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Geophysical Investigation of Road Failure in The Chad Basin, A Case Study of Damaturu Metropolitan Roads, Nigeria

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Abstract

Road failure is a significant factor contributing to the increased costs of transportation as well as road accidents in the research area. It has negatively impacted the prices of goods and services throughout the Chad Basin. To tackle the causes of road failure, this study analyzed road failure in Damaturu, employing both Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) techniques. The road subgrades were characterized as low resistivity materials with resistivity varying from 5 to 40 Ωm. The subgrades were identified as clay formations in the study area based on their resistivity properties. The ERT findings and the VES findings correlated effectively in pinpointing the unsuitable materials beneath the road pavements. The clay soil appeared in the ERT outcomes across all three profiles in deep blue hues indicative of low resistivity. In some regions of the study area, the clay formation was found directly beneath the road pavement, while in other areas, it was interrupted by sand. In profiles 1 and 3, the clay formation serves as the subgrade, whereas in profile 2, it lays beneath the sandy-clay formation. The responses of the clay materials to moisture variations result in swelling and shrinking characteristics of the clay, which leads to the roads deformation and ultimate failure. It is therefore recommended that sections of roads with incompetent subgrades be removed and replaced with more solid and competent materials that possess the essential stability and load-bearing strength. Furthermore, road construction should include comprehensive geophysical surveys to identify areas with less competent subgrades and ensure they receive proper attention. The results of this investigation also indicated that the closeness of clay formation to the Earth's surface in the study area is a key factor in the frequent and recurring road failures. Consequently, geophysical exploration during road construction in the Chad Basin should be prioritized to guarantee that the roads built in the study area are resilient and lasting.

Keywords: Geophysical, road, failure, Chad basin, clay

INTRODUCTION

The condition of roads in Nigeria has been deemed as one of the reasons for the alarming frequency of road accidents on the highways. Roads can be categorized into four types: Private drive pathways, Two-lane highways, Dual carriageways, and Expressway. Roads are constructed to link villages, towns, and cities. They provide a means for distributing and marketing goods and services. The expense of transporting goods and services has become notably high in recent times due to the poor condition of roads across various regions of Nigeria. Numerous roads in Nigeria are filled with potholes, cracks, fractured surfaces, and sinkholes. The expenses associated with road maintenance have become concerning due to

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the recurring deterioration of highways attributed to inadequate understanding of the subsurface structure in the areas where roads are constructed.

The employment of substandard materials for road construction leads to the inability of the roads to withstand the pressure from passing vehicles. Many of the roads are built on geological features that can undermine the stability, load-bearing capacity, and longevity of the roads. Geological formations such as clay and shale deposits, faults, joints, buried channels, and sinkholes may render a newly built road or highway unsuitable for use. Poor execution of road construction additionally contributes to swift road failure. The use of inferior materials for reinforcement during road construction also plays a role in the rapid failure of roads throughout Nigeria. A significant amount of resources has been invested by various stakeholders in Nigeria into road maintenance, yet this investment has not produced any significant results due to the failure of road maintenance engineers to integrate geophysical surveys into addressing road failures.

Agada and Adegoke (1980) reported that construction practices, road maintenance, and usage are factors in road failure. In many regions within the Chad Basin part of Nigeria, road failures have become a prevalent issue that requires immediate attention to protect lives and conserve resources. Some researchers have indicated that insufficient information regarding the subsurface where roads are constructed is one of the primary factors that lead to road failure in Nigeria (Oladapo *et al*., 2004; Adiat *et al*., 2009; Adeyemo and Omosuyi, 2012). Road failure in the study area significantly affects economic activities as they lead to road accidents, increased transportation costs, and accelerated degradation of vehicle components (Figure 1). Various geological factors that contribute to road failure include fractures, faults, voids, buried riverbeds and channels, along with drainage systems (Adegoke and Agada, 1980; Momoh *et al*., 2008). The ongoing reconstruction of malfunctioning sections of the highways in the study area has become a regular occurrence, incurring substantial expenses. Road reconstruction in Nigeria has never provided a lasting solution to the issue of road failure in Nigeria, as many road construction firms frequently overlook geophysical surveys as a crucial aspect of road construction initiatives. This practice must be rectified, as its significance cannot be overstated.

