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Geology and Geotechnical Characterization of Subsurface Conditions for Building Construction at Federal University Gusau

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Abstract

This study presents a comprehensive geological and geotechnical characterization of subsurface conditions at Federal University Gusau, Zamfara State, and Northwestern Nigeria, to evaluate the suitability of the campus for sustainable building construction. The research employed integrated field geological mapping, vertical electrical sounding (VES), and geotechnical laboratory testing to delineate subsurface stratigraphy and assess engineering properties of foundation materials. Twenty (20) VES stations were surveyed across the campus using the ADMT ZN300 instrument to determine resistivity variations and subsurface layering. Results reveal a three-to-four layer geo-electric sequence comprising: (1) topsoil/lateritic overburden (0.5–6 m thickness; resistivity 24–394 Ωm); (2) weathered basement (8–15 m thickness; 150–735 Ωm); (3) fractured basement (variable thickness; 200–750 Ωm); and (4) fresh basement bedrock (>15 m depth; 750–1200 Ωm). Geotechnical analysis indicates that the lateritic overburden exhibits variable engineering properties, with some zones showing low shear strength (cu = 15–35 kPa) and high compressibility, rendering them unsuitable for shallow foundations without improvement. Conversely, the fresh basement bedrock demonstrates high bearing capacity (>500 kPa) and competence for foundation support. Structural measurements from 17 outcrops indicate an average dip of 19.2°, with dominant structural trends oriented NE–SE, which may influence foundation alignment and groundwater flow patterns. The study recommends deep foundation systems (piled or raft foundations) extending to the fresh basement layer for multi-story structures, comprehensive site-

specific investigations prior to construction, and avoidance of foundations on uncompact lateritic clay zones. This research provides critical baseline data for infrastructure development at Federal University Gusau and similar basement complex terrains in Northwestern Nigeria.

Keywords: Basement Complex; Geotechnical characterization; Subsurface stratigraphy; Foundation engineering; Electrical resistivity; Federal University Gusau; Building construction.

Introduction

Geological and geotechnical site characterization constitutes a fundamental prerequisite for safe, economical, and sustainable building construction. This process involves the systematic investigation of subsurface conditions to gather critical data on soil and rock properties, groundwater regimes, and geological structures that may influence foundation performance and structural stability (Okeke & Ogbu, 2021). Such investigations typically encompass field geological mapping, geophysical surveys, borehole drilling, and laboratory testing of soil and rock samples to determine engineering parameters essential for modern foundation design.

The rapid expansion of tertiary institutions in Nigeria, particularly in the northwestern region, has necessitated accelerated infrastructure development to accommodate growing student populations and academic programs. Federal University Gusau (FUGUS), established in 2013 in Zamfara State, is experiencing significant campus development requiring rigorous subsurface evaluation to mitigate structural failures and ensure long-term building performance. Construction within the Nigerian Basement Complex terrain presents unique geotechnical challenges due to heterogeneous weathering profiles, variable rock competence, differential settlement potential, and the presence of problematic clay minerals that can compromise foundation integrity (Amadi et al., 2020; Adeyemi & Oladunjoye, 2023).

While numerous studies have addressed geological mapping and groundwater exploration in various parts of Northwestern Nigeria (Yahaya & Ibrahim, 2022; Bello & Ahmed, 2021; Danbatta et al., 2023), limited attention has been devoted to integrated geological-geotechnical characterization specifically for building construction at Federal University Gusau. This knowledge gap poses significant risks for infrastructure development, as inappropriate foundation design without adequate subsurface information can lead to structural distress, excessive settlement, and premature building failure.

Geotechnical investigations for construction purposes involve systematic site examination by qualified geologists and engineers who document surface geology, collect representative soil and rock samples, measure structural features, and conduct in-situ and laboratory tests to determine engineering properties. The resulting data are integrated into geological and geotechnical

maps that illustrate the spatial distribution of foundation materials, structural elements, and potential geohazards—information critical for informed decision-making in construction planning and design (Ekwueme & Nwankwoala, 2020).

This study aims to provide the first comprehensive geological and geotechnical characterization of Federal University Gusau campus and its immediate environs. Specific objectives include: (1) documenting the geological setting and structural attributes of the study area; (2) delineating subsurface stratigraphy and material properties through integrated field and geophysical methods; (3) evaluating the engineering suitability of identified geological units for foundation support; and (4) providing practical recommendations for foundation design and site investigation protocols. The findings will contribute to sustainable infrastructure development at FUGUS and inform best practices for construction in basement complex terrains of Northwestern Nigeria.

Shallow Foundations

Shallow foundations, also known as spread footings, transfer structural loads to the earth near the surface, typically at depths less than the foundation width. These include isolated footings, strip footings, raft/mat foundations, and combined footings. Shallow foundations are economically advantageous and construction-friendly but require competent bearing strata within accessible depths. In basement complex terrains, shallow foundations may be feasible where fresh bedrock occurs within 1.5–3 m of the surface or where lateritic materials exhibit adequate bearing capacity and low compressibility compacted.

Deep Foundations

Deep foundations transmit structural loads to deeper, more competent strata when shallow soils are inadequate. Common types include driven piles, bored piles, drilled shafts, and caissons. In the Nigerian Basement Complex, deep foundations are often necessary due to thick weathering profiles (5–30 m) and the presence of compressible lateritic clays. Pile foundations socketed into fresh basement bedrock provide reliable support for multi-story buildings, bridges, and heavy industrial structures, though they entail higher construction costs and require specialized equipment.

