquifers in the Precambrian Bedrock: The Case of the San-Pedro Region (Southwestern Côte d'Ivoire), Doctoral thesis, Félix Houphouët-Boigny University, Abidjan, Côte d'Ivoire, 209 pp.
- [15] Jourda, J.P. (2005) Methodology for the Application of Remote Sensing Techniques and Geographic Information Systems to the Study of Fissured Aquifers in West Africa. Concept of Space Hydrotechnics: The Case of the Test Areas of Côte d'Ivoire. Doctoral Thesis in Natural Sciences, University of Cocody-Abidjan.
- [16] Soro, G.; Soro, N.; Ahoussi, K. E.; Lasm, T.; Kouame, F. K.; Soro, T. D.; and Biemi J. (2010). Evaluation of the hydraulic properties of fractured aquifers in crystalline and metamorphic formations in the Lakes Region (central Côte d'Ivoire). Estudios Geológicos, Vol. 66, No. 2, pp. 227–242.