https://dx.doi.org/10.4314/dujopas.v10i3c.6
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 10 No. 3c September 2024*

Application of Remote sensing/GIS in the Appraisal of Geotechnical Stability of Civil Engineering Structures in Cretaceous Sedimentary Units in Gombe, Northeastern, Nigeria

Abdullateef Lawal [1] · Usman Yahaya Yero[1] · Adamu Usman Mohammed[1,2]

[1]Department of Applied Geology,
Abubakar Tafawa Balewa University,
740272 ATBU Yelwa Road,
Bauchi,
Nigeria.

[2]Department of Environment,
Faculty of Forestry and Environment,
Universiti Putra Malaysia,
43000 UPM Serdang,
Selangor,
Malaysia.

E-mail: lawalabdull@yahoo.com

Abstract
The increasing urbanization in Gombe township has necessitated the need for a city-wide assessment of the area to ascertain its spatial geotechnical stability. In this study, the geotechnical stability of Gombe township and environs, Northeastern, Nigeria, was appraised using the geospatial approach. Four different thematic maps (lithology, lineament, elevation, and slope) were generated in a GIS environment. Weights were allocated to the subclasses of the thematic maps based on their contribution to the stability of engineering structures. The thematic maps were integrated using ArcGIS 10.3 software to generate a geotechnical stability model of the study area, which was validated through an on-site inspection of the structures in the area. The study area was delineated into three zones: unstable (17.24%), moderate (77.2%), and stable (4.74%). The moderate zones characterised by medium elevation and slope, average lineament density, and underlain by sandstones were the predominant zones in the area. However, the stable and the unstable zones predominate in the western and eastern parts of the study area respectively. The stable zones that occur in the northwestern and southwestern zones of the study area are underlain by the Kerri-Kerri Formation while the poor and unstable areas are underlain by argillaceous materials of the Pindiga Formation. The validation of the model revealed numerous cracked buildings and bridges and a failed bridge in the unstable zones. The moderate stability zones suffer a mixed fortune, having some stable structures in some parts and failing structures in other parts. The buildings in the stable zones, however, are generally devoid of structural cracks.

Keywords: GIS, Remote sensing, Thematic maps, Gombe, Geotechnical stability

INTRODUCTION

Nigeria is one of the developing countries in Africa and most third-world countries are usually characterized by enormous infrastructural transformation within the last couple of decades. The construction of residences, roads, bridges, and other infrastructures is very consequential for the day-to-day activities of the populace, and in terms of significance, these infrastructures have been ranked next essential to man as air, water, and food (Salau, 1996). In recent years, the stability of buildings, dams, and roads are experiencing a lot of challenges in different parts of Nigeria. The collapse of most engineering structures is mostly associated with loss of life and properties and the incessant failures of buildings nowadays are so enormous that it has become a serious concern to the professionals in the building industry, clients, governments, and the general public (Una et al., 2015). The frequent structural collapse in Nigerian cities is attributable to the absence or inadequacy of geotechnical investigation on the project site during the preconstruction, construction, and post-construction phases of the project (Amadi, 2012).

Gombe State, a fast-growing state, has seen a lot of transformational developments since it attained a state status in the last couple of decades. These developments cover the construction of residences, bridges, dams, road networks, and other infrastructures that are vital for the life and livelihood of the populace. According to Salau, 1996, the aforementioned structures are next as crucial to humans as air, water, and food as they constitute residences, worship centres, administrative and social centres as well as means of transportation for humans, goods, and services. Ede, (2010), suggests that a structure is considered to a have failed when it can no longer deliver on the purpose for which it was constructed and such failures can be total or partial. Irrespective of the type or nature of failure of a structural unit, the consequences are at most times devastating as lives and economic resources are lost. Structural failures occur when the weight of the structure (i.e., building or bridge) exceeds the bearing capacity of the soils and rocks on which it originated (Una et al., 2015). By implication, the importance of the quality of underlying soils and geology to the safety and stability of an engineering structure cannot be overemphasized.

The recent growth which is associated with urbanization in Gombe Township calls for appropriate geotechnical investigation of the soils of the area to forestall the structural stability challenges (Mallo and Akuboh, 2012). Unfortunately, over the past few years, the failure of buildings, bridges, and other civil structures in Gombe Township has become a source of concern as it is mostly associated with attendant fatalities and economic losses (Mbaya, 2017). There is therefore an urgent need to deploy a recent low-cost and un-destructive approach to delineate the geotechnically stable and safe land masses in Gombe Township.
Against this backdrop, this study attempts to develop a GIS-based structural stability model of Gombe town through an integration of pertinent geological and geomorphological parameters like geology, elevation, slope, lineament, land use land cover, water table depth, and distance from gully sites. Using suitable satellite imageries as input data these parameters will be generated into thematic maps and subjected to different GIS operations before they are integrated into a model using overlay analysis in the ArcGIS environment. Integrated remote sensing /GIS approaches to data modelling and analysis have recently become a very vital tool in characterizing the stability of structures to forestall the loss of lives and properties.

The traditional techniques deployed in the assessment of structural failures include; aerial photographs, satellite imagery, geological, geophysical, geotechnical, and aerial photographs. The application of geospatial tools in a landslide and other structural stability studies has been well documented in textbooks and some works of literature (Mbaya et al, 2012; Mbaya 2017; Igwe et al., 2020), however, the generation of GIS-based models of structural stability of developing areas or regions have received limited attention. The significance lies in the fact that it seeks to shed further light on the geotechnical and geological causes of this structural failure from a geospatial viewpoint and the model generated will be a valuable tool for all concerned stakeholders. The objectives of the study are as follows: to produce relevant thematic maps pertinent to the geotechnical stability of structures (geology, lineaments, slope, and elevation), to conduct a field mapping to verify the geological map and to assign suitable weights and ranks to the thematic maps, rasterize and reclassify the maps, to develop a GIS-based structural stability map of the study area through integration of the thematic maps and to validate the resulting map through ground truthing and visual inspection of structures in the study area.

This study also seeks to help ameliorate the impact of this menace on infrastructures through awareness and informed policy formulation by the government.

Location and Geology of Study Area

The study area is the Gombe sub-catchment, an integral portion of the Northern Benue Trough of Nigeria (Fig. 1). The area falls approximately within longitudes 10 ° 15 ˈ 00 to 10 ° 25 ˈ 00 E and latitudes 11 ° 10 ˈ 00 to 10 ° 14 ˈ 0 N and characterized by two distinct seasons; the wet and dry seasons, with a mean annual rainfall of 850 mm and temperature of 32 °C (Ige et al., 2020). Precipitation is common from June to September. In July and August, however, rainfall is usually associated with storms. The vegetation of the area can be best described as Sudan Savannah and is typified by shrubs and grassland. In terms of geomorphology, Gombe town is generally a flat-lying terrain with Gombe hill and Liji hill constituting the inliers in the area (Arabi et al. 2009).