Subsurface Conditions in Basement Complex Terrains

The Nigerian Basement Complex is characterized by complex weathering profiles that significantly influence foundation design. A typical weathering sequence includes: (1) topsoil (0–1 m); (2) lateritic clay and laterite (1–6 m); (3) weathered basement/saprolite (5–20 m); (4) fractured basement (variable thickness); and (5) fresh bedrock. The thickness and engineering properties of these layers vary considerably based on lithology, structural controls, drainage patterns, and climatic conditions.

Lateritic clays, common in Northwestern Nigeria, often exhibit problematic geotechnical behavior including high plasticity, swell-shrink potential, low shear strength, and high compressibility. These characteristics necessitate careful evaluation before use as foundation

materials. Conversely, fresh basement rocks (granites, gneisses, and migmatites) generally provide excellent bearing capacity but may require verification of fracture density and weathering grade.

GROUNDWATER CONSIDERATIONS FOR CONSTRUCTION

Groundwater conditions significantly influence foundation design, excavation stability, and basement construction. In basement complex terrains, groundwater occurs in unconfined conditions within the weathered overburden and in semi-confined to confined conditions within fractured bedrock zones. The water table depth varies seasonally and spatially, typically ranging from 1.5–15 m below ground level in Northwestern Nigeria.

High groundwater tables can compromise foundation bearing capacity, induce buoyancy effects on basement structures, and necessitate dewatering during excavation. Additionally, groundwater chemistry may affect concrete durability through sulfate attack or chloride-induced corrosion of reinforcement. Therefore, hydrogeological assessment should be integrated with geotechnical investigations to inform foundation design and construction methodology.

Lateritic Soils

Lateritic soils, products of intense tropical weathering, exhibit variable engineering properties depending on their degree of laterization and clay content. Well-laterized gravels can serve as suitable sub-base materials when properly compacted (CBR > 30%), while clay-rich laterites often display low strength and high compressibility. Key geotechnical parameters include:

- **Atterberg Limits:** Liquid limit = 30–60%; Plasticity Index = 10–30%
- **Shear Strength:** Undrained cohesion (cu) = 15–50 kPa
- **Compressibility:** Compression index (Cc) = 0.15–0.45
- **Compaction:** Maximum dry density = 1.6–2.0 Mg/m^3; Optimum moisture content = 10–20%

Weathered Basement (Saprolite)

Weathered basement materials retain the fabric of the parent rock but exhibit reduced strength and increased permeability due to chemical alteration and fracturing. Engineering properties are highly variable and depend on weathering grade:

- **Moisture Content:** 10–30%
- **Unconfined Compressive Strength:** 0.5–5 MPa
- **Deformability Modulus:** 50–500 MPa
- **Permeability:** 10^{-6} to 10^{-4} m/s (fracture-controlled)

Fresh Basement Bedrock

Fresh basement rocks (granites, gneisses, and migmatites) provide high bearing capacity and low compressibility, making them ideal foundation materials. However, structural discontinuities (joints, faults, shear zones) can significantly reduce mass strength and increase permeability. Typical properties include:

- **Unconfined Compressive Strength:** 50–250 MPa
- **Young's Modulus:** 20–70 GPa
- **Poisson's Ratio:** 0.15–0.30
- **Bulk Density:** 2.6–2.8 Mg/m³

THE STUDY AREA

Federal University Gusau is located in Gusau, the capital of Zamfara State, Northwestern Nigeria. The campus lies approximately between Latitudes 12° 5' 0" N ,and 12°10 0"N and Longitudes 06°43′0" E and 06° 48′ 0" E (Figure 1). The university occupies a land area of approximately 2,500 hectares and is bounded by residential areas to the north, agricultural lands to the south and east, and the Gusau-Sokoto highway to the west.

The topography of the study area is characterized by gently undulating plains with elevations ranging from 350 to 450 m above sea level. The landscape features scattered inselbergs (granitic outcrops), shallow valleys, and seasonal drainage channels that flow southward toward the Rima River basin. The climate is tropical semi-arid, with a distinct wet season (May–September) receiving 800–1000 mm of annual rainfall and a prolonged dry season (October–April) characterized by harmattan dust winds.

Vegetation consists of Sudan savanna woodland with scattered trees (Acacia, Baobab, Neem) and seasonal grasses. Soils are predominantly tropical ferruginous types (laterites and lateritic clays) derived from in-situ weathering of the underlying Basement Complex rocks.

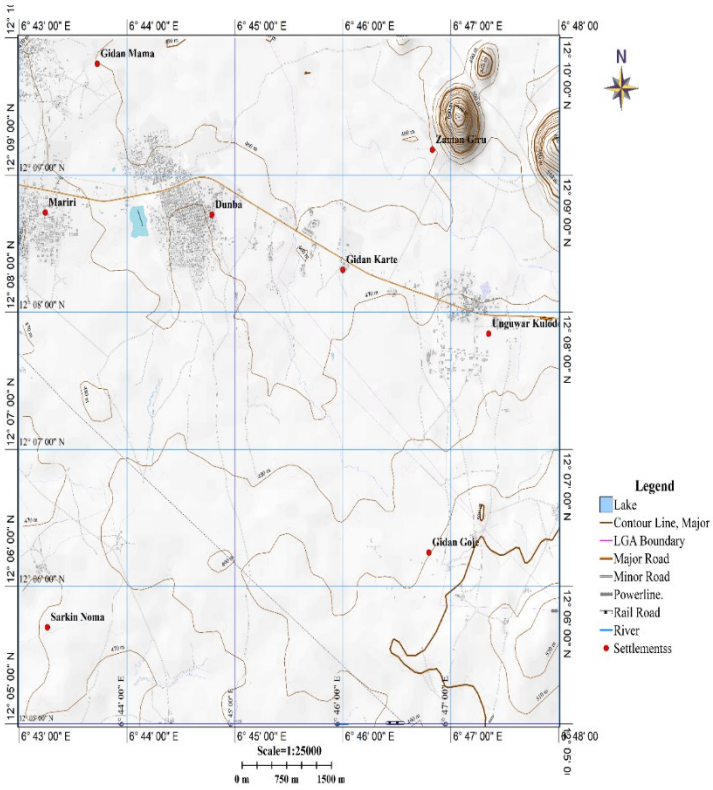


Figure 1. Topographic map of Federal University Gusau within Zamfara State.

