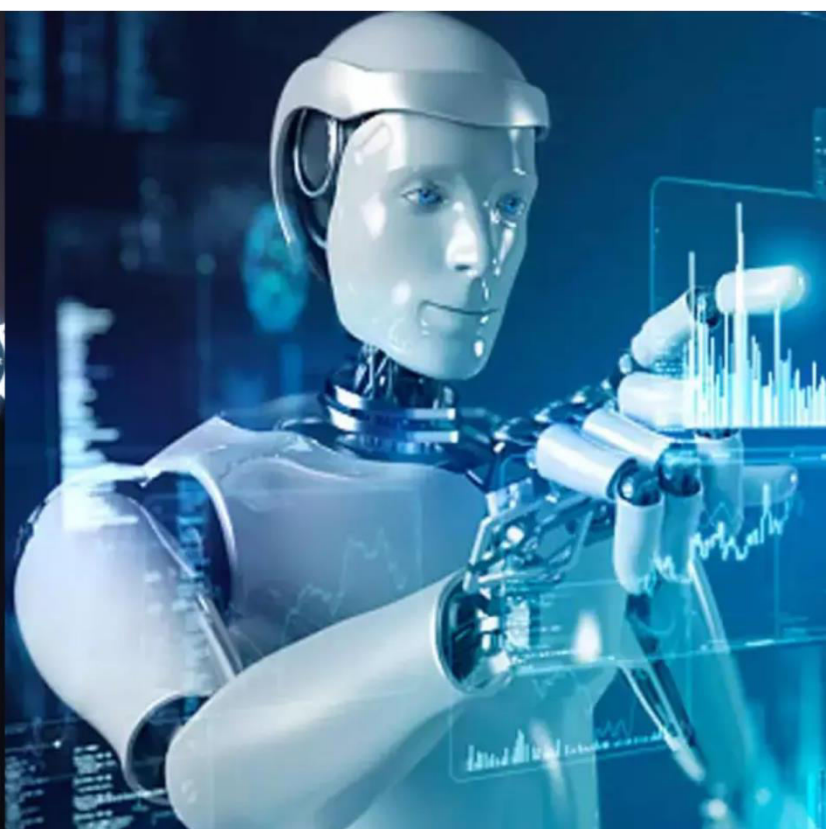




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Contribution of geophysical methods to the characterization of the subsoil for the installation of telecommunications infrastructure in a tropical urban environment: The case of Kinshasa (Democratic Republic of Congo)

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ABSTRACT: The rapid development of telecommunications infrastructure in urban areas requires a thorough understanding of the geological and geotechnical characteristics of the subsoil to ensure the stability, safety, and durability of the structures. In Kinshasa, the expansion of telecommunications networks is taking place in a complex geological context marked by significant lithological variability, the presence of sandy-clay formations, and shallow groundwater that can affect the foundations of pylons and other equipment. This study evaluates the contribution of geophysical methods, particularly the electrical resistivity method using vertical electrical sounding (VES), to the characterization of the subsoil for the deployment of telecommunications infrastructure. The investigations identified the main geoelectrical units, highlighted the variations in resistivity related to geological formations, and distinguished areas with favorable or unfavorable conditions for construction. The results show that compact sandy formations characterized by relatively high resistivities are the most suitable sites for infrastructure development, while saturated clay formations present potential risks of settlement and instability. Integrating geophysical methods into preliminary studies thus reduces geotechnical uncertainties, optimizes site selection, and limits the costs associated with destructive investigations. This study highlights the strategic role of applied geophysics in planning telecommunications infrastructure in tropical urban environments and contributes to the development of non-destructive approaches for communication network development in the Democratic Republic of Congo.

KEYWORDS: Applied geophysics; electrical resistivity; vertical electrical sounding; telecommunications infrastructure; subsurface characterization; geotechnics; Kinshasa.