The Gombe area is an integral part of the northern portion of the Benue Trough, one of the sedimentary basins in Nigeria. The basin has been divided into Southern (Lower), Middle, and Northern (Upper portions) (Fig. 1). It is about 6000 m deep and filled with Cretaceous – Tertiary sedimentary rocks. A greater part of the basin was affected by the Santonian event and has been folded, faulted, and uplifted as a result (Tijani, 2023). The Northern Benue Trough is further divided into Yola Arm which trends in the east-west direction and Gongola Arm trending in the north-south direction (Fig. 1). The geology of the Upper Benue Trough has been well elucidated and documented by Zaborski, 2000; Dike, 2002; Tijani, 2023 amongst others.

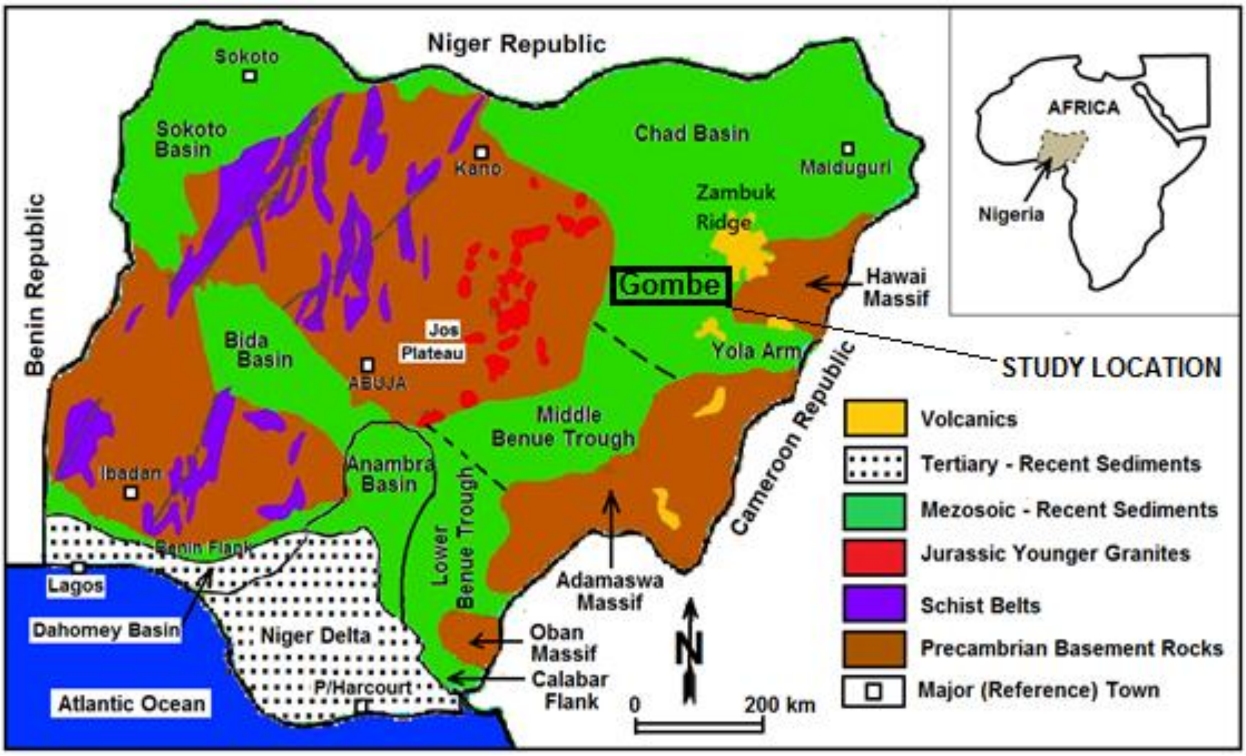

Fig. 1 Geological map of Nigeria showing the location of the study area (Modified after Tijani, 2023)

The Precambrian Basement Complex rocks constitute the oldest rocks in the study region. They are overlain unconformably by a sequence of folded Cretaceous sedimentary rocks, the oldest of which is the Bima Formation (Jurassic to Albian) consisting of continental grits and clays. Overlying the Bima Formation is the Yolde Formation of the Cenomanian age, consisting of continental to marine sandstones and shales at the base, and overlain by sandstones, shales, and calcareous sandstones (Tijani, 2023). The Yolde Formation is overlain by the Pindiga and the Gongila/Fika Formations which are contemporaneous marine sediments. The youngest of the Cretaceous sequences in the Northern Benue Trough are confined to the Gongola Basin and are represented by the lacustrine to deltaic Gombe Formation which unconformably overlies the Pindiga Formation. The Paleogene Kerri – Kerri Formation a sequence of sandstones, siltstones, and shales of continental origin marked the close of sedimentation in the Northern Benue Trough (Tijani, 2023).

MATERIALS AND METHODS

In line with the study objectives, pertinent data on soils, lithological units, lineaments, and geomorphologic conditions of the study area were collated. The overall study concept involved the integration of 4 critical thematic maps of geology, and lineaments, as well as remotely sensed elevation and slope maps using ArcGIS version 10.31 GIS software.

Preparation of thematic layers

The geology map of the study area obtained from the Nigeria Geological Survey Agency (NGSA) with a scale of 1:100,000 was georeferenced and digitized in ArcGIS 10.31 software platform. Geology is of paramount significance in civil engineering construction considering that most construction operations take place on the ground following the philosophy of engineering geology. Thus, the geological makeup of an area is consequential to most engineering construction endeavors since it influences their nature, appearance, and overall cost (Bell, 1992). The lineaments map of the area was produced from the spot 5 image covering the study location. Lineaments are manifestations of linear features that can be identified directly on the rock units or from remote sensing data while lineaments and their intersections play a significant role in the occurrence and movement of groundwater resources in crystalline rocks (Rao 2006; Prasad et al. 2008). Conversely, the same geological structures exemplified by faults, and discontinuities are calamitous for engineering structures such as dams, buildings, roads, and other infrastructure (Egwuonwu and Sule, 2012). The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, weakens the foundation of structures or initiates expansion in clays (Obi Reddy et al., 2000; Lawal and Ahaji-unanka, 2020). The lineament density map was calculated in terms of the length of the lineament per unit area (km/km^2).

Geomorphology is a combination of the elevation and slope of an area and it is a reflection of various topographical features and landforms (Fashae et al. 2014). The elevation and slope of an area can have a consequential effect on the stability of an engineering structure (Ghosh and Debbarma, 2019). Therefore, to properly capture the geomorphology of the study area an ASTER DEM (Digital Elevation Model) of the of 2002 at 30 m resolution was used to develop thematic maps for the slope and elevation of the area.

Weights assignments and integration of thematic maps

Following the preparation of the relevant thematic maps (lithology, lineaments, slope, and elevation thematic maps), the maps were rasterized and suitable weights were assigned in order of their hierarchy to the structural stability of civil engineering structures (Table 1). The attributes of each of the thematic maps employed in this study were assigned a weightage of 1–4, depending on their relative contribution to the stability of structures. A weight factor of 1 denotes low/poor contribution to stability, 2 implies moderate, 3 represents good and 4 denotes high impact on structural stability. The assigned and normalized weights of the themes and their subclasses for the delineation of the geotechnical stability of the study area are presented in Table 2. All the thematic layers were subsequently integrated with the ArcGIS 10.3 platform using overlay analysis to demarcate the structural stability zones in the study area.