The considerable funds allocated to ongoing road rehabilitation could be redirected towards other more profitable projects if the roads were properly constructed based on comprehensive geological and geophysical insights regarding the subsurface of the site. Numerous researchers have highlighted the importance of geophysical surveys in road construction (Adegoke and Agada, 1980; Momoh *et al*., 2008; Adeyemo and Omosuyi, 2012; Okechukwu and Okogbue, 2011; Osinowo *et al*., 2011). Emmanuel *et al*. (2021) investigated the cause of road failure along Sagamu-Papalanto highway southwestern Nigeria. They reported that clayey soil was responsible for the road failure in their study area. Several researchers have used electrical resistivity method to investigate road failure (Akinlabi and Christianah, 2021; Ogungbe *et al*., 2021; Omowumi, 2021; Bisong *et al*., 2023; Arekumo and Lawrence, 2023; Feyisa and Gabissa 2023; Oghenovo *et al*., 2025).

This study aims to uncover the factors that lead to persistent road failure in the Chad Basin through the application of electrical resistivity sounding and Electrical Resistivity Tomography (ERT) survey techniques.

Figure 1: Image of the affected parts of the highway roads in the study area.

MATERIALS AND METHODS

Materials

To achieve the objectives of this study, Vertical Electrical Sounding and Electrical Tomography methods were employed. The following materials, which include ABEM SAS 1000 Terrameter, reels of wires, electrodes, hammers, a GPS device, a car battery, measuring tapes, a laptop computer system, pegs, and a recording book, were used to collect both the VES and ERT data. The acquired data were analyzed using IP2WIN software and RES2DIV software.

THE STUDY AREA

The study area is positioned at latitude11.7470^{o} N and longitude11.9662^{o} E. It is located within Nigeria's Sahel region. The climate in the study area is semi-arid, with a brief rainy season occurring between June and September, and an extended dry season lasting from October to May. Damaturu is found within the Chad Basin, which comprises interbedded sand and clay formations. The sand bodies represent the upper, middle, and lower aquifers (Barber and Jones, 1960).

The Chad Basin is composed of sedimentary rocks such as sand, clay, sandy-clay, and shale. The stratigraphy of the Chad Basin is entirely sedimentary (Figure 2).