I. INTRODUCTION

The rapid development of telecommunications infrastructure is now a major driver of digital transformation, economic development, and improved access to digital services in developing countries. In sub-Saharan Africa, the growth of mobile phone networks, base transceiver stations (BTS), and transmission infrastructure requires rigorous planning to ensure their stability, security, and sustainability (International Telecommunication Union, 2023; GSMA, 2024).

In the Democratic Republic of Congo (DRC), the city of Kinshasa is experiencing rapid urbanization accompanied by a significant expansion of telecommunications infrastructure. This growth is occurring within a complex geological context characterized by sandy, sandy-clay, lateritic, and clayey formations belonging primarily to the Congo Basin sedimentary basin [Cahen, 1954; Bultot, 1954]. These formations exhibit highly variable geotechnical properties that can directly influence the mechanical behavior of the foundations of pylons and other telecommunications infrastructure.

The stability of infrastructure depends largely on the physical and mechanical characteristics of the subsoil. Soils with low bearing capacity, high compressibility, or significant water saturation can cause differential settlement, foundation deformation, and a reduced service life of structures [Coduto et al., 2016; Bowles, 1996]. Therefore, a preliminary subsoil investigation is an essential step in any infrastructure development project.

Among the various investigation techniques available, geophysical methods occupy an important place due to their non-destructive nature, their speed of implementation, and their ability to provide continuous information on the physical properties of the subsurface [Telford et al., 1990; Reynolds, 2011]. They make it possible to characterize the geological structure, locate discontinuities, identify aquifer levels, and assess the geotechnical properties of formations without systematically resorting to destructive investigations.

Electrical resistivity sampling is particularly well-suited to characterizing shallow geological formations. Its principle is based on measuring the apparent resistivity of materials, which depends primarily on their lithology, porosity, degree of fracturing, water content, and the mineralization of interstitial fluids [Parasnis, 1997; Kearey et al., 2002; Loke, 2004]. Vertical Electrical Sounding (VES) techniques allow for the determination of the vertical sequence of geological layers and the estimation of their thicknesses, while Electrical Resistivity Tomography (ERT) provides a two-dimensional or three-dimensional representation of lateral resistivity variations [Dahlin, 2001; Loke and Barker, 1996].

In the field of infrastructure, several studies have demonstrated that geophysical methods are effective tools for selecting sites for buildings, dams, roads, bridges, and telecommunications infrastructure by reducing geotechnical uncertainties and the costs associated with conventional investigations [Soupios et al., 2007; Sharma, 1997; Burger et al., 2006]. Despite these advantages, their use remains relatively limited in preliminary studies for the siting of telecommunications infrastructure in the Democratic Republic of Congo.

In Kinshasa, heavy rainfall, seasonal rises in groundwater levels, gully erosion, and lithological heterogeneity make a detailed characterization of the subsoil essential before any critical infrastructure is built. Several recent studies have shown that the geophysical characteristics of the subsoil play a major role in the dynamics of flooding, erosion, and the stability of structures in the city of Kinshasa [Lumpungu Lutumba et al., 2025a; Lumpungu Lutumba et al., 2025b].

In this context, the present study aims to demonstrate the contribution of geophysical methods, particularly the Vertical Electrical Sounding (VES) method, to the characterization of the subsurface for the purpose of deploying telecommunications infrastructure in the city of Kinshasa. The specific objectives are to identify the main geoelectric units, interpret their lithological characteristics, assess their geotechnical suitability, and propose scientific criteria to aid decision-making for site selection.

II. STUDY AREA

The study area is located in the city of **Kinshasa**, capital of the Democratic Republic of Congo (DRC), between latitudes **4°18'–4°30' S** and longitudes **15°12'–15°36' E**. Kinshasa is situated on the left bank of the Congo River and covers an area of approximately **9,965 km²**, a significant portion of which is urbanized. The city's rapid growth is accompanied by sustained development of telecommunications infrastructure, necessitating prior assessment of subsurface conditions [INS, 2023; Bultot, 1954]. Geologically, Kinshasa belongs to the **Congo Basin sedimentary rock formation** and is primarily composed of sandy, sandy-clay, clayey, and lateritic formations of Tertiary to Quaternary age [Cahen, 1954; Lepersonne, 1974]. This lithological diversity directly influences the geotechnical properties of the land and its suitability for supporting the foundations of pylons and other infrastructure.