Unlike the field geotechnical methods which are expensive, time-consuming, and often localized, the advantage of this methodology approach (geospatial) lies in the fact that it gives a more holistic and spatial perspective to the problem. The GIS-based model was validated using ground truthing/ on-site inspection of the delineated areas.

Table 1 Weights of the thematic maps of the potential groundwater

S/No	Thematic Layer	Assigned Weight	Normalised value
1	Lithology	5	0.25
2	Lineaments	5	0.25
3	Elevation	5	0.25
4	Slope	5	0.25

RESULTS AND DISCUSSION

Lithology

The geological map of the study area, presented in Fig. 2 revealed that the area is underlain by 6 different lithological units namely: Basement complex rocks (Inlier), Bima Sandstones, Yolde Formation, Pindiga Formation (Fika and Kanawa members), Gombe Formation and Kerri—Kerri Formation. In terms of geotechnical strength and stability which is the main focus of the present study, the Basement Complex rocks which cover 3.34% of the area were ranked highest (4) because of their isotropic fabric and superior mechanical strength. Bedded sandstones have a characteristic anisotropic fabric which has a great impact on civil engineering, and other projects (Li et al., 2018; Hu et al., 2021; Zhang et al., 2021).

In addition, the mechanical strength of interbedded sandstones is lower compared to massive and intact sandstone layers and the reduction in the strength is controlled by the interlayer composition, thickness, bonding, and attitude (Wang and Xiong, 2019).

Table 2 Assigned and normalized weights of the features of themes for the delineation of the geotechnical stability of the study area

S/no.	Themes	Sub-classes	Weight	Theme weight	Normalised Weight
1	Lithology	Basement	4	**5**	0.25
		Bima	3		
		Yolde	2		
		Pindiga	1		
		Gombe	2		
		Kerri-Kerri	2		
2	Lineaments	< 0.21	4	**5**	0.25
		0.21-0.42	3		
		0.42-0.63	2		
		0.63-0.84	1		
3	Elevation	378-434	1	**5**	0.25
		434-478	2		
		478-534	3		
		530-612	4		
4	Slope	< 2.07	4	**5**	0.25
		2.07-7.21	3		
		7.21-16.49	2		
		16.49-31.14	1		

By implication, interbedded sandstones with thicker interlayers have lower uniaxial compressive strength as compared to an intact sandstone layer. The ranking of the sedimentary rock unit in the area was undertaken based on the above premise. The Bima Formation underlies 14.93 % of the study area. The lithofacies in the Lower Bima Sandstone Member consist of coarse-grained, arkosic arenites with occasional pebbles occurring in alternation with shales and purple clays, calcareous sandstone, medium-grained sandstone, and thin layers of siltstone. The Middle Member consists of very coarse-grained, feldspathic sandstones, thin clays, shales, calcareous sandstone, and impure limestone with numerous bivalves. The Upper Bima comprises medium- to coarse- and very coarse-grained feldspathic sandstone which are commonly cross-bedded (Tijani, 2023).

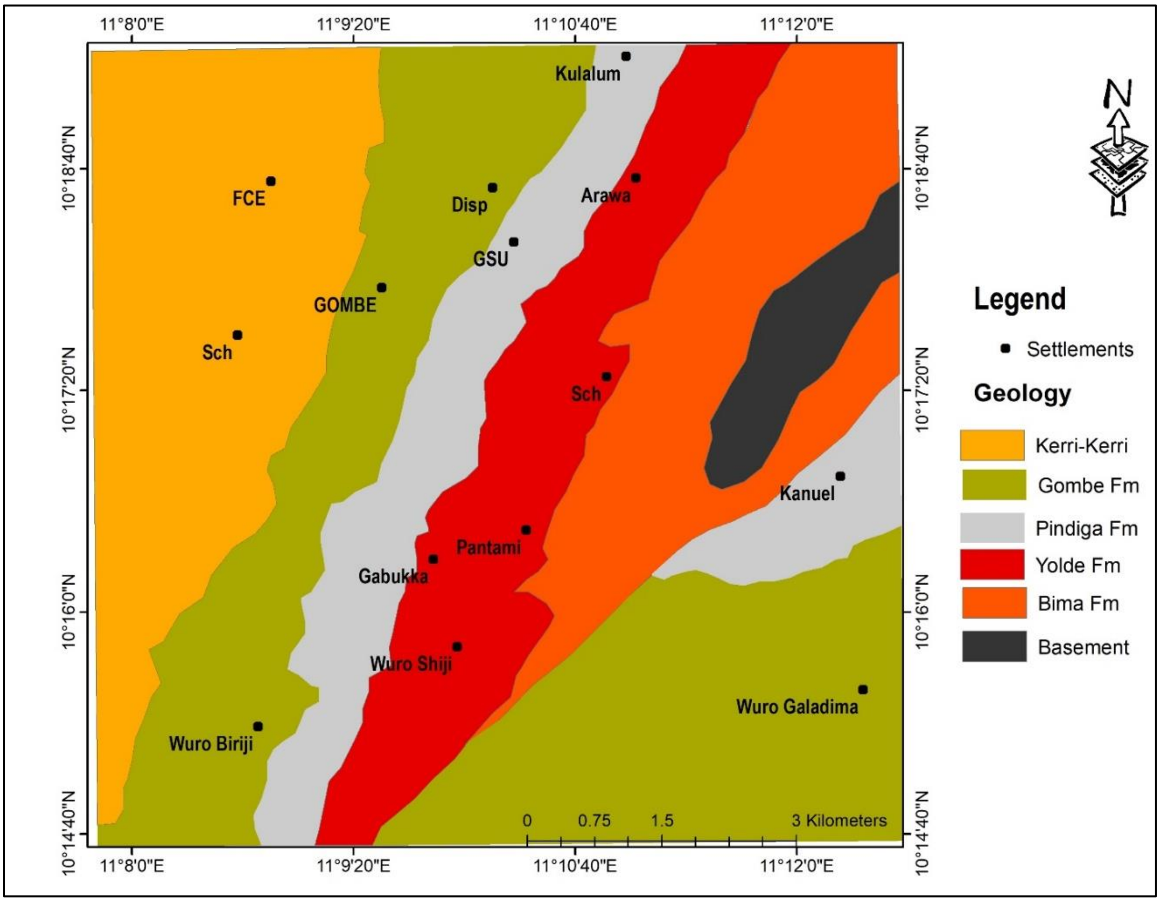

Fig. 2 Geology map of the study area (modified after NGSA, 2006)

Exposures of the Bima formation in the study area are typical of the Middle to Upper members and are often silicified when they occur around the Gombe Inlier, the grits of the Bima Formation were ranked 3. The lithofacies of the Yolde Formation as summarized by Waziri et al., 2020, comprise massively bedded, clay and shale and medium to coarse-grained sandstone with varying forms of cross beddings and stratification. Some of the sandstone units of this formation are interbedded with clays, shales, or mudstone which will affect their shear strength considerably, hence, the Yolde Formation underlies 13.9% of the area and was ranked 2. The shales and mudstones of the Kanawa and Fika put the formation in a disadvantaged position based on structural stability and bearing capacity. Owing to the weak and expansive nature of clays and shales the Kanawa and Fika units were ranked poor (1) as far as their engineering stability and bearing capacity are concerned. The Pindiga Formation comprising the Fika and Kanawa members occupy 13.47% while the Gombe sandstones cover 33.07% of the study area.

