Volume 11, Issue 6, June – 2026 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun645

Geotechnical Characterization and Analysis of the Behavior of Compressible Soils in a Tropical Urban Environment: Case Study of the Yolo Sud IV District in Kinshasa (DR Congo)

Ir Magloire Komende Komende Alung[1*]; Ir Kevin Lumpungu Lutumba[1]; Komende Hikuuru Nadja[1]

[1] Geophysical Research Center, Department of Internal Geophysics, Gravimetry and Geodesy Section, Kinshasa DRC

Corresponding Author: Ir Magloire Komende Komende Alung[1*]

Publication Date: 2026/06/27

Abstract: The urban expansion of the megacity of Kinshasa necessitates the occupation of marginal areas with precarious mechanical characteristics. The Yolo Sud IV district, located in the Funa plain, exhibits complex Quaternary sedimentation characterized by a sub-surface water table at 0.20 m. This study examines the mechanical response of the surface formations using an integrated approach combining geotechnical investigations (oedometer tests, dynamic penetration) and geophysical methods (Electrical Resistivity Tomography - ERT). The results reveal a profile dominated by silty clays and highly compressible organic muds ($C_c \approx 0.18$). The predicted settlements calculated under a three-story building reach 89.4 mm, significantly exceeding the critical threshold of 50 mm allowed by Eurocode 7. The article recommends mitigation strategies based on vertical drainage, reinforcement with geosynthetics, and ecological stabilization using coffee husk ash.

Keywords: *Urban Geotechnics, Compressible Soils, Oedometer Consolidation, ERT, Kinshasa, Geogrids, Coffee Husk Ash.*

How to Cite: Ir Magloire Komende Komende Alung; Ir Kevin Lumpungu Lutumba; Komende Hikuuru Nadja (2026) Geotechnical Characterization and Analysis of the Behavior of Compressible Soils in a Tropical Urban Environment: Case Study of the Yolo Sud IV District in Kinshasa (DR Congo). *International Journal of Innovative Science and Research Technology*, 11(6), 1480-1487. https://doi.org/10.38124/ijisrt/26jun645

I. INTRODUCTION

The saturation of stable building areas on the hills of Kinshasa has led to a massive migration towards the alluvial plains. Yolo Sud IV, located in the Kalamu district, is emblematic of this transformation: historically marshy, this site has undergone uncontrolled human-induced landfilling, where approximately 30% of the buildings rest on former landfill sites. The observed structural problems (cracking, tilting) demonstrate the inadequacy of conventional foundations in the face of the soil's suction and the anisotropy of permeability.

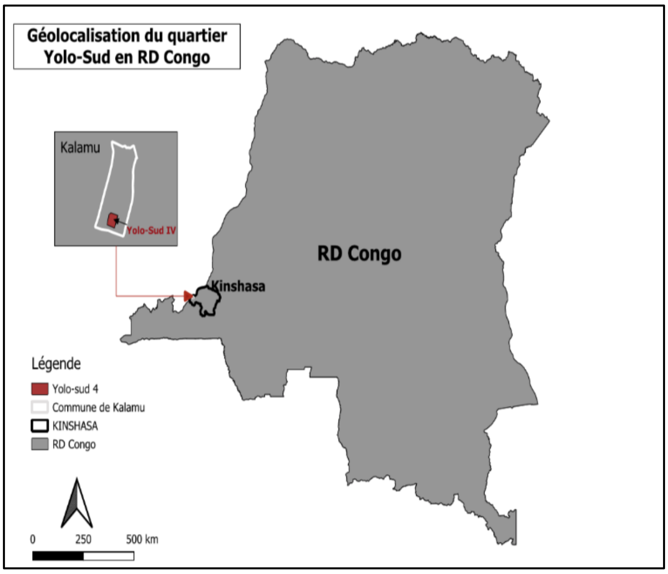

Fig 1 Map of the Location of Yolo Sud IV in Kinshasa and Kinshasa in the Democratic Republic of Congo

➢ *State of the Art*

Classical approaches to saturated soil mechanics prove limited in this context. The introduction of unsaturated soil mechanics is necessary to understand the influence of matrix suction on bearing capacity during low-flow periods, and its abrupt drop during rainy seasons, causing structural collapses.

➢ *Study Objectives*

The objective is to produce an integrated and spatial knowledge of the subsoil of Yolo Sud IV in order to quantify the risks of settlement and propose sustainable reinforcement solutions, based on the work of Nzau Umba-di-Mbudi on geosynthetics

II. MATERIALS AND METHODS

➢ *In Situ Investigations*

The program included 14 dynamic penetration tests (8 light tests of 10 daN and 6 heavy tests of 50 daN) to a depth of 5.8 m, supplemented by lithological soundings with a manual auger to correlate the mechanical parameters with the nature of the soil.