The climate is **tropical humid**, characterized by a rainy season and a dry season. Rainfall, combined with a sometimes shallow water table, locally promotes soil saturation, gully erosion and ground instability, which can compromise the stability of structures [Lumpungu Lutumba et al., 2025a; Lumpungu Lutumba et al., 2025b].

Given this geological and hydrogeological context, Kinshasa is a relevant study site for evaluating the contribution of geophysical methods to subsurface characterization for the purpose of telecommunications infrastructure deployment. The location of the study area is shown in **Figure 1**.

1) 1

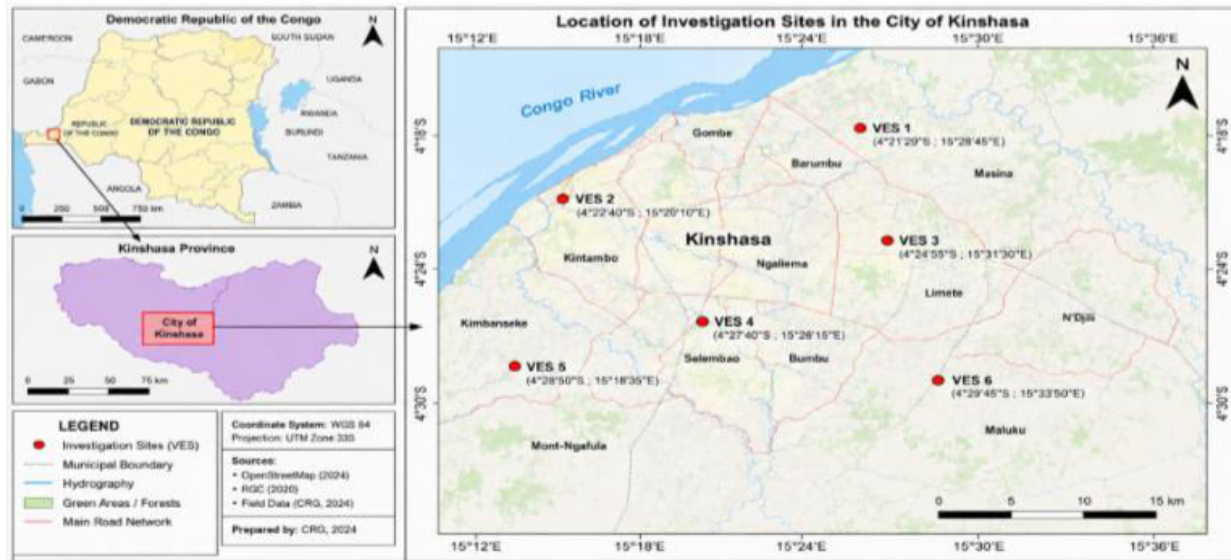


Figure.1. Location of the study area in the city of Kinshasa (DRC) showing the main geophysical investigation sites

III. MATERIALS AND METHODS

3.1 Principle of the electrical resistivity method

The subsurface was characterized using electrical resistivity, a non-destructive geophysical technique widely used in geotechnics, hydrogeology, and engineering studies. This method involves injecting a direct current into the soil using two current electrodes and measuring the potential difference between them. The resulting measurements allow for the calculation of the apparent resistivity of the geological formations, a parameter directly influenced by the lithology, porosity, water content, and degree of fracturing of the materials [Telford et al., 1990; Reynolds, 2011; Kearey et al., 2002].