The Gombe Formation is divided into a basal interbedded unit, a bedded facie unit (in the middle), and red sandstone facies at the top (Tijani, 2023). The bottom layer constitutes fine to medium-grained sandstone interbedded with silty shales, while the middle zone is made up of fine to medium-grained sandstones with silty clays, silts, and ironstone interbeds. The upper section of the formation consists of brick red-colored sandstone, popularly called the red sandstone facie. The Gombe Formation was ranked 2 (moderate) due to its friable nature and the presence of argillaceous interlayers, which have been reported to undermine the mechanical strength of sandstones (Wang et al. 2022). The Paleocene Kerri-Kerri Formation is a continental unit composed of sandstones, grits, and interlayers of siltstones, gravels, medium to fine sands, and clays (Dike, 2000) was ranked 3 and covers 21.3% of the study area.

In summary, the assigned weights in terms of increasing geotechnical stability are in the order of Basement rocks (4), Bima Formation (3), Yolde Formation (2)\ Kanawa and Fika members (1) Gombe sandstones (2), and Kerri-Kerri formation (2)

Lineaments

As can be observed from the lineament map of the study area (Fig. 3), the area is characterised by lineaments arising from the tectonic episodes that have affected the basin in the past. Studies have shown that lineaments can constitute consequential problems to the stability of engineering structures because they represent a zone of weakness in rock and through their association with fault zones, seismic activity, and groundwater flow (Gabrielse and Braathen, 2014; Wang et al. 2022). According to Gabrielsen and Braathen 2014, lineaments represent zones of an enhanced fracture frequency which usually reflects a stress-induced zone of weakness in the bedrock, as exemplified by fracture corridors and faults. Based on the above premise, diligent site investigation and characterization of lineaments in a site is vital for the safety and durability of civil engineering structures. A lineament density map is a measure of the quantitative length of linear feature per unit area which can indirectly reveal weak and permeable zones in a rock (good groundwater potentials) and such zones are detrimental to the stability of engineering structures as lineaments are mostly linked with subsurface fractures faults and faults, which can initiate differential settlement and instability in civil engineering structures Egwuonwu and Sule, 2012).

The lineament density in the study area varies from < 0.21 km/km^2 in most parts of the study to 0.84 km/km^2 in the northeastern and southeastern parts underlain by the basement rocks and the Bima sandstones (Fig. 3). It is worthy of note that the northwestern and the southwestern parts of the study are generally characterised by lower lineament densities and this could be attributed to the fact that the rocks (Gombe and Kerri-Kerri) underlying these were not affected by the Santonian episode. Thus, areas with higher lineament density are classified as having poor geotechnical stability and, hence ranked lowest (1). Consequently, a higher weightage of between 3 and 4 was assigned to areas with low density of lineaments, which are mostly underlain by the Pindiga, Gombe, and Kerri-Kerri Formation.

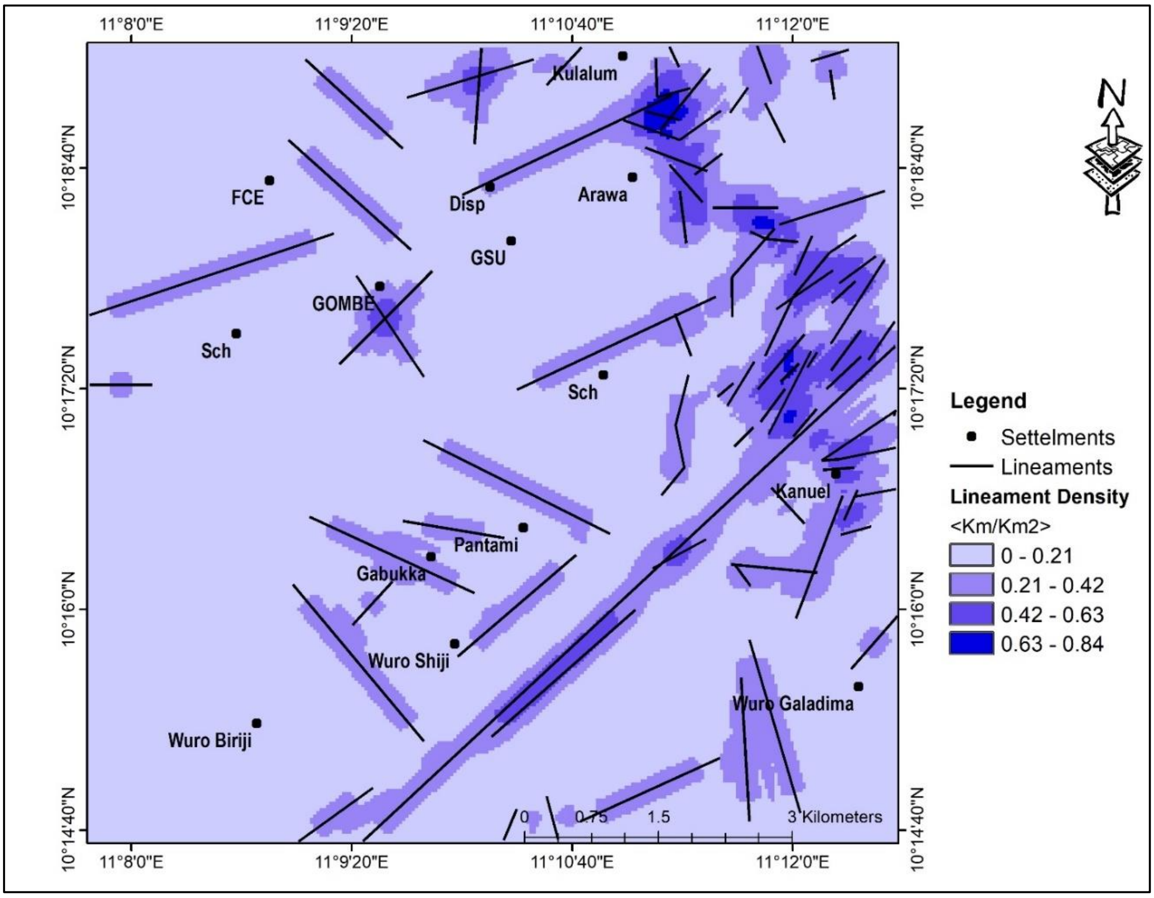

Fig. 3 Combined lineament and lineament density map of the study area

By and large, the lineaments ranking based on the structural stability of the rocks increased with decreasing lineament densities as follows: 0-0.21 km/km² (4), 0.21-0.42 m/km² (3), 0.42-0.63 km/km² (2) and 0.63-0.84 m/km² (1).