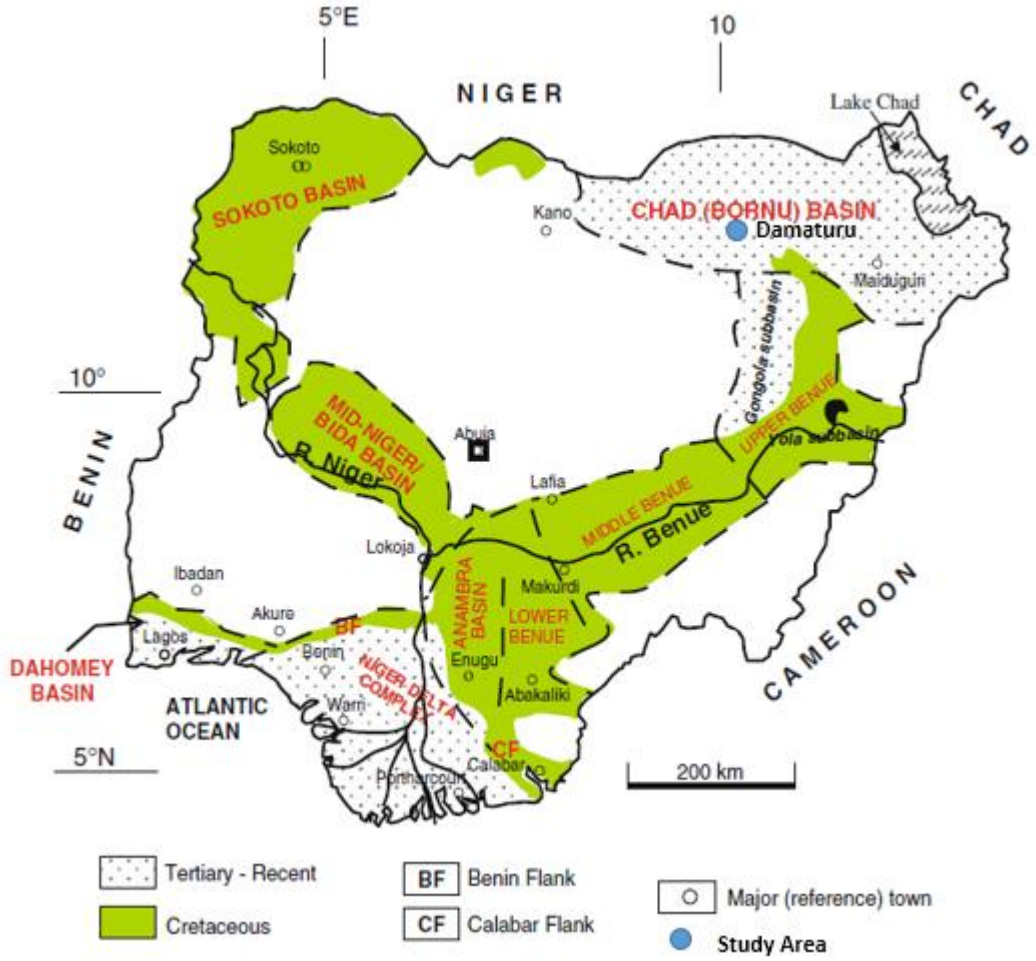

Figure 2: Map of Nigeria Showing the study area located in the Chad Basin (modified after Obaje, 2009).

METHODS

During the reconnaissance survey, the regions that were noticeably damaged on the highway were carefully identified and designated as points where the investigation will be conducted. To sufficiently delineate the subsurface materials underlying the study area, both Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT) surveys were conducted in the study area. The ERT traverses were deliberately selected to run parallel to both the affected and unaffected sections of the road. The VES data were analyzed using IP2WIN software, whereas the ERT data were interpreted using RES2DIV software. Initially, the ERT data were converted from BIN files to DAT files utilizing PROSYS II software. The acquired data were subsequently inverted using RES2IDV software. This software employs a non-linear optimization algorithm to yield two-dimensional Pseudo-sections. The inversion algorithm of the software is grounded in the Gauss Newton optimization standard (Loke, 2000). Six vertical electrical soundings were conducted to support the ERT survey. The VES survey encompasses both the damaged and undamaged portions of the road.

RESULTS AND DISCUSSION

The Electrical Resistivity Tomography (ERT) survey findings indicated that there were significantly low resistivity materials present in the highway subgrade of the study area. The materials exhibit low resistivity values, ranging from 5 to 30 Ωm at a very shallow depth within the study area (Figure 3). The resistivity characteristics of the materials suggested that

they were composed of clay. The materials are represented in deep blue color in the ERT survey findings (Figures 3, 4, and 5). The clay materials extend from the surface to a depth of 3.5 m in profile 1 (Figure 3). The clay materials stretch a few meters along the road. In profile two (2), the clay materials are the subgrades lying beneath the road pavement (Figure 4). In certain areas, it extends from the surface down to a depth of 6.5 m, though its thickness varied from one location to another in the study area. The distribution of the clay materials in Profile 3 revealed that it extends from the surface, and its thickness fluctuated along the road (Figure 5).