The apparent resistivity (ρ_a) is calculated according to Ohm's law:

$$\rho_a = K \frac{\Delta V}{I}$$

where K is the geometric factor of the device, ΔV the measured potential difference (V) and I the injected current (A) [Parasnis, 1997].

3.2 Experimental setup

The measurements were performed using the **Schlumberger configuration**, known for its good vertical resolution and its ability to explore different depths with a limited number of potential electrode displacements [Loke, 2004]. In this setup, the current electrodes (A and B) are progressively moved apart while the potential electrodes (M and N) remain relatively close together.

The geometric factor is given by:

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

3.3. Equipment and Data Acquisition

The investigations were carried out using a digital resistivity meter, four metallic electrodes, connecting cables, a power supply, a GPS for georeferencing the measurement points, and a measuring tape for electrode positioning. Measurements were performed by progressively increasing the current electrode spacing to investigate increasing depths. Current and potential difference data were recorded in the field and then converted into apparent resistivities for geoelectrical interpretation [Loke, 2004; Reynolds, 2011].

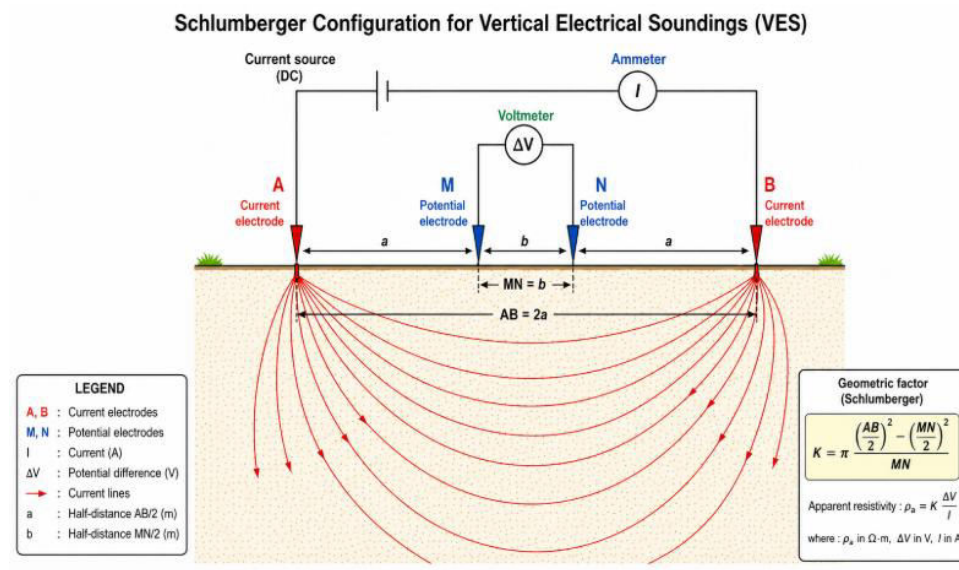


Figure.2. Principle of the electrical resistivity method and electrode configuration according to the Schlumberger device used for vertical electrical soundings (SEV).

2) 3.4 Field Measurement Procedure

Geophysical measurements were carried out using a standard vertical electrical sounding procedure. Initially, electrodes were placed on the ground surface according to the Schlumberger array configuration. An electric current was then injected into the ground through the current electrodes, while the potential difference between the potential electrodes was measured.

The spacing between the current electrodes was progressively increased to investigate increasing depths of the subsurface. For each electrode configuration, the injected current and potential difference values were recorded, allowing the **apparent resistivity of the ground to be calculated**.

The data obtained were then interpreted to determine the geoelectric structure of the subsoil and to identify the geological formations present in the study area. This analysis makes it possible to locate areas with favorable conditions for the installation of telecommunications infrastructure.