Elevation

The thematic map showing the spatial distribution of the elevation of the study area is presented in Fig. 4. The map shows a gradual decrease in topography from the western parts (underlain by the Kerri-Kerri and Gombe sandstone) to eastern zones covered by the Pindiga, Yolde and Bima Formations. As can be seen from the elevation thematic map, a conspicuous highly elevated area exists in the northeastern zones of the study around the Gombe Inlier. The significance of topography in the geotechnical stability of structures cannot be overstated as studies have shown that soils in higher elevations are less susceptible to erosion (soil loss) and degradation and this is supported by the general absence of gullies in the elevated regions (Kawajiri et al., 2024).

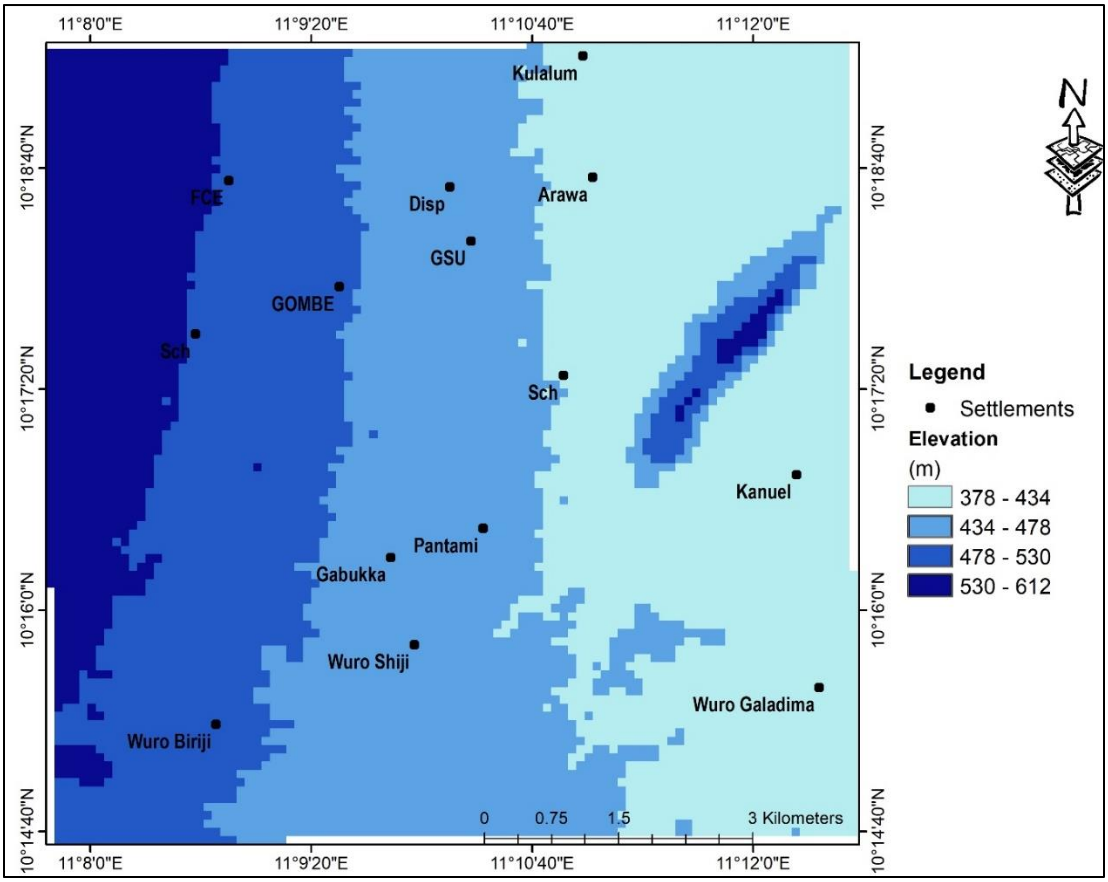

Fig. 4 Elevation map of the study area

When viewed from the prism of differential weathering, elevated areas generally reflect zones of higher resistance to weathering and denudation. The ranking of the elevation was based on the above premise. The elevation map of the study area (Fig. 4) was categorized into 4 zones and ranked as follows; 378 - 434 m (1), 434 - 478 m (2), 478 – 530 m (3) and 530 – 612 m (4).

Slope

The slope is an aspect of geomorphologic features that control the vulnerability of engineering structures to earthquakes and landslides as structures founded on a slopy ground are generally more susceptible than those sited on flat ground, and the severity is directly proportional to the increment of slope angle (Ghosh and Debbarma, 2019). While higher topography can offer several merits over lower elevations in terms of stability of structures, the steep slopes sometimes associated with higher topography can constitute serious engineering problems as they can increase the risk of landslides in the area. In this study, the areas with the steepest slopes were identified and delineated using a slope thematic map (Fig. 5). The steepest slopes were ranked low (1) while the gently and flat areas were ranked higher (2-4). The slope in the study area was ranked as follows; < 2.07 (4), 2.07 – 7.21 (3), 7.21 – 16.49 (2), 16.49 – 31.14 (1)