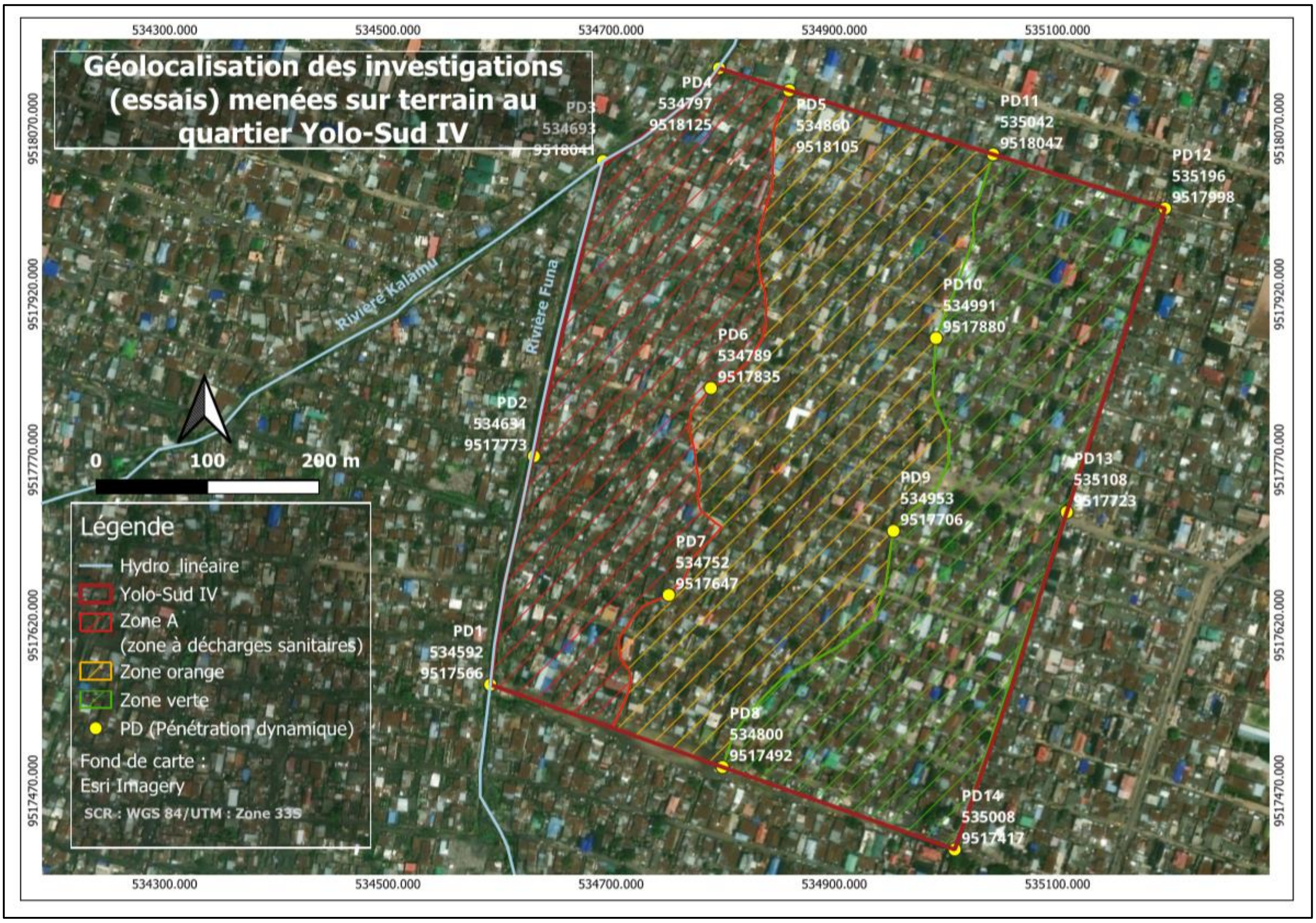

Fig 2 Geolocation of in Situ Trials (Personal Adaptation)

- *Auger Drilling*

A campaign at four representative points (ST1 to ST4) was conducted to cover the variability of the Yolo South IV site:

- ✓ ST1 (Central Reference): Characteristic profile of silty clays overlying fine sands down to a depth of approximately 0.50 m, with a whitish to blackish clayey sand at the surface. This surface layer is likely disturbed by human activity and subject to seasonal variations in humidity. In some places, it is necessary to dig down to 4 m to reach the sand, a consequence of years of dumping of waste on a significant portion of the site, which was formerly a public landfill.
- ✓ ST2 (Anthropogenic Sector): Reveals an accumulation of heterogeneous fill (plastic debris, organic waste) over 2.5 m. The borehole shows active decomposition of organic matter, generating pockets of gas and extreme compressibility.
- ✓ ST3 (Hydromorphic Zone) : Located at a low point, this borehole encountered a shallow water table (0.8 m). The samples taken show an almost liquid consistency, confirming the need for vertical drainage.
- ✓ ST4 (Transition Zone): Shows a sedimentary wedge where compressible layers thin out in favor of earlier clayey sands, illustrating the lateral anisotropy of the basin.

➢ *Laboratory Characterization*

Intact samples taken from 2.5 m were subjected to particle size analysis, Atterberg limits (NF P 94-051) and loading-step oedometer tests (NF P 94-090-1). The latter aim to quantify the delayed mechanical behavior or consolidation.