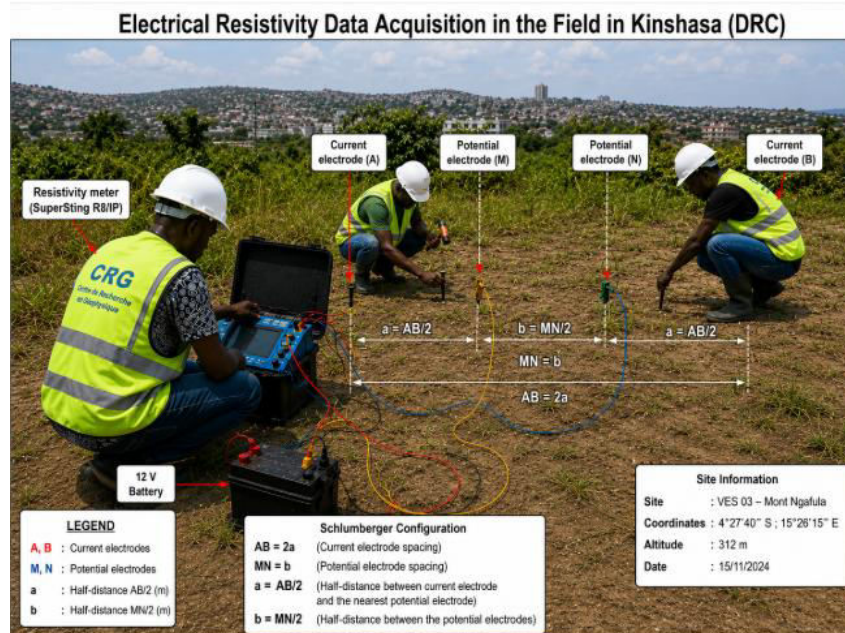


Figure.3. Acquisition of electrical resistivity data in the field using a resistivity meter in the study area

IV. RESULTS

4.1 Results of vertical electrical soundings (VES)

Geophysical investigations carried out in the city of Kinshasa yielded apparent resistivity curves from various vertical electrical soundings (VES). The measurements reveal a significant variation in resistivity with increasing electrode spacing, reflecting the lithological heterogeneity of the subsurface. The curves obtained generally reveal a succession of three to four geoelectric layers characterized by varying resistivities and thicknesses, reflecting the diversity of formations encountered in the Kinshasa sedimentary basin [Telford et al., 1990; Reynolds, 2011]. The experimental curves obtained for the different sites are shown in **Figure 4**.

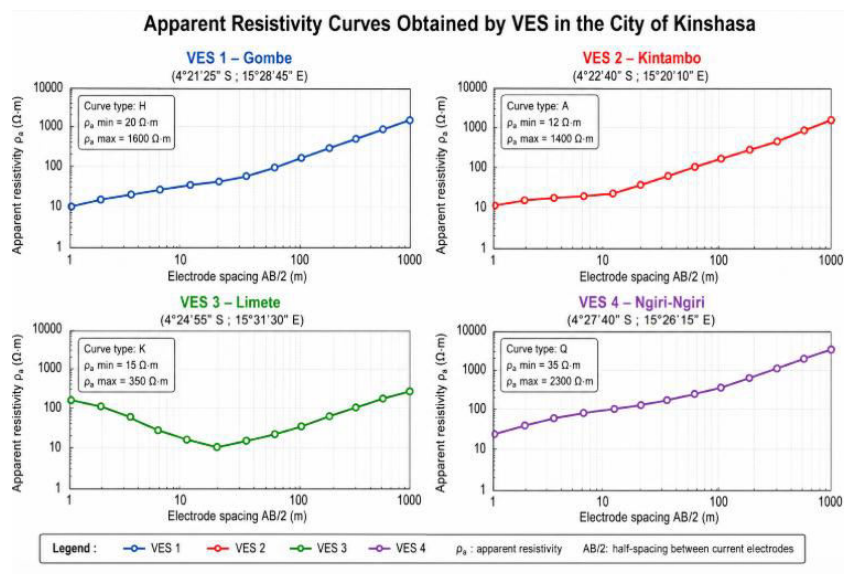


Figure.4. Apparent resistivity curves obtained from vertical electrical soundings (VES) carried out in the study area.