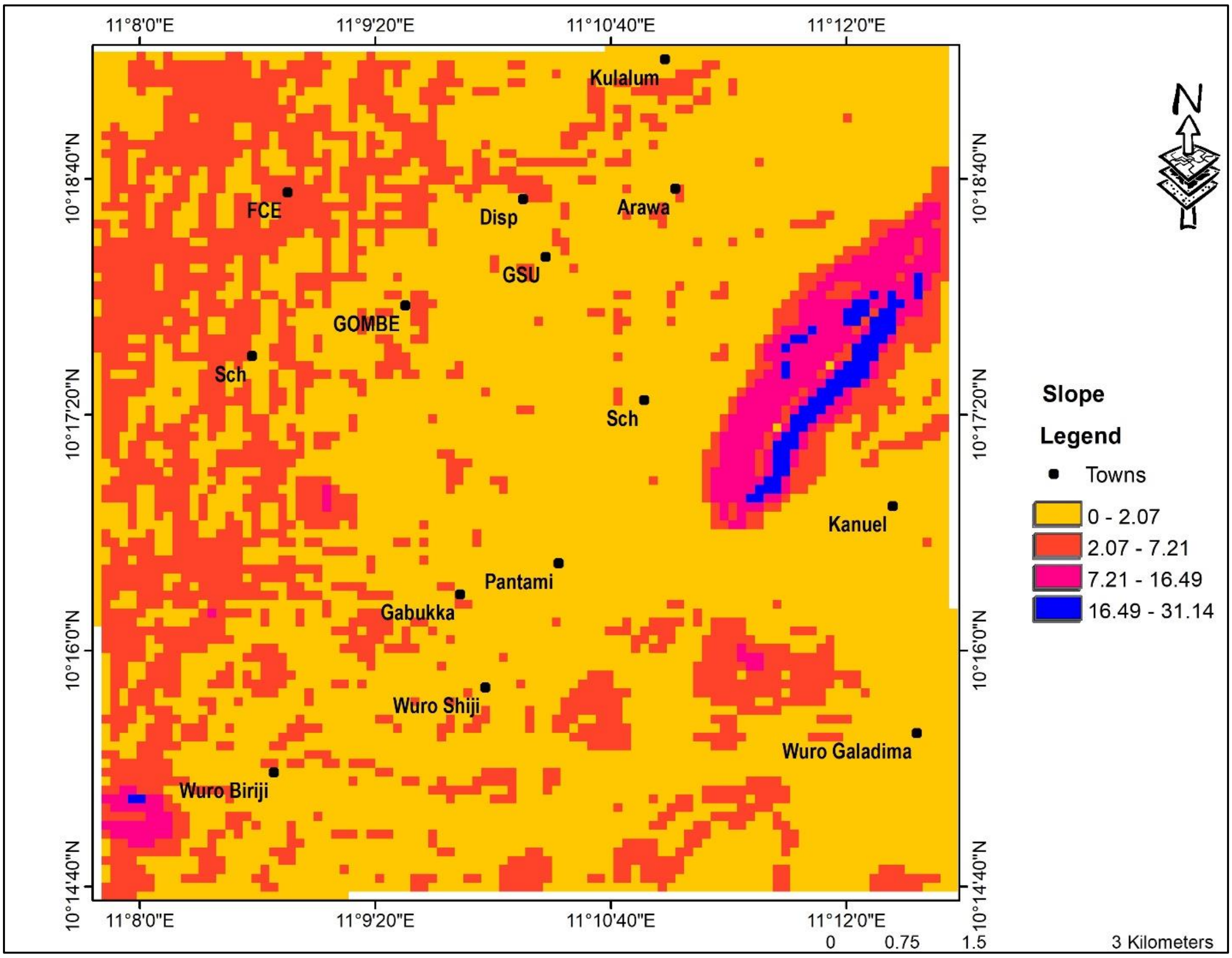

Fig. 5 Slope map of the study area

Geotechnical Stability Map

In line with the overall objective of this study, the same representative weights were assigned to the thematic maps in the study area. Subsequently, all the thematic maps were integrated to generate the stability map of the area (Fig. 6). The stability map of the study area revealed three distinct zones, namely unstable, moderately stable, and stable zones. The spatial distribution of the and extents of the delineated zones are 135.15 km^2 (17.34 %), 607.43 km^2 (77.2 %), and 36.95 km^2 (4.74 %) respectively. The structural stability map, shown in Fig. 6, provides a synoptic assessment of the geotechnical stability of the rocks in the study area. The map revealed that the area is predominantly moderately stable especially in the extreme western half (NW and SW) of the study area around the Federal College of Education and Wuro Biriji areas which revealed significant portions of stable zones. The eastern half (NE and SE), however, is dominated by unstable zones (Kulalum, Kanuel, and Wuro Galadima areas) and partly by moderately stable zones. This result corroborates the study by Mallo and Akuboh, 2012, which also described the soils from Kulalum, Kanuel, and parts of Pantami areas as unsuitable for engineering construction, owing to their argillaceous nature and poor bearing capacities. The central portion of the study areas is covered by moderately stable zones with patches of unstable areas exemplified by Gabbuka, Wuro Shiji, and Gombe town. A closer look at the geotechnical stability map revealed that the distribution of the structural stability zones is more or less a reflection of structural, geomorphological, and geological control. Additionally, areas underlain by the Gombe and Kerri-Kerri Formation, especially in the northwestern and southwestern parts of the study area which are characterized by higher topography relatively lower lineament densities, and relatively gentle slopes revealed good stability. Conversely, areas underlain by Pindiga and Yolde Formations are characterised by lower topography and higher lineament densities, and numerous gullies, hence, are dominated by geotechnically unstable zones. Some areas however fall in the middle with characteristic marginal topography and lineament densities and are underlain by different lithological units. Such areas that predominate the study area are classified as moderate stability zones. The limited size of the stable zones (4.74 %) in the study area is a reflection and a confirmation of generally poor geotechnical stability of sedimentary terrains and this further substantiates the frequent structural failures usually witnessed in the study area. It is also important to note that gully erosion and unsuitable surficial deposits contribute immensely to the poor geotechnical stability of the study area.

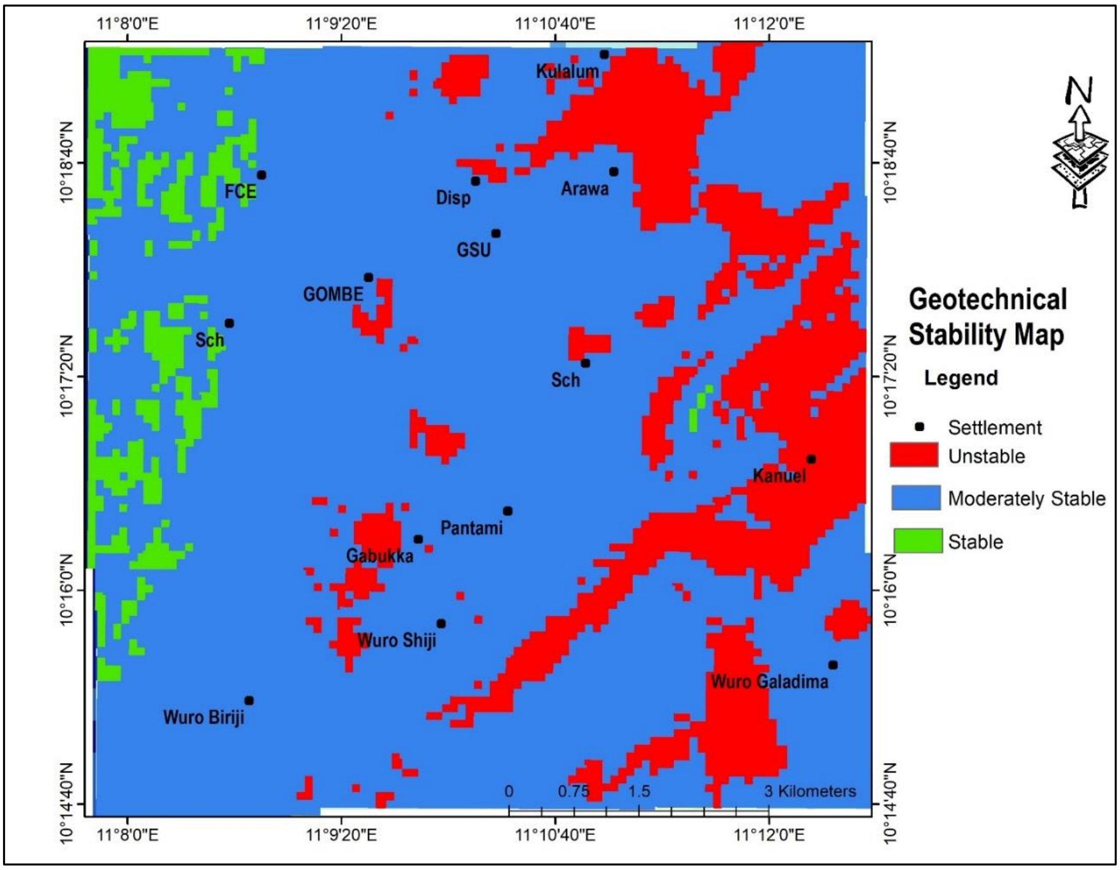

Fig. 6 Geotechnical stability map of the study area

Map/Model Validation

To verify and validate the generated geotechnical stability model on-site inspection of engineering structures in the stud area was conducted. The validation entailed visual inspection of buildings, bridges, and exposed soil sections in the delineated areas. The soils in the unstable zones (Fig. 7a) are generally clayey (black cotton soils) and partly silty or sandy in nature and buildings and bridges in this zone were characterised by numerous cracks as can be seen in Fig 7b. A failed bridge structure was sighted in this zone Fig 7c. This area is generally unsuitable for buildings and other engineering construction works owing to the low bearing capacity and the expansive nature of the clays (Kanawa and Fika members) in the area. According to Egwuonwu and Sule, 2012, structures built on concealed tectonic structures, exemplified by fractures, faults, karst topography, and expansive clays, are liable to fail due to settlement or heaving of subsurface soils. The moderate stability zones that predominate the study area, however, are usually underlain by massive sandstones, bedded sandstones, interbedded sandstones, and sands of the Bima, Yolde, Gombe, and Kerri-Kerri