- *Geotechnical Interpretation*

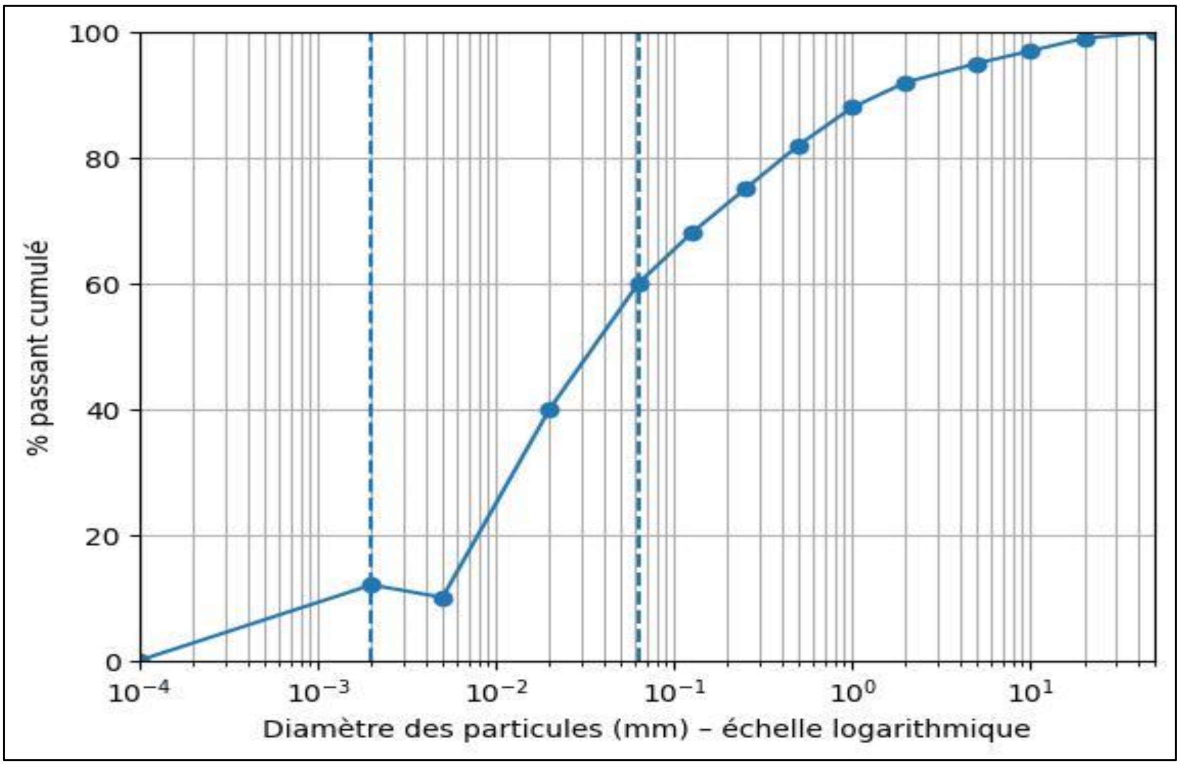

Fig 3 Estimated Particle Size Distribution Curve of the Yolo South IV Soil

- ✓ $D_{50} \approx 0.1$ mm → Fine to medium soil.
- ✓ Percentage passing through 0.063 mm sieve ≈ 48% → Soil classified as silty-sandy.
- ✓ Clay (< 0.002 mm) ≈ 12% → Low colloidal activity, limited cohesion.
- ✓ Spreading curve → Soil heterogeneity, typical of alluvial deposits and landfill embankments.