GEOLOGICAL SETTING

Federal University Gusau is located within the Precambrian Basement Complex of Northwestern Nigeria, a geological domain associated with the Pan-African orogenic system that underwent significant tectonothermal reworking approximately 600 ± 150 million years ago (Abdullahi & Mohammed, 2022; Ibrahim et al., 2021). The Nigerian Basement Complex is conventionally subdivided

into three major lithotectonic assemblages: (i) the Migmatite-Gneiss Complex, representing high-grade metamorphic basement; (ii) Schist Belts composed of metasedimentary and metavolcanic sequences; and (iii) syntectonic to post-tectonic Older Granites that intrude the preceding units.

The study area falls within the Older Granite province of the Northwestern Nigerian Massif, where the bedrock is dominated by coarse-grained to porphyritic granitic intrusions, with localized occurrences of migmatitic gneisses and narrow schistose belts (Figure 2). Regional geological reconstructions suggest these granitic bodies were emplaced during the terminal stages of the Pan-African orogeny and have subsequently been modified by polyphase deformation, prolonged subaerial weathering, and erosional unroofing (Ogunleye & Adeoti, 2023).

Structural analysis of the area reveals a dominant fabric orientation trending NE–SW to NNE–SSW, expressed through foliation planes, mineral lineations, joint sets, and fault zones that align with regional Pan-African strain patterns (Suleiman & Bello, 2024). Field evidence of brittle deformation includes fault breccias, fractured rock zones, and quartz–aplite vein networks. Weathering intensity exhibits marked spatial variability, generating residual soil profiles ranging from 5 to 25 m in thickness; thicker regolith development is typically observed in topographic lows and areas with restricted drainage (Danbatta et al., 2023).

The regional geological evolution reflects a multiphase tectonic history encompassing:

(1) deposition of protolith sediments and volcanic sequences in a marginal basin environment; (2) regional metamorphism and deformation linked to the Eburnean orogenic cycle (~2000 Ma); (3) granitic magmatism and high-grade metamorphism during the Pan-African thermo-tectonic event (~600 Ma); (4) continental uplift and peneplanation throughout the Paleozoic–Mesozoic transition; and (5) intense tropical weathering and laterite formation during the Cenozoic under humid climatic regimes (Amadi & Nwankwoala, 2020; Yahaya & Ibrahim, 2022).

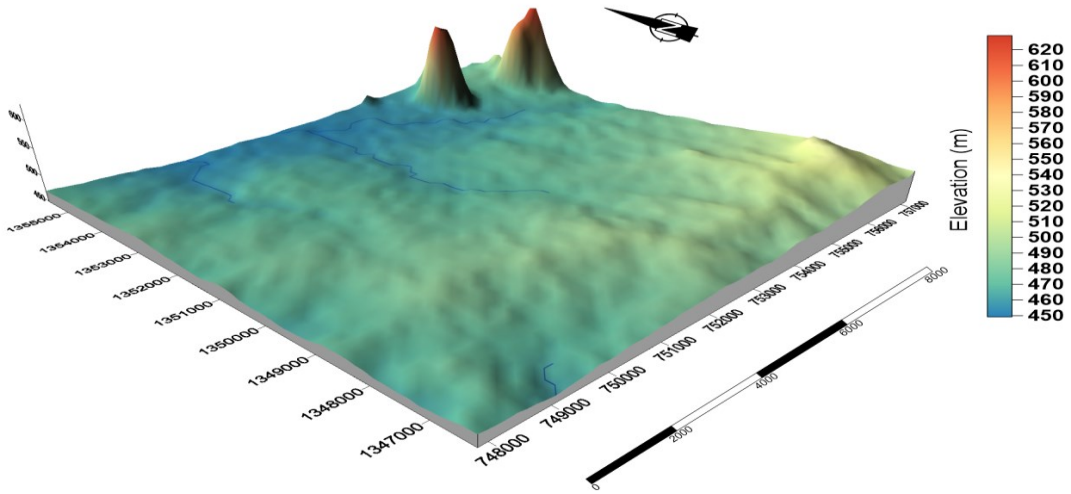


Figure 2. DEM map of Federal University Gusau within Zamfara State.

METHODOLOGY

This study employed an integrated approach combining field geological mapping, geophysical surveying, and geotechnical laboratory testing to characterize subsurface conditions at Federal University Gusau. The methodology was designed to provide comprehensive data on lithology, structural features, subsurface stratigraphy, and engineering properties of foundation materials.

FIELD GEOLOGICAL MAPPING

Detailed geological mapping was conducted across the Federal University Gusau campus using standard compass-traverse methods. Seventeen (17) outcrops were identified, logged, and sampled for lithological description,

GEOPHYSICAL INVESTIGATION

Vertical Electrical Sounding (VES) using the Schlumberger array was employed to delineate subsurface resistivity variations and infer lithological layering. Twenty (20) VES stations were surveyed across the campus along six profiles (A–F) with 200–500 m spacing to ensure adequate coverage of the study area (Figure 3).