4.2 Interpreted Geoelectric Model

The interpretation of the SEV curves allowed for the identification of several geoelectric units corresponding to the main subsurface formations. The surface layer is generally composed of lateritic or sandy-clay soils with resistivities ranging from **100 to 500 $\Omega \cdot m$** . A second layer, characterized by lower resistivities (**20–80 $\Omega \cdot m$**), is associated with clayey materials that are locally saturated with water. The deeper horizons exhibit higher resistivities (**300–1200 $\Omega \cdot m$**), indicating the presence of compact sandy formations suitable for construction.

The interpreted geoelectric models are illustrated in **Figure 5**.

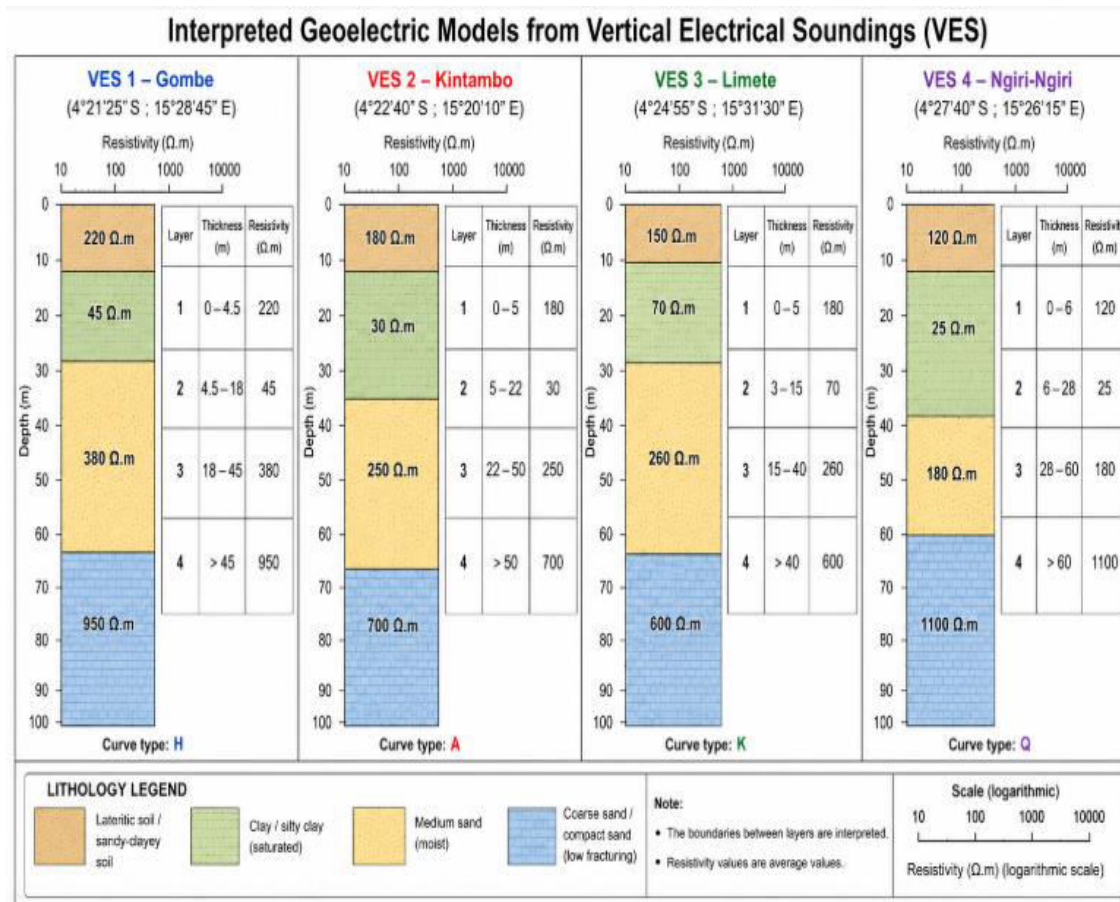


Figure.5. Interpreted geoelectric models showing the succession of the main geological layers identified in the study area

4.3 Geotechnical characterization of the soils

The results show that compact sandy formations offer the best geotechnical conditions for the installation of telecommunications infrastructure due to their high resistivity and good mechanical stability. Conversely, saturated clay formations exhibit low resistivity and are likely to cause differential settlement, particularly during periods of heavy rainfall [Sharma, 1997; Coduto et al., 2016].