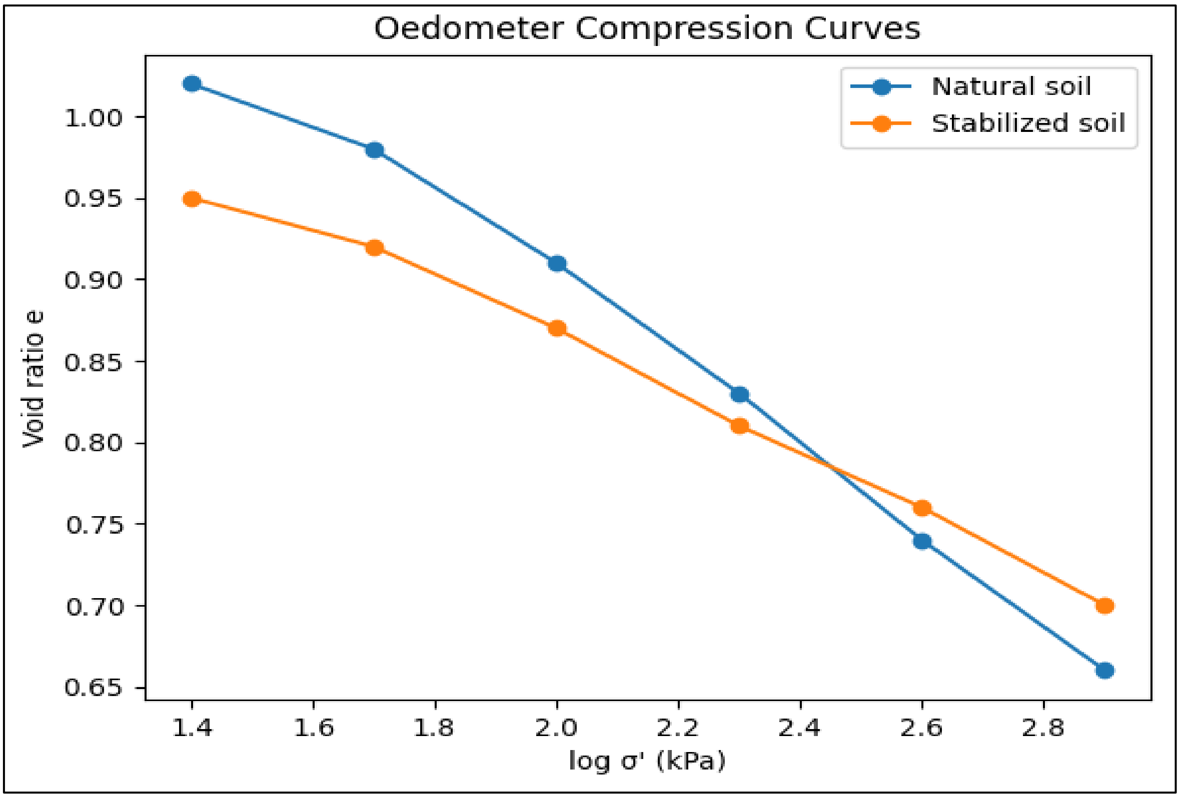

Fig 4 Oedometer Test and Consolidation Curve e = f(Logσ)

- *Electrical Resistivity Tomography (ERT)*

The use of the Wenner-Schlumberger method made it possible to map the heterogeneities of the subsoil and to delimit the plume of pollution from buried waste, whose biochemical decomposition alters the rigidity of the mass.

Spatial analysis of the data makes it possible to distinguish areas of anthropogenic influence from healthy geological areas.

Table 1 Summary of Electrical Resistivities in the Yolo South IV District

Horizon	**Depth (m)**	**Dominant lithological nature**	**Hydration status**	**Estimated resistivity (Ω · m)**	**Geotechnical interpretation**
H1	0.0 – 0.5	Topsoil / reworked clayey sand	Moist to semi-saturated	25 – 80	Heterogeneous surface layer, low compactness
H2	0.5 – 2.5	Compacted organic anthropogenic waste	Saturated	5-20	Very low resistivity due to humidity and leachate
H3	2.5 – 4.0	Compressible sandy silts / organic muds	Saturated	8 – 30	Highly compressible and conductive horizon
H4	4.0 – 5.5	Steep, fine clayey sands	Moderately saturated	40 – 120	Improved mechanical rigidity
H5	> 5.5	Silicified sandstone / substrate	Low saturated	250 – 1500	High resistivity resistant horizon