Equipment and Configuration:

- Instrument: ADMT ZN300 Digital Resistivity Meter
- Array Type: Schlumberger configuration
- Maximum Current Electrode Separation (AB/2): 100 m
- Potential Electrode Separation (MN/2): 0.5–20 m (incremental)
- Probing Depth: Approximately 80–120 m

Survey Procedure:

1. VES stations were selected based on accessibility, proposed construction zones, and geological variability
2. Electrodes were positioned along straight lines with careful spacing to minimize contact resistance
3. Resistivity measurements were taken at incremental electrode separations
4. Field data were quality-checked for consistency and repeatability
5. GPS coordinates and elevation data were recorded at each station

Data Processing and Interpretation: VES data were processed using IPI2WIN software to derive true resistivity-depth models. The interpreted models were correlated with available borehole logs and geological observations to assign lithological units to geo-electric layers. Resistivity ranges were used to distinguish between:

- Topsoil/laterite: 20–400 Ωm
- Weathered basement: 100–750 Ωm
- Fractured basement: 200–800 Ωm

- Fresh basement: >750 Ωm

GEOTECHNICAL LABORATORY TESTING

Representative soil and rock samples collected from outcrops and trial pits were subjected to standard geotechnical tests at the Federal University Gusau Geotechnical Laboratory. Tests were conducted in accordance with Nigerian Standard Specifications and international standards (ASTM, BS).

Soil Tests:

- **Grain Size Distribution:** Sieve analysis and hydrometer method
- **Atterberg Limits:** Liquid limit, plastic limit, plasticity index
- **Moisture Content:** Oven-drying method
- **Compaction Characteristics:** Standard Proctor test (BS 1377)
- **California Bearing Ratio (CBR):** Soaked and unsoaked conditions
- **Shear Strength:** Unconfined compression test, direct shear test
- **Consolidation Properties:** Oedometer test for compressibility parameters

Rock Tests:

- **Unconfined Compressive Strength (UCS):** Core samples tested in compression
- **Point Load Index:** For irregular rock fragments
- **Slake Durability Index:** To assess weathering resistance
- **Bulk Density and Porosity:** Using saturation and buoyancy methods

Engineering assessments were performed to evaluate:

- Bearing capacity of different geological units
- Settlement potential of compressible layers
- Suitability for shallow vs. deep foundations
- Groundwater conditions and drainage requirements
- Construction material availability and quality

GEOLOGICAL MAPPING FINDINGS

Field mapping confirms that Federal University Gusau campus is underlain by Older Granites of the Nigerian Basement Complex, exhibiting textural variations from fine-grained to coarse porphyritic types. Three main exposure types were identified:

1. **Low-lying ridges:** Comprising moderately weathered granite with visible jointing
2. **River channel exposures:** Showing fresh to slightly weathered granite with minimal overburden
3. **Whale-back outcrops:** Large dome-shaped exposures of fresh granite with exfoliation joints