Formations. The stability of the structures in this zone largely depends on the bedrock and surficial deposits in the particular area. Massive sandstone beds provide a modest foundation for structures in this zone, while the stability of structures in areas underlain by interbedded, inclined, or bedded sandstones could suffer a mixed fortune (Fig. 8). It is important to note however, that the moderately stable areas are greatly undermined by the occurrence of gullies in parts of the study area (Fig. 9 and 10). Figure 11 shows buildings devoid of structural cracks in the stable zones around FCE, Gombe. Among the limitations of the present study is the fact that the nature of topsoil and the occurrence of gullies which are both very consequential to the stability of structures in this terrain was not factored.

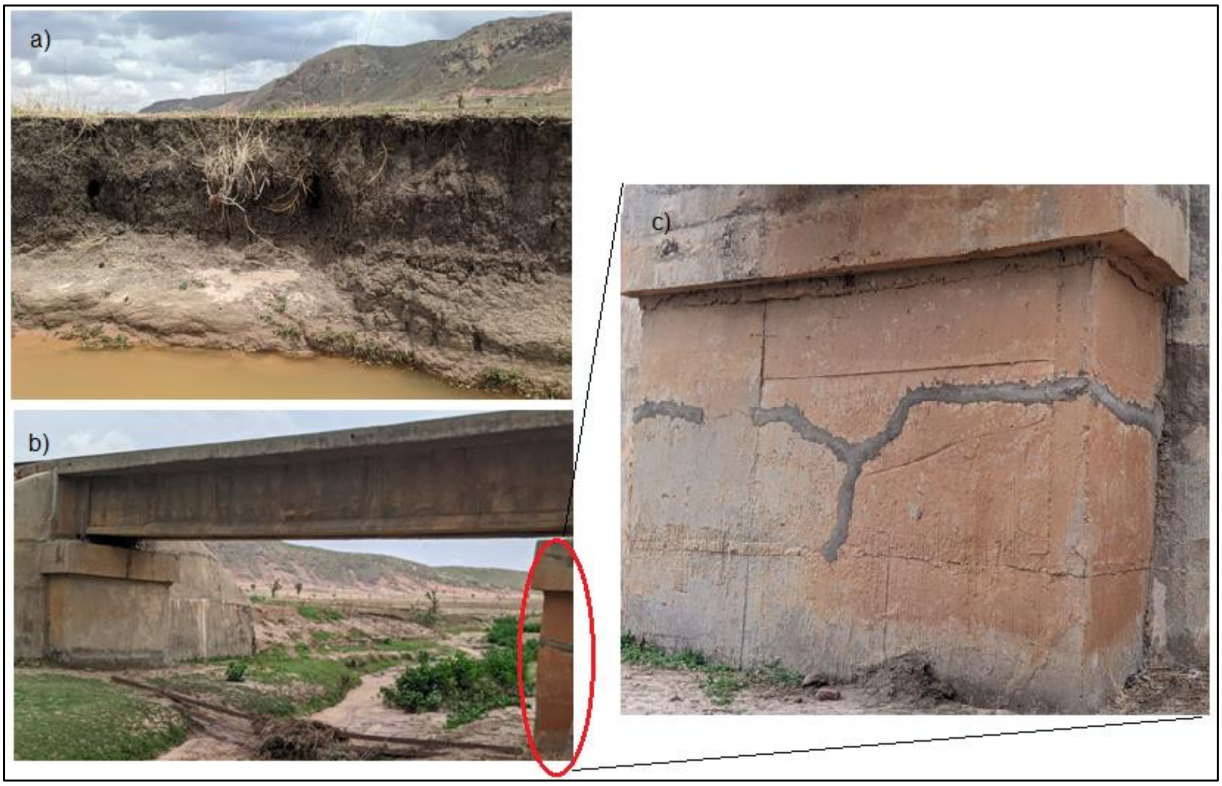

Fig 7 (a) Weak clays of Kanawa member which underlies the unstable zones, (b) A failing bridge founded on the clays of Kanawa, (c) Enlarged bridge abutment with massive cracks

Fig 8 (a) Cracking walls of a new building in the unstable zones, (b) A collapsed bridge founded on the clays of Kanawa.

Fig. 9 (a) Unstable bridge founded on a bedded sandstone foundation, (b) Unstable buildings founded on sandstone with clay interlayer, (c) Stable building founded on massive sandstone, (d) Stable bridge resting on an inclined bed of Yolde formation along Doma Stream

Fig. 10 Gully-induced slope failures in the moderately stable zones along Pantami Stream

Fig. 11 Buildings devoid of structural cracks in the stable zones around FCE, Gombe

CONCLUSION

The safety of engineering structures is essential in every developing society for safeguarding human life and properties. This study examined the influence of geomorphology, tectonic structures, and geology on the stability of engineering structures in parts of the Northern Benue Trough of Nigeria (Gombe town) using geospatial techniques. The geotechnical stability map of the area generated from the integration of four critical thematic maps delineated the study area into unstable, moderately stable, and stable zones. The unstable zones occupy 17.34% of the study area and are characterised largely by clays of the Pindiga Formation and partly by bedded and interbedded sandstones of Yolde and Bima with high lineament densities, covering the northeastern and southeastern regions of the investigated area. The moderate stability zones cover about 77.2% of the area while the stable zones underlie 4.74%. The map revealed that the study area is predominantly moderately stable especially in the extreme western half (NW and SW) of the study area around the Federal College of Education and Wuro Biriji areas which revealed significant portions of stable zones. This zone is underlain mostly by sandy units of the basin i.e., the Gombe and Kerri-Kerri, Bima, and Yolde which are characterised by anisotropic fabric and moderate lineament density. The stable zones were restricted to the northwestern fringes of the study occupied by the Kerri-Kerri Formation, with characteristic high topography, low lineament density, and minimal slopes and gullies.

The low percentage of stable zones in the study area corroborates the generally poor geotechnical stability of sedimentary terrains and the frequent structural failures usually witnessed in the study area. The validation of the GIS-based model (stability map of the study area) was done through on-site assessment of the civil engineering structures in the delineated zones, which further ascertained the efficacy of the remote sensing/GIS technique in the large-scale geotechnical assessments of sedimentary terrains. It is, however, recommended that future studies should incorporate the nature of topsoil and the occurrence of gullies in the GIS- model.

CONFLICT OF INTEREST

The authors declared that there was no competing interest.