The spatial distribution of favorable and unfavorable areas is shown in **Figure 6**.

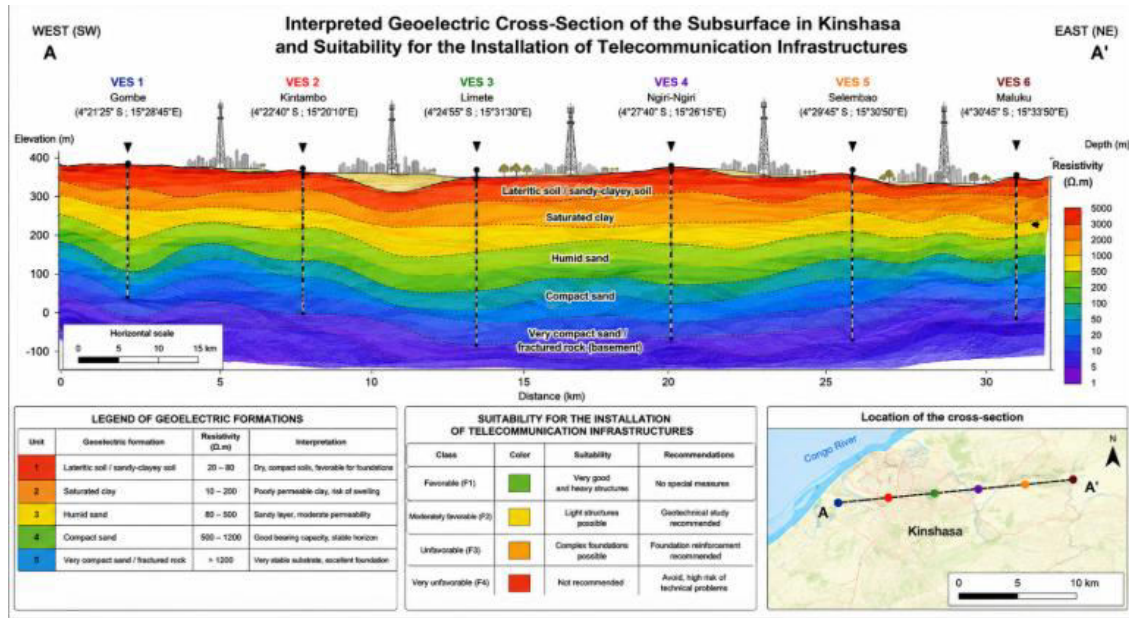


Figure.6. Interpreted goelectric cross-section highlighting areas favorable and unfavorable for the installation of telecommunications infrastructure

4.4 Summary of goelectric characteristics

Table 1 presents the main goelectric characteristics of the identified formations and their suitability for hosting telecommunications infrastructure.

Geological formation	Resistivity ($\Omega \cdot m$)	Geotechnical interpretation	Suitability implantation for
Saturated clay	20–80	Low load-bearing capacity, high compressibility	Unfavorable
Sandy clay	80–200	Average lift	Moderately favorable
Wet sand	200–500	Good stability	Favorable
Compacted sand	500–1200	Very good lift	Very favorable
compact laterite	>1200	Excellent stability	Very favorable

V. DISCUSSION

The results obtained show that the electrical resistivity method is an effective tool for characterizing the subsoil intended for the installation of telecommunications infrastructure. The observed resistivity variations reflect the lithological and hydrogeological differences of the formations encountered in Kinshasa, making it possible to distinguish favorable horizons from areas with geotechnical constraints. These observations are consistent with the work of Telford et al. (1990), Reynolds (2011), and Kearey et al. (2002), which emphasize that electrical resistivity is strongly influenced by the nature of the materials, their porosity, and their water content.