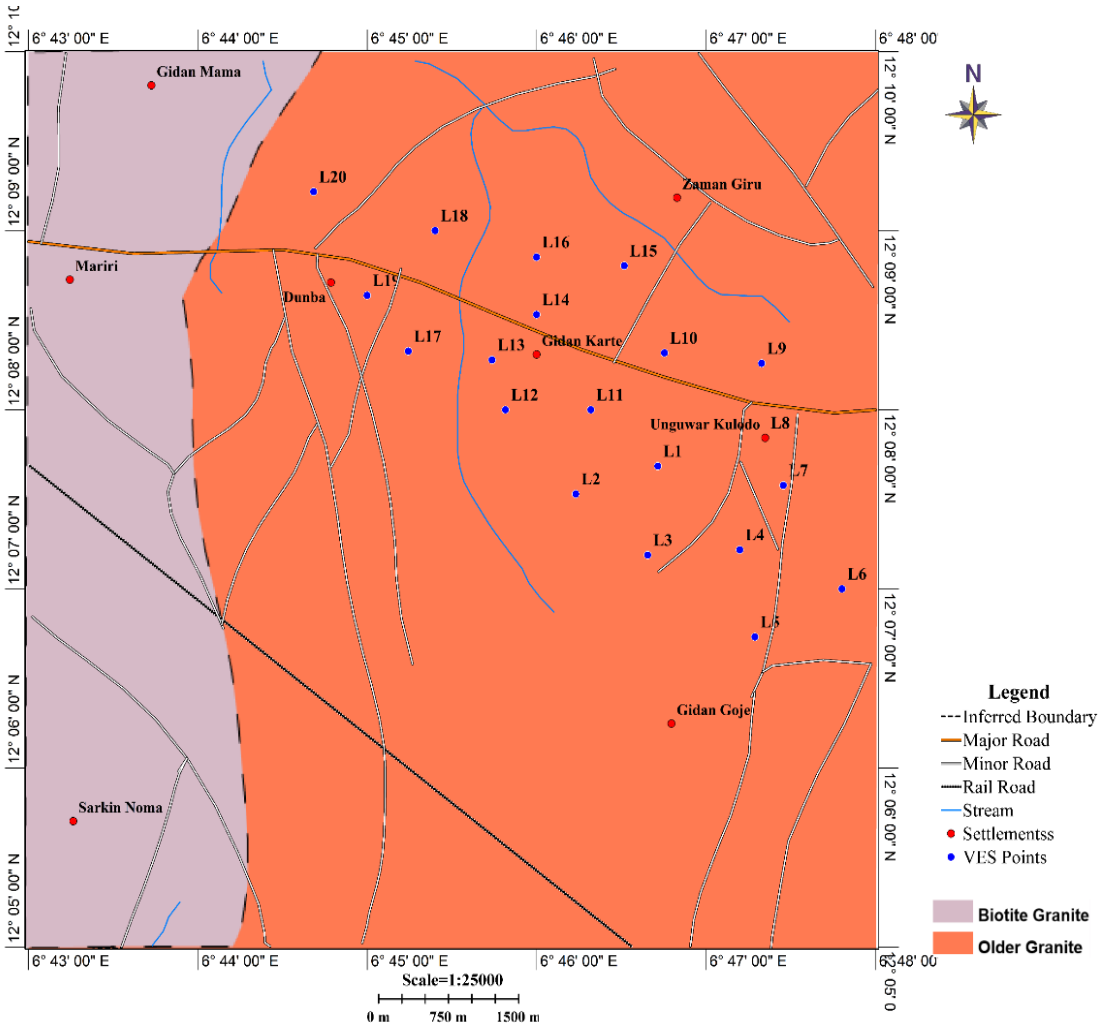


Figure 3. Geological map of Federal University Gusau campus showing lithological units, outcrop locations.

GEOPHYSICAL RESULTS

VES interpretations delineate three to four geo-electric layers across the study area. Representative curve types and layer parameters are summarized in Tables 1 and 2.

Table 1: Summary of VES Curve Types and Layer Characteristics

VES Point	Curve Type	Layer 1 (Topsoil)	Layer 2 (Weathered)	Layer 3 (Fractured)	Layer 4 (Fresh)
VES 1	H	2.1 m / 145 Ωm	12.5 m / 380 Ωm	-	>15 m / 890 Ωm
VES 2	K	1.8 m / 210 Ωm	8.3 m / 520 Ωm	18.7 m / 680 Ωm	>30 m / 1050 Ωm
VES 3	H	3.2 m / 98 Ωm	15.1 m / 290 Ωm	-	>20 m / 820 Ωm
VES 4	HK	1.5 m / 175 Ωm	6.8 m / 410 Ωm	12.3 m / 590 Ωm	>25 m / 950 Ωm
VES 5	H	2.8 m / 132 Ωm	11.4 m / 340 Ωm	-	>18 m / 870 Ωm

Note: Values represent thickness (m) / resistivity (Ωm)

Table 2: Geo-electric Layer Parameters for All VES Stations

Layer	Lithological Interpretation	Resistivity Range (Ωm)	Thickness Range (m)	Average Thickness (m)	Engineering Significance
1	Topsoil/Laterite/Lateritic Clay	24–394	0.5–6.0	2.3	Variable competence; clay-rich zones prone to swelling
2	Weathered Basement (Saprolite)	150–735	5.0–18.5	10.8	Moderate bearing capacity; fracture-dependent permeability
3	Fractured Basement	200–750	0–25.0	8.5	Potential aquifer; requires grouting for foundation support
4	Fresh Basement Bedrock	750–1200	∞ (to depth)	-	High competence; optimal foundation bearing stratum