ACKNOWLEDGEMENT

This research was supported by the TETFUND Award Number

TETF/DR&D/CE/UNI/BAUCHI/IBR/2022/VOL.I through the TETFUND institution-based research intervention allocation.

REFERENCES

Amadi, A.N., Eze, C.J., Igwe, C.O., Okunola, I.A. and Okoye, N.O. (2012). Architect's and Geologist's view on the causes of building failures in Nigeria. Modern Applied Science, 6 (6), 31-38.

Arabi, A. S., Nur, A., Dewu, B.B.M. (2009). Hydro Geo-Electrical Investigation in Gombe Town and Environs, Northeastern Nigeria. J. Appl. Sci. Environ. Manage. September, 2009 Vol. 13(3) 65 – 68

Bell F.G. (ed.). (1992). Engineering in Rock Masses. Oxford, UK: Butterworth-Heinemann

Dike, E.F.C. (2002). Sedimentation and tectonic evolution of the Upper Benue Trough and Bornu

Basin, NE Nigeria (Abstract). 38th Nigerian Mining and Geosciences Society Annual Internat. Conference, Port Harcourt, Nigeria. March 4-8th 2002

Ede, A. N. (2008). "Structural Damage Assessment of FRP-Strengthened Reinforced Concrete Beams under Static and Fatigue Loads": PhD Thesis in Composite Materials for Civil Structures, Department of Innovative Engineering, University of Salento, Lecce- Italy.

Egwuonwu G.N., Sule O. (2012). Geophysical investigation of foundation failure of a leaning super structure in Zaria Area, Northern Nigeria. Res J Eng Appl Sci 2012; 1(2):110–6.

Fashae, O.A., Tijani, M.N., Talabi, A.O., Adedeji, O.I. (2014). Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach. Appl. Water Sci. 4, 19–38.

Gabrielsen, R.H.; Braathen, A. (2014). Models of fracture lineaments—Joint swarms, fracture corridors and faults in crystalline rocks, and their genetic relations. Tectonophysics 2014, 628, 26–44.

Ghosh, R. · Debbarma, R. (2019). Effect of slope angle variation on the structures resting on hilly region considering soil–structure interaction. International Journal of Advanced Structural Engineering 11:67–77 https://doi.org/10.1007/s40091-019-0219-3

Hu, Z., Shen, J., Wang, Y., Guo, T., Liu, Z., and Gao, X. (2021). Cracking Characteristics and Mechanism of Entrance Section in Asymmetrically-Load Tunnel with Bedded RockMass: A Case Study of aHighway Tunnel in SouthwestChina. Eng. Fail. Anal. 122, 105221. doi:10.1016/j.engfailanal.2021.105221

Igwe, O., John, N., U.I., Solomon, O., and Obinna, O. (2015). GIS-based gully erosion susceptibility

modeling, adapting bivariate statistical method and AHP approach in Gombe town and environs Northeast Nigeria. Geoenvironmental Disasters (2020) 7:32 https://doi.org/10.1186/s40677-020-00166-8

Kawajiri, S., Watanabe, T., Yamaguchi, K. (2024). Geotechnical characteristics and seismic stability evaluation of pumice-fall deposits soil on collapse slope by the 2018 Hokkaido eastern Iburi earthquake. Nat Hazards 120, 5233–5255 (2024). https://doi.org/10.1007/s11069-024-06418-2

Lawal A. Ahaji-unanka U.C. (2020). Assessment of geotechnical properties of soils around Yelwan Tudu and environs in Bauchi Area, Northeastern Nigeria. Proceedings of the 5th International Conference of the Nigerian Association for Engineering Geology and the Environment (NAEGE), Ibadan, Nigeria, vol. 4, 2020.

Li, H.; Wang, J.; Li, H.; Wei, S.; Li, X. (2022). Experimental Study on Deformation and Strength Characteristics of Interbedded Sandstone with Different Interlayer Thickness under Uniaxial and Triaxial Compression. Processes 2022, 10, 285. https://doi.org/10.3390/pr10020285

Li, A., Xu, N., Dai, F., Gu, G., Hu, Z., and Liu, Y. (2018). Stability Analysis and Failure Mechanism of the Steeply Inclined Bedded Rock Masses Surrounding a Large Underground Opening. Tunnelling Underground Space Technology 77, 45–58. doi:10.1016/j.tust.2018.03.023

Mallo, S.J., Akuboh I.N. (2012) Geotechnical Investigation of Soils: A Case Study of Gombe Town (Sheet 152NW), North Eastern Nigeria. International Journal of Modern Engineering Research (IJMER). Vol.2, Issue.6, Nov-Dec. 2012 pp-4280-4286 ISSN: 2249-6645

Mbaya LA, Ayuba HK, Abdullahi J. (2012) An assessment of gully erosion in Gombe town, Gombe state, Nigeria. J Geogr Geol 4(3):110

Mbaya L..A. (2017) Spatial analysis of gully erosion control measures in Gombe town, Gombe state Nigeria. Adv Image Video Process 5(4):17–17

Obi Reddy G.P., Chandra Mouli K., Srivastav S.K., Srinivas C.V., Maji A.K. (2000). Evaluation of groundwater potential zones using remote sensing data- a case study of Gaimukh watershed, Bhandara district, Maharashtra. J Indian Soc Remote Sens 28(1):19–32

Prasad R.K., Mondal, N.C., Banerjee P., Nandakumar, M.V., Singh, V.S. (2008) Deciphering potential groundwater zone in hard rock through the application of GIS. Environ Geol 55:467–475

Rao, N.S. (2006). Groundwater potential index in a crystalline terrain using remote sensing data. Environ Geol 50:1067–1076

Salau, M. A., (1996). “Structural Failures in Collapsed Buildings – Causes and Prevention”. Reports on collapsed Structures in Nigeria, Nigerian Society of Engineers, Lagos.

Tijani M.N. (2013) Geology of Nigeria, in: A. Faniran et al. (eds.), Landscapes and Landforms of Nigeria, World Geomorphological Landscapes, Springer Nature Switzerland, https://doi.org/10.1007/978-3-031-17972-3_1

Una C.O, Igwe, O., Maduka, R., Brooks, A., Ajodo, R., Adepehin, E.J., Okwoli, E. (2015). Integrating geotechnical and geophysical techniques in assessing frequent building collapse in Akpugo, NkanuWest L.G.A., Enugu State, Nigeria. Arab J Geosci DOI 10.1007/s12517-015-1946-9

Wang, Z.H.; Xiong, L.X (2019). Uniaxial compression test of single-joint fractured rock mass considering the influence of thickness and length of joint surface and numerical simulation. J. Geol. Hazards Environ. Preserv. 2019, 30, 81–85.

Zaboski, P.M. (2000). The Cretaceous and Paleocene transgressions in Nigeria and Niger. Journal of Mining and Geology, 36(2), 153–173.

Zhang, X., Liu, W., Jiang, D., Qiao, W., Liu, E., Zhang, N. (2021). Investigation on the Influences of Interlayer Contents on Stability and Usability of Energy Storage Caverns in Bedded Rock Salt. Energy 231, 120968. doi:10.1016/j.energy.2021.120968