Geoelectrical interpretation reveals compact sandy formations with relatively high resistivities, likely to provide good load-bearing capacity for the foundations of pylons and base stations. Conversely, saturated clay formations, characterized by low resistivities, are more susceptible to settlement, swelling, and instability, particularly during

periods of heavy rainfall. These results are consistent with the observations of Sharma (1997) and Coduto et al. (2016), who indicate that saturated clay soils represent a major risk factor for civil engineering structures.

One of the main contributions of this study lies in the application of geophysics to telecommunications infrastructure planning. In practice, the choice of a site often relies on criteria such as radio coverage, accessibility, or land availability. The results obtained show that prior characterization of the subsoil allows for the integration of geotechnical constraints from the design phase, thereby reducing the risks of foundation deformation, maintenance costs, and corrective interventions after the infrastructure is commissioned. This approach aligns with the recommendations of Burger et al. (2006) and Dahlin (2001), who advocate the integration of geophysical methods into engineering studies to optimize site selection decisions. In the context of Kinshasa, where erosion, gulying, and soil saturation are frequent, the use of geophysical methods also provides a valuable tool for managing natural hazards. Areas identified as geotechnically unfavorable generally correspond to sectors dominated by clay or highly weathered formations, which can increase the vulnerability of infrastructure. These observations are consistent with recent work on flood and gully dynamics in the city of Kinshasa (Lumpungu Lutumba et al., 2025a; Lumpungu Lutumba et al., 2025b), confirming the influence of subsurface geophysical characteristics on the stability of structures.

This study, however, has some limitations. The investigations rely exclusively on vertical electrical soundings (VES), which provide primarily vertical information. Integrating electrical resistivity tomography (ERT), in-situ geotechnical tests (SPT or CPT), and borehole data would improve spatial resolution and reduce uncertainties related to interpretation. Furthermore, validation through direct geotechnical measurements would strengthen the robustness of the proposed geoelectric models. Looking ahead, future research could focus on an integrated approach combining geophysics, geotechnics, geographic information systems (GIS), and remote sensing to produce multi-criteria maps of suitability for telecommunications infrastructure deployment. Such an approach would contribute to improved network planning, reduced construction costs, and enhanced infrastructure resilience to geological and climatic hazards in tropical urban environments.

VI. CONCLUSION

This study evaluated the contribution of geophysical methods, particularly the electrical resistivity method using vertical electrical sounding (VES), to the characterization of the subsurface for the purpose of deploying telecommunications infrastructure in the city of Kinshasa. The investigations made it possible to identify the main geoelectric units, characterize their lithological and geotechnical properties, and distinguish areas with favorable or unfavorable conditions for the construction of these structures.

The results show that compact sandy formations and horizons with high resistivity offer the best conditions for the installation of pylons and other telecommunications infrastructure, while saturated clay formations, characterized by low resistivity, present increased risks of settlement and instability. These observations confirm that geophysical methods are a reliable, rapid, and non-destructive tool for improving site investigation and reducing uncertainties associated with preliminary geotechnical studies.

Integrating geophysical investigations into telecommunications projects is a relevant approach for optimizing site selection, strengthening infrastructure safety, and reducing costs associated with foundation failures. In a context of rapid urbanization like Kinshasa's, this approach can contribute to more sustainable planning of communication infrastructure.

Future work could focus on integrating vertical electrical soundings with electrical resistivity tomography (ERT), in-situ geotechnical testing and remote sensing or geographic information system (GIS) tools, in order to produce multi-criteria maps of suitability for the deployment of telecommunications infrastructure and to further improve decision-making.

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