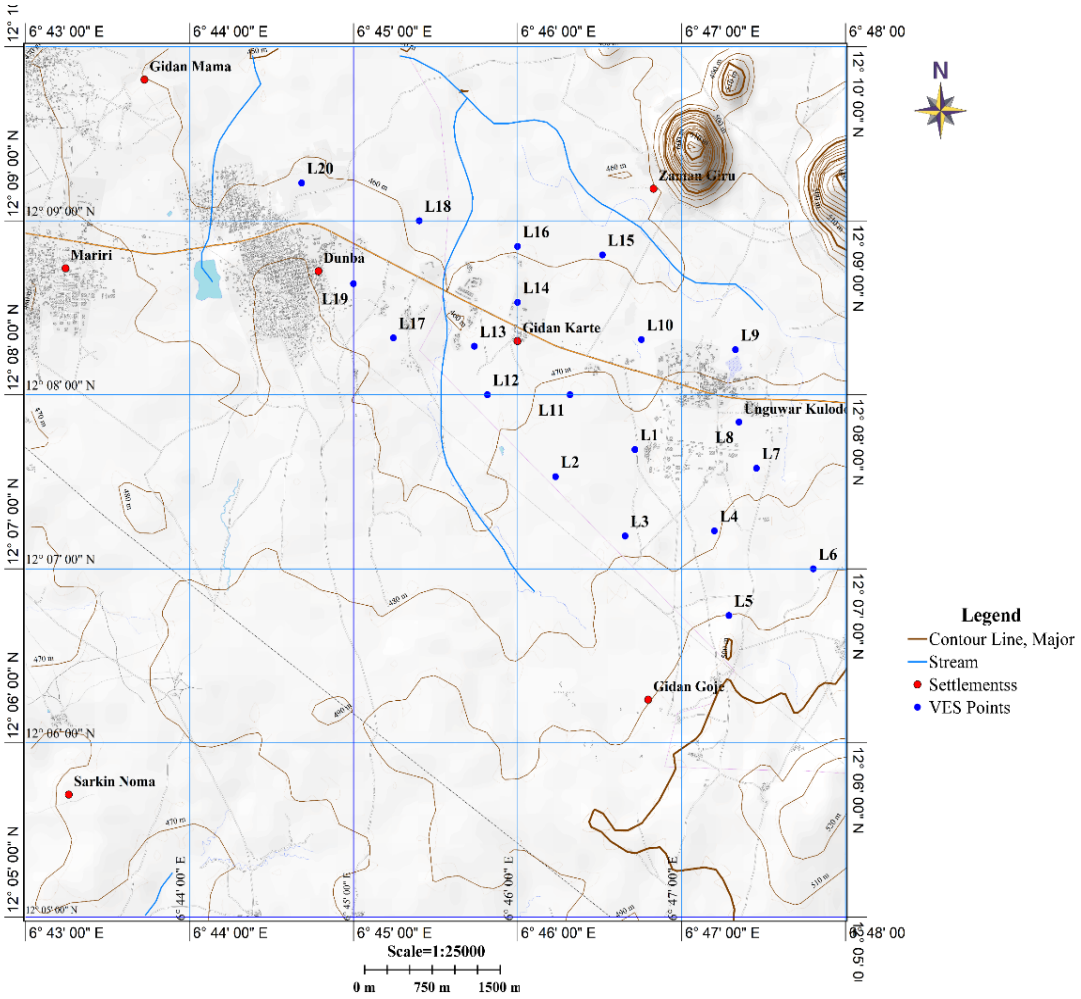
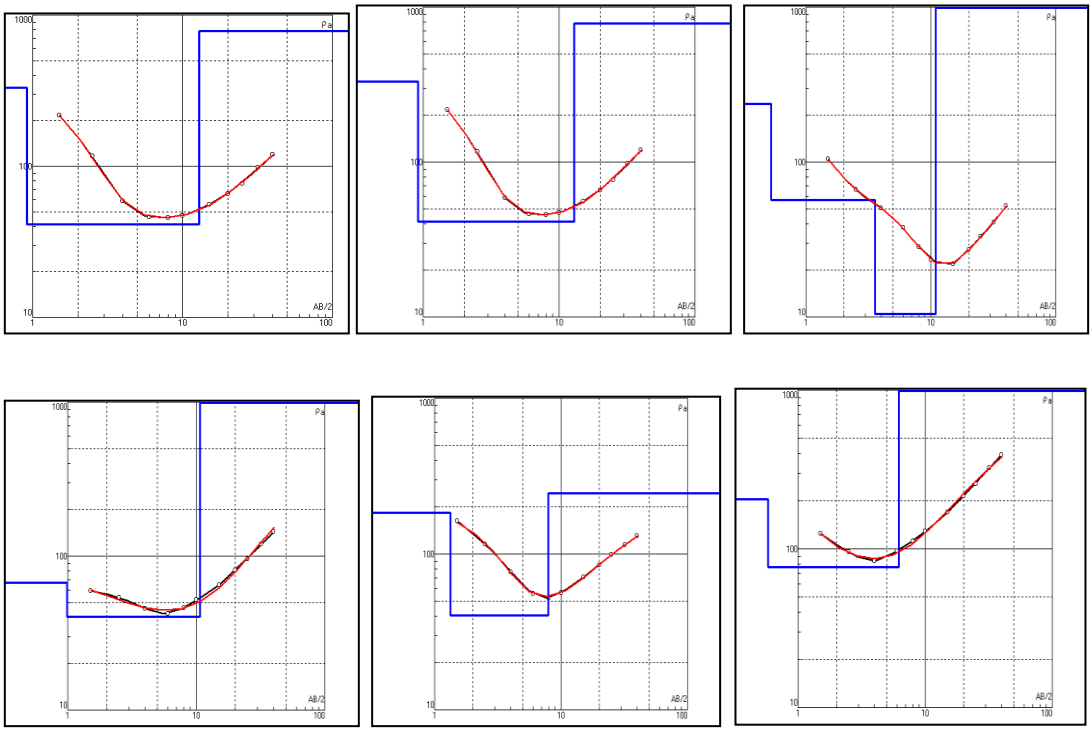


Figure 3. Topographic map of Federal University Gusau showing VES Point

Vertical Electrical Sounding (VES) curves for Location 1-6 obtained using IPI2WIN software



Curve Type Distribution:

- **H-type ($\rho_1 > \rho_2 < \rho_3$):** 45% of stations (9 points)
  - Indicates thick weathered zones with lower resistivity than overburden
  - Common in topographic depressions and areas with high clay content
- **K-type ($\rho_1 < \rho_2 > \rho_3$):** 35% of stations (7 points)
  - Suggests competent weathered layer or thin overburden
  - Typical of ridge crests and well-drained areas
- **HK-type (four-layer):** 20% of stations (4 points)
  - Reflects complex weathering profiles with fractured zone
  - Indicates heterogeneous subsurface conditions

GEOTECHNICAL PROPERTIES

Laboratory test results on soil and rock samples are summarized in Tables 3 and 4.