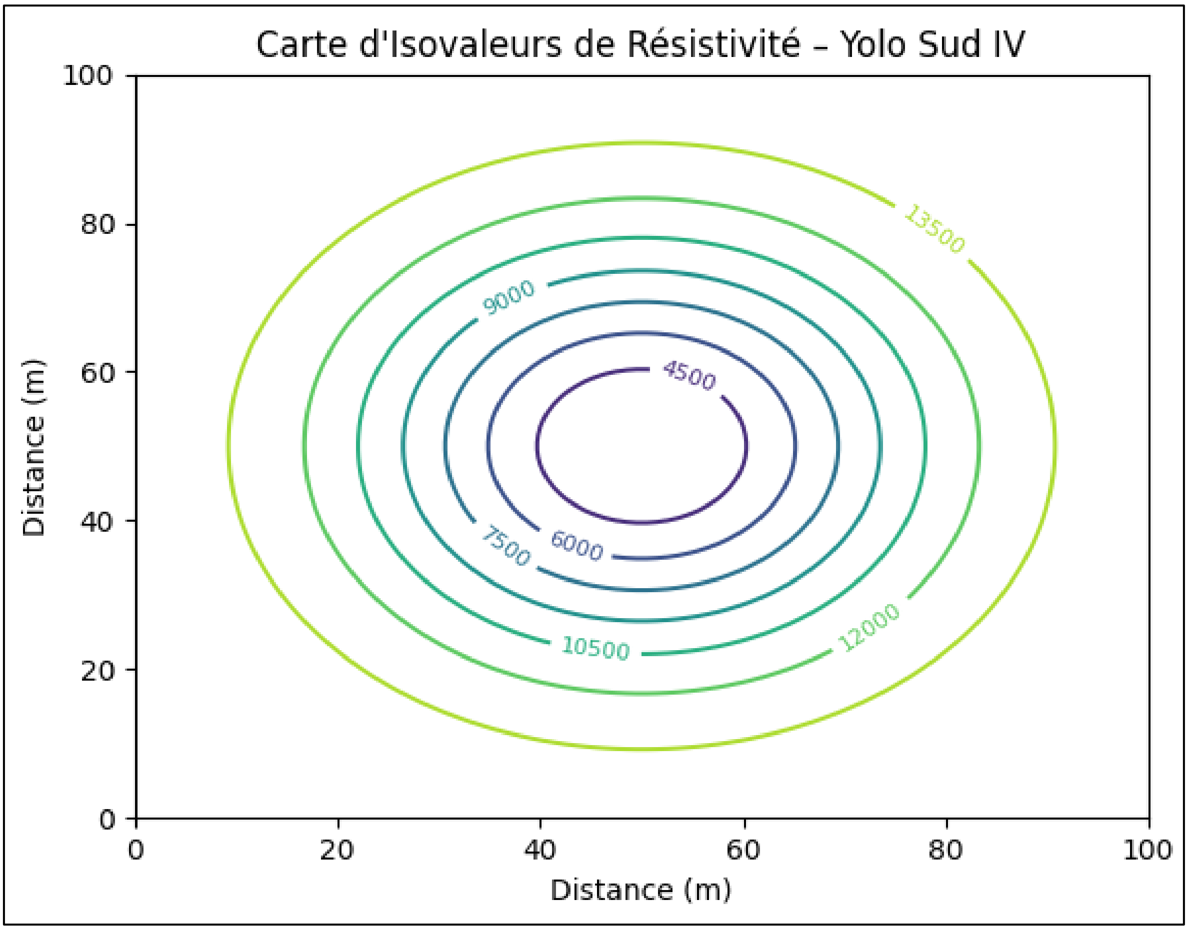

Fig 5 Map of Apparent Resistivity ISO Values for the Detection of Groundwater and Pollution Zones

- *General Geophysical Interpretation*

- *Areas with Very Low Resistivity (5–20 Ω·m)*

These correspond mainly to anthropogenic waste, saturated organic sludge, areas contaminated by leachate and areas with a sub-surface water table. These areas are associated with high compressibility, low bearing capacity, and high risks of differential settlement.

- *Areas of Average Resistivity (30–120 Ω·m)*

Associated with sandy silts, clayey sands and partially consolidated materials.

These horizons exhibit moderate lift, slow consolidation, and permeability anisotropy.

- *Areas of High Resistivity (>250 Ω·m)*
  These correspond to the sandstone substrate, more compact formations, and mechanically stable layers.

These horizons constitute the best anchoring layers for deep foundations and the geomechanical reference levels.

III. RESULTS

➢ *Stratigraphic Profile and Dynamic Resistance*

The diagnosis reveals a structure divided into five major and distinct horizons, exhibiting marked resistance contrasts and replacing a simplified view with precise metric data.

Table 2 Geotechnical Characterization Averages per Horizon

Horizon	Depth (m)	Lithological Nature	Rd (MPa)
H1	0.0 – 0.5	Reworked surface layer (sandy fill).	≈ 0.8
H2	0.5 – 2.5	Compacted waste (former landfills). Extremely low resistance	0.1 - 0.8
H3	2.5 – 4.0	Sandy silts and compressible muds (Alluvium)	0.8 - 1.5
H4	4.0 – 5.5	Fine clayey sands, more compact.	1.5 - 3.3
H5	> 5.5 m	Substratum of soft, silicified sandstone.	> 12 MPa.

➢ *Consolidation Behavior and Settlement*

- Oedometer tests show normally consolidated soil (OCR ≈ 1.67).
- Compression index (Cc) : Approximately 0.18, confirming high compressibility.
- Pre-consolidation pressure (σ '): Approximately 120 kPa.
- Consolidation coefficient (Cv) : 3.3 x 10^{-7} m²/s.

➢ *Hydraulic Properties and Anisotropy*

- *Estimated Permeability*
  Based on the theoretical relationship:

K = $\underline{\text{Cv x Yw x mv}}$

1 + e_0

With:

✓ Cv = 3.3 x $^{10^{-7}}$ m² / ^{s}
✓ Yw = 10 kN/ $^{m^3}$
✓ mv = $\underline{\text{0.434 x Cc }}$ = $\underline{\text{0.434 x 0.18 }}$ ≈ 6.38 x 10^{-4} kPa $^{-1}$

(1+e_0) x σ'_0 (1 + 0.70) x 72

→ Kv = $\underline{\text{(3.3 x } 10^{-7}\text{) x 10 x (6.38 x } 10^{-4}\text{) }}$ ≈ 1.24 x 10^{-9} m/s (vertical)

1 + 0.7

- *Hydraulic Anisotropy*
  According to O'Kelly (2005) on similar laminate flooring:

✓ Kh/Kv ratio = 2.0 (conservative value for sandy silts)

→ Kh ≈ 2.48 × 10^{-9} m/s (horizontal)

- Justification: The alluvial soils of the Kinshasa plain exhibit marked horizontal stratification.

➢ *Load-Bearing Capacity and Settlement*

- *Load-Bearing Capacity at 4.0 m*
  For a continuous footing (B = 1.2 m; D = 4.0 m):

✓ Terzaghi's Formula:

qult = c'Nc + qNq + 0.5YBNY

With φ' = 28° → Nc = 25.8, Nq = 14.7, Nγ = 11.2

✓ Calculation:

qult = (15 x 25.8) + (72 x 14.7) + (0.5 x 18 x 1.2 x 11.2) = 1566 kPa

With an overall safety factor Fs = 3, the allowable stress is: qadm = 1566/3 = 522 kPa

✓ Verification:

Load of an R+3 ≈ 60 kPa << 522 kPa ☑

- *Projected Settlements*

✓ *Calculation Data*

- Applied load: Δσ = 60 kPa
- Compressible layer thickness: H = 2.5 m
- Oedometer modulus: E _o = 4 x 10³ kPa
- Poisson's ratio: ν = 0.3
- Influence factor: Is = 1.2 (continuous sole)
- Cv = 0.18, e_o = 0.70, σ'o = 72 kPa

- *Immediate (Elastic) Settling:*

Si = $\underline{\text{qB}(1-\nu^2)\text{ Is }}$ = $\underline{\text{60 x 1.2 x (1 – }0.3^2\text{) x 1.2 }}$ = $\underline{\text{60 x 1.2 x 0.91 x 1.2}}$

E_0 4000 4000

If ≈ 19.7 mm

- *Consolidation Settlement:*

$$S_c = \frac{C_c}{1+e_0} \times H \times \log\left(\frac{\sigma'_0+\Delta\sigma}{\sigma'_0}\right) = \frac{0.18}{1.70} \times 2.5 \times \log\left(\frac{72+60}{72}\right) \approx 69.7 \text{ mm}$$

- *Total Short-Term (1 year) Settlement:*

Total S = Si + Sc = 19.7 + 69.7 = 89.4 mm (> 50 mm unacceptable and corresponding to the reality observed on the ground)

➢ *Shear Parameters*

- *Reconstructed Values at a Depth of 4.00 m*

✓ *Effective State (Long Term):*

- Effective cohesion: c' = 15 kPa
- Effective friction angle: φ' = 28°
- Density: $\gamma = 18$ kN/m³
- Saturated unit weight: $\gamma_{sat} = 20$ kN/m³

✓ *Undrained State (Short Term):*

- Undrained cohesion: Cu = 80 kPa
- Undrained friction angle: $\varphi_u = 0°$ (assuming saturated soil)

- *Equation of the Rupture Envelope*

✓ *Regarding the Actual State:*

$\tau_f = c' + \sigma'_n \tan(\varnothing')$

$\tau_f = 15 + \sigma'_n \tan(28°)$

$\tau_f = 15 + 0.5317\ \sigma'_n$

✓ *For the Undrained State:*

$\tau_f = C_u = 80$ kPa (independent of σ_n)

- *Settlement Analysis:*

For a 3-story building (load of 60 kPa), the estimated settlement is 89.4 mm at one year, which far exceeds the service threshold (L/500).

IV. DISCUSSION AND STRENGTHENING STRATEGIES

➢ *ERT Analysis and Hydrogeology*

The ERT reveals that resistivities below 20 *Ω·m* correspond to saturated and polluted horizons. The water table, surfacing at 0.20 m, makes the soils sensitive to seasonal cycles. The hydraulic gradient, oriented southwest to northeast (SW-NE), controls pollutant transport.

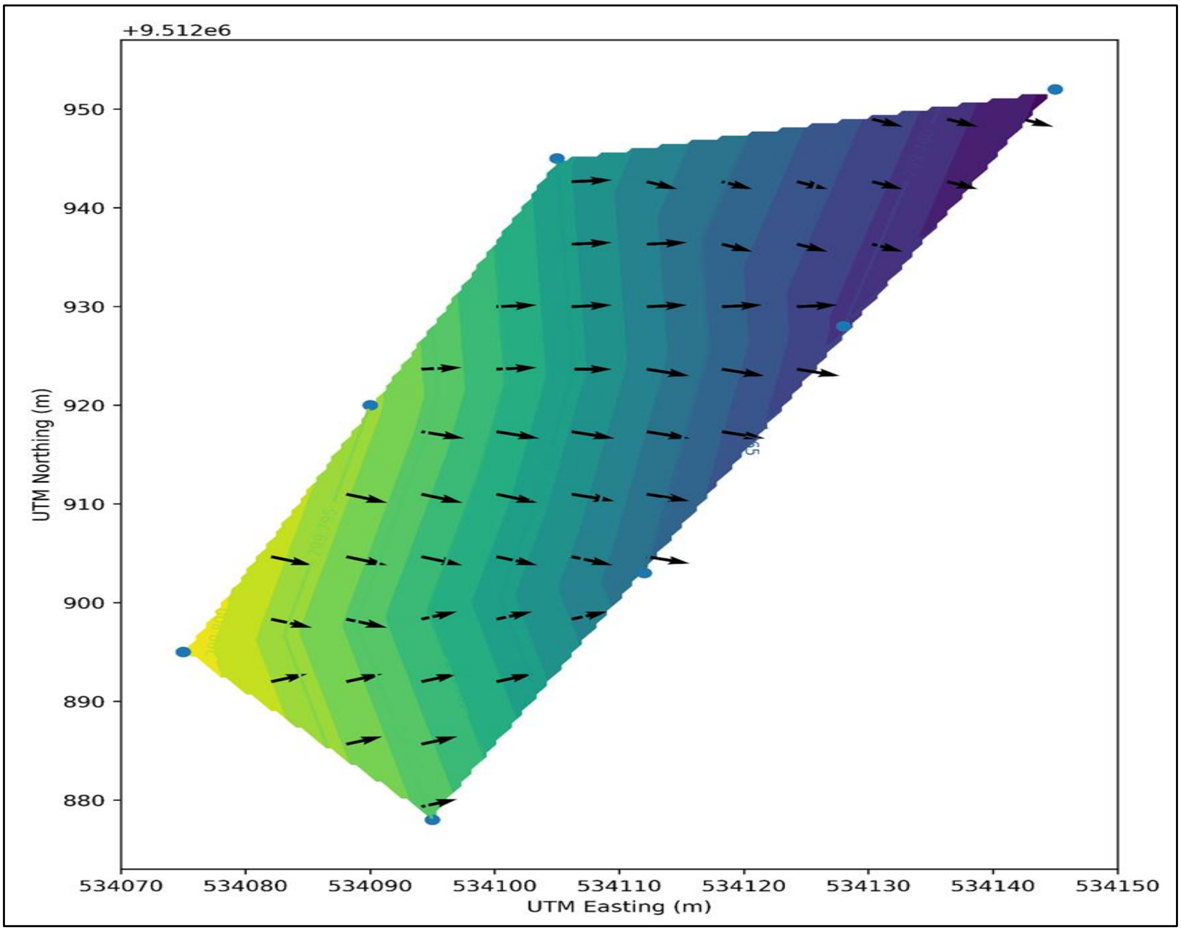

Fig 6 Map of Groundwater Flow (Personal Adaptation)

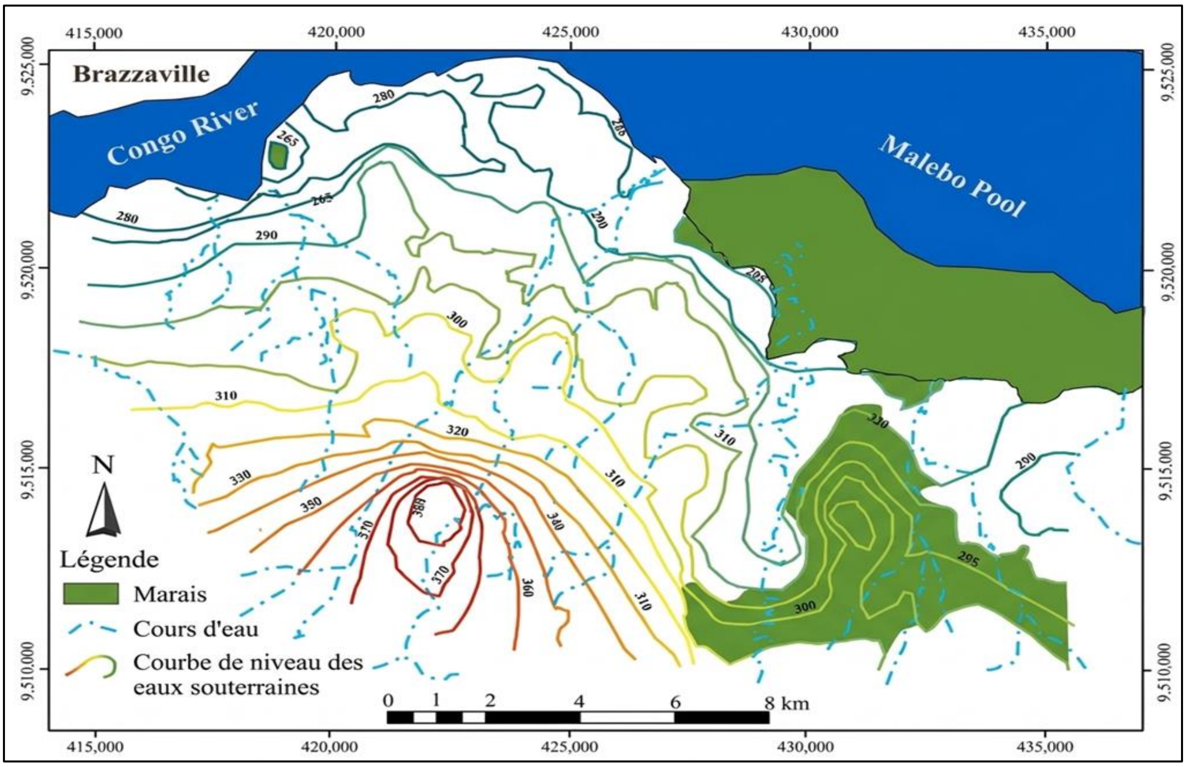

Fig 7 Superimposition of the Kinshasa City Drainage System onto the Curves Groundwater Level (Lateef et al., 2010)

➢ *Risk Zoning and Mitigation Solutions*

A territorial classification is proposed to guide planning:

- Red Zone (30%) : Landfill areas. Recommendation: total excavation (6-8 m) or strict containment.
- Orange Zone (35%) Degraded soils. Reinforcement is imperative with vertical drains (PVD) or geogrids.
- Green Zone (35%) : Soils suitable for controlled construction.

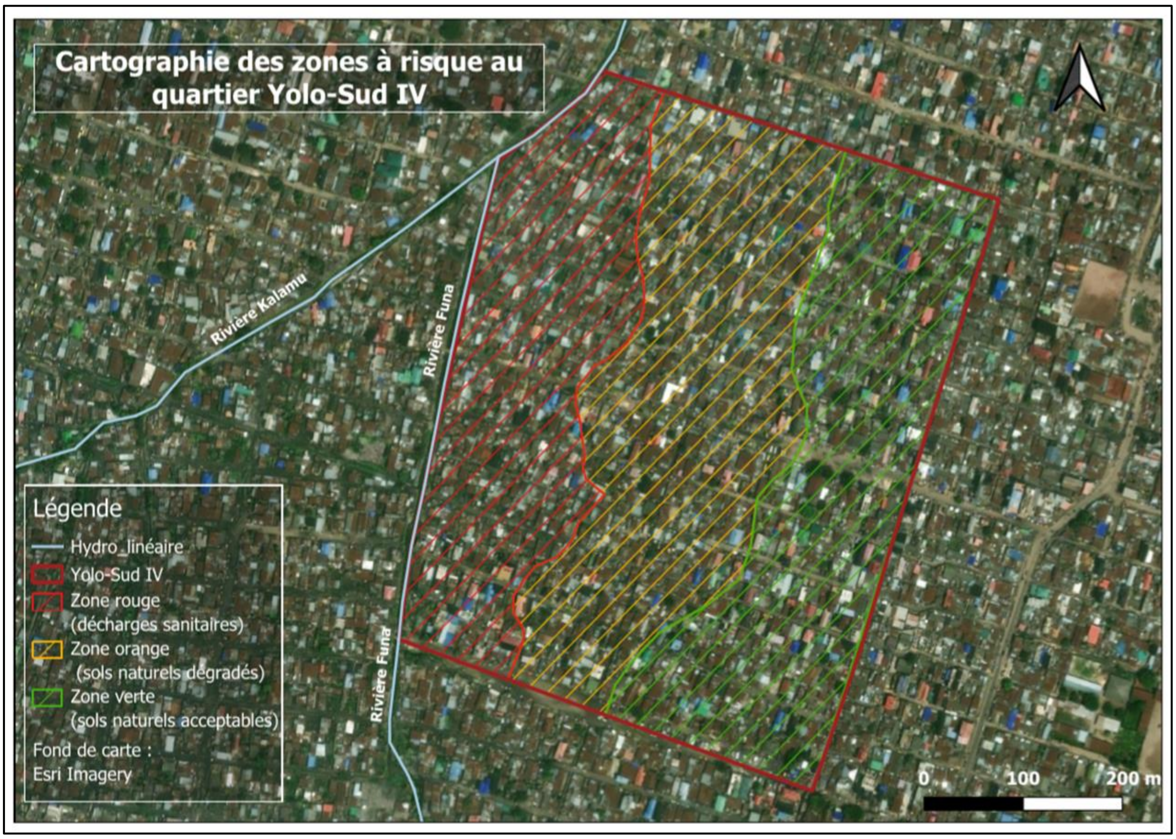

Fig 8 Mapping of Risk Areas

➢ *Technical Solutions for Resilience*

- *Geogrid Reinforcement:* The use of Fornit 40 type geogrids allows for:

  ✓ Distribute the loads: Reduction of vertical pressure on the H2 horizon.
  ✓ Improving CBR: Bearing gains ranging from +13% to +150% have been modeled for the reinforced soils of Kinshasa.

- *Vertical Drainage:* The installation of PVD drains is imperative to accelerate primary consolidation.

- *Ecological Stabilization (CHA):* The incorporation of 15-20% coffee husk ash improves load- bearing capacity by utilizing local waste. It also modifies the flocculated structure of Yolo clay, increasing the shrinkage limit and reducing the swelling index (Cs), thus offering an ecological and economical solution for local builders.

V. CONCLUSION AND RECOMMENDATIONS

The study proves that the sustainability of infrastructure in Kinshasa depends on a "territorial" approach. The study also demonstrates that Kinshasa can no longer ignore areas of anthropogenic fill. Integration, specifically the integration of geophysics, allows for precise risk zoning. It is imperative to systematically adopt vertical drainage (to accelerate consolidation before construction) and geosynthetic reinforcement to ensure urban resilience in these compressible contexts and stabilize subgrade layers.

It is imperative to adopt rigorous piezometric monitoring to anticipate seasonal drops in bearing capacity.

REFERENCES

[1]. Atahu, MK, et al. (2019). Geotechnical Properties of Clay Soil Stabilized with Coffee Husk Ash. IJER.
[2]. Fredlund, D.G., & Rahardjo, H. (1993). Soil Mechanics for Unsaturated Soils. John Wiley & Sons.
[3]. Komende Komende Alung, M. (2026). Geotechnical characterization and analysis of the behavior of compressible soils: Case of Yolo South IV. Master's thesis, ISAU-INBTP.
[4]. Lateef et al. (2010). Geological constraints on urban, sustainability, Kinshasa, City, Democratic Republic of Congo. Environmental Geosciences. V.17, no.1. pp.17-35.
[5]. Nzau Umba-di-Mbudi, C. (2025). Improving the Load-Bearing Capacity of Pavement Soils of Kinshasa (DR Congo) Using Geogrids. IOSR-JMCE, 22(5).
[6]. Wang, L., et al. (2024). Foam conditioning and muck compressibility in shield tunnel.