Table 3: Geotechnical Properties of Overburden Materials

Parameter	Lateritic Clay	Lateritic Gravel	Weathered Saprolite	Granite
Grain Size Distribution				
Gravel (%)	5–15	45–65	20–40	
Sand (%)	20–35	25–40	30–50	
Silt (%)	25–40	5–10	10–20	
Clay (%)	25–40	<5	5–15	

Parameter	Lateritic Clay	Lateritic Gravel	Weathered Granite Saprolite
Atterberg Limits			
Liquid Limit (%)	35–55	NP	28–42
Plastic Limit (%)	18–28	NP	15–22
Plasticity Index	15–28	NP	10–22
USCS Classification	CL-CH	GW-GP	SC-SM
Compaction			
Max. Dry Density (Mg/m³)	1.62–1.78	1.95–2.12	1.75–1.92
Optimum Moisture (%)	14–22	8–12	11–16
Strength Properties			
CBR (soaked, %)	8–25	35–65	15–35
Unconfined Comp. Strength (kPa)	45–120	-	150–450
Cohesion, cu (kPa)	15–35	-	25–65
Friction Angle, φ (°)	12–22	32–38	22–32
Compressibility			
Compression Index, Cc	0.25–0.45	0.08–0.15	0.12–0.25
Coefficient of Consolidation, Cv (m²/yr)	2–8	15–35	6–18

NP = Non-plastic; USCS = Unified Soil Classification System

SUBSURFACE STRATIGRAPHY AND SPATIAL DISTRIBUTION

Integration of geological, geophysical, and geotechnical data reveals the following subsurface stratigraphy across Federal University Gusau campus:

Layer 1: Topsoil and Lateritic Overburden (0–6 m)

- Comprises organic topsoil (0–0.5 m), lateritic clay, and lateritic gravel
- Thickness varies from 0.5 m (outcrop areas) to 6 m (depressions)
- Engineering properties highly variable; lateritic clay zones problematic
- Requires removal or improvement for foundation support

Layer 2: Weathered Basement/Saprolite (5–20 m depth)

- Residual soil and decomposed rock retaining parent rock fabric
- Thickness: 5–18.5 m (average 10.8 m)
- Resistivity: 150–735 Ωm
- Moderate bearing capacity (100–250 kPa)
- Suitable for light structures with raft foundations

Layer 3: Fractured Basement (variable thickness)

- Semi-weathered rock with interconnected fracture network
- Acts as secondary aquifer in some locations

- Requires grouting or ground improvement for foundation support
- Resistivity: 200–750 Ωm

Layer 4: Fresh Basement Bedrock (>15 m depth)

- Competent granite and migmatite with minimal weathering
- Resistivity: 750–1200 Ωm
- High bearing capacity (>500 kPa)
- Optimal foundation stratum for multi-story buildings

IMPLICATIONS FOR FOUNDATION DESIGN

The heterogeneous subsurface conditions at Federal University Gusau necessitate a risk-based, site-specific approach to foundation selection and design. The following recommendations are proposed based on integrated geological-geotechnical characterization:

Shallow Foundations:

- **Feasibility:** Limited to areas where fresh bedrock occurs within 1.5–3 m of surface (primarily northern campus sectors)
- **Applicable Structures:** Single-story buildings, light warehouses, perimeter fencing
- **Design Considerations:**
    - Complete removal of compressible lateritic clay
    - Compaction of granular fill to ≥95% MOD AASHTO density
    - Provision of moisture control barriers to prevent swell-shrink movement
    - Minimum foundation depth of 1.0 m to avoid seasonal moisture fluctuations

Raft/Mat Foundations:

- **Feasibility:** Suitable for medium-rise buildings (2–4 stories) on moderately thick saprolite
- **Design Considerations:**
    - Detailed settlement analysis required
    - Differential settlement mitigation through stiffened raft design
    - Ground improvement (vibro-compaction, stone columns) may be necessary
    - Raft thickness: 300–600 mm depending on structural loads

Deep Foundations (Piles):

- **Feasibility:** Recommended for multi-story buildings (>4 stories) across most of campus
- **Pile Types:** Bored cast-in-situ piles or driven precast piles
- **Design Considerations:**
    - Pile tips should be socketed ≥2 m into fresh basement (resistivity >750 Ωm)
    - Pile load testing essential for design verification
    - Typical pile diameters: 400–900 mm
    - Estimated pile lengths: 15–30 m depending on bedrock depth

- Allowable pile capacities: 800–2500 kN (subject to load testing)

Ground Improvement Techniques: For areas with thick compressible overburden where deep foundations are economically prohibitive:

- **Vibro-compaction:** For granular lateritic soils
- **Stone Columns:** For clay-rich laterites
- **Preloading with Vertical Drains:** To accelerate consolidation of compressible clays
- **Chemical Stabilization:** Cement or lime treatment of lateritic clays

INFLUENCE OF STRUCTURAL FEATURES

The dominant NE–SE structural trend identified in outcrop mapping has important implications for construction:

1. **Foundation Alignment:** Buildings should be oriented perpendicular to major joint sets where possible to minimize differential movement along discontinuities
2. **Excavation Stability:** Slopes and excavations should be designed considering joint orientations to prevent planar or wedge failures
3. **Groundwater Flow:** Structural trends may control preferential groundwater flow paths, necessitating drainage design in basement construction
4. **Seismic Considerations:** Although Northwestern Nigeria is seismically stable, fault zones should be avoided for critical infrastructure

GROUNDWATER AND DRAINAGE CONSIDERATIONS

Groundwater conditions significantly influence foundation design and construction methodology:

- **Water Table Depth:** Varies from 2–12 m below ground level, shallowest in topographic depressions
- **Seasonal Fluctuations:** Water table rises 1–3 m during wet season
- **Implications:**
  - Basements require waterproofing and drainage systems
  - Excavations below water table need dewatering
  - Buoyancy effects must be considered for underground structures
  - Concrete durability requires sulfate-resistant cement in aggressive groundwater

COMPARISON WITH REGIONAL STUDIES

Findings from this study align with broader Basement Complex geotechnical behavior documented in Nigeria:

- **Weathering Profile Thickness:** 5–25 m at FUGUS compares with 5–30 m reported in southwestern Nigeria (Olorunfemi & Olorunfemi, 1987) and 8–25 m in north-central Nigeria (Dan-Hassan & Olorunfemi, 1999)
- **Lateritic Clay Behavior:** High plasticity and compressibility consistent with problematic soils documented across tropical Africa (Jones, 1985; Clark, 1985)

- **Bedrock Bearing Capacity:** Fresh basement rocks at FUGUS (UCS = 85–180 MPa) fall within typical ranges for Nigerian Older Granites (50–250 MPa)
- **Foundation Recommendations:** Preference for deep foundations in thick weathering profiles aligns with best practices for Basement Complex terrains (Wright, 1992; Acworth, 1987)

However, FUGUS exhibits relatively shallow bedrock in certain sectors compared to deeper weathering profiles (>30 m) reported in some southwestern Nigerian locations, potentially reducing foundation costs in favorable zones.

CONSTRUCTION MATERIAL AVAILABILITY

The study area offers potential sources of construction materials:

1. **Lateritic Gravel:** Suitable for sub-base and fill materials; requires compaction control
2. **Granite Aggregates:** Fresh bedrock can be quarried for concrete aggregates
3. **Sand:** Seasonal drainage channels contain sand deposits for mortar and concrete
4. **Clay:** Lateritic clay may be used for brick production after proper processing

Quality control and laboratory testing are essential before utilizing these materials in construction.

CONCLUSIONS

Based on integrated geological mapping, geophysical surveying, and geotechnical testing at Federal University Gusau, the following conclusions are drawn:

1. **Geological Setting:** The campus is underlain by Older Granites of the Nigerian Basement Complex, with a weathering profile comprising lateritic overburden (0–6 m), saprolite (5–20 m), fractured basement (variable), and fresh bedrock (>15 m depth).
2. **Subsurface Stratigraphy:** VES interpretations reveal three to four geo-electric layers with resistivity ranges of 24–394 Ωm (topsoil/laterite), 150–735 Ωm (weathered basement), 200–750 Ωm (fractured basement), and 750–1200 Ωm (fresh basement).
3. **Geotechnical Properties:** Lateritic clay exhibits problematic behavior with low shear strength (cu = 15–35 kPa), high compressibility (Cc = 0.25–0.45), and swell-shrink potential, rendering it unsuitable for shallow foundations without improvement. Fresh basement bedrock demonstrates high competence (UCS = 85–180 MPa) and bearing capacity (>500 kPa).
4. **Structural Controls:** Dominant structural trends (NE–SE) and fracture patterns influence foundation alignment, excavation stability, and groundwater flow paths.
5. **Spatial Variability:** Significant heterogeneity exists across campus, with shallow bedrock (<10 m) in northern/southwestern sectors and deep overburden (>20 m) in central-eastern areas.

6. **Foundation Implications:** Deep foundations (piles socketed into fresh bedrock) are recommended for multi-story buildings, while shallow foundations may be feasible only in areas with shallow bedrock and after removal of compressible overburden.

RECOMMENDATIONS FOR PRACTICE

For University Management and Developers:

1. **Mandatory Site Investigation:** Conduct VES or seismic refraction surveys plus trial pits/boreholes at all new construction sites prior to design. Minimum investigation spacing: 50 m for buildings, 100 m for infrastructure.
2. **Foundation Selection Guidelines:**
   - **Single-story structures:** Raft foundations on compacted laterite with moisture control barriers
   - **2–4 story buildings:** Stiffened raft foundations or short piles (10–15 m)
   - **>4 story buildings:** Piled foundations to fresh bedrock with pile load testing
   - **Critical infrastructure (laboratories, library):** Piled foundations regardless of height
3. **Construction Controls:**
   - Specify compaction requirements (≥95% MOD AASHTO) for engineered fills
   - Avoid placing foundations on unrecompacted lateritic clay
   - Implement moisture control measures (drainage, vapor barriers)
   - Use sulfate-resistant cement in aggressive groundwater zones
4. **Drainage Design:**
   - Incorporate subsurface drainage to mitigate moisture-induced volume changes
   - Design surface drainage to prevent water ponding near foundations
   - Protect excavations from water infiltration during construction
5. **Monitoring:**
   - Install settlement markers on new structures for 24-month post-construction monitoring
   - Conduct periodic inspections for signs of distress (cracking, tilting)
   - Maintain as-built records of foundation depths and materials

For Regulatory Agencies:

1. Enforce compliance with Nigerian Building Code requirements for geotechnical investigations
2. Require geotechnical certification before issuing building permits
3. Establish database of subsurface conditions for urban planning

RECOMMENDATIONS FOR FUTURE RESEARCH

1. **Advanced Geophysical Imaging:** 3D electrical resistivity tomography or seismic refraction tomography to map fracture networks and weathering profiles in greater detail

2. **Long-term Monitoring:** Installation of piezometers and inclinometers to monitor groundwater fluctuations and slope stability
3. **Soil-Chemical Studies:** Detailed analysis of lateritic clay mineralogy and swell-shrink behavior under varying moisture conditions
4. **Rock Mass Characterization:** In-situ rock mass rating (RMR) and geological strength index (GSI) assessments for tunnel and excavation design
5. **Life-Cycle Cost Analysis:** Comparative economic evaluation of foundation options for campus development planning
6. **Climate Change Impacts:** Assessment of how changing rainfall patterns may affect groundwater levels and foundation performance

CONFLICTS OF INTEREST

The authors declare no conflicts of interest. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

DATA AVAILABILITY STATEMENT

Geological maps, geophysical data, and laboratory test results supporting this study are available from the corresponding author upon reasonable request, subject to institutional data-sharing policies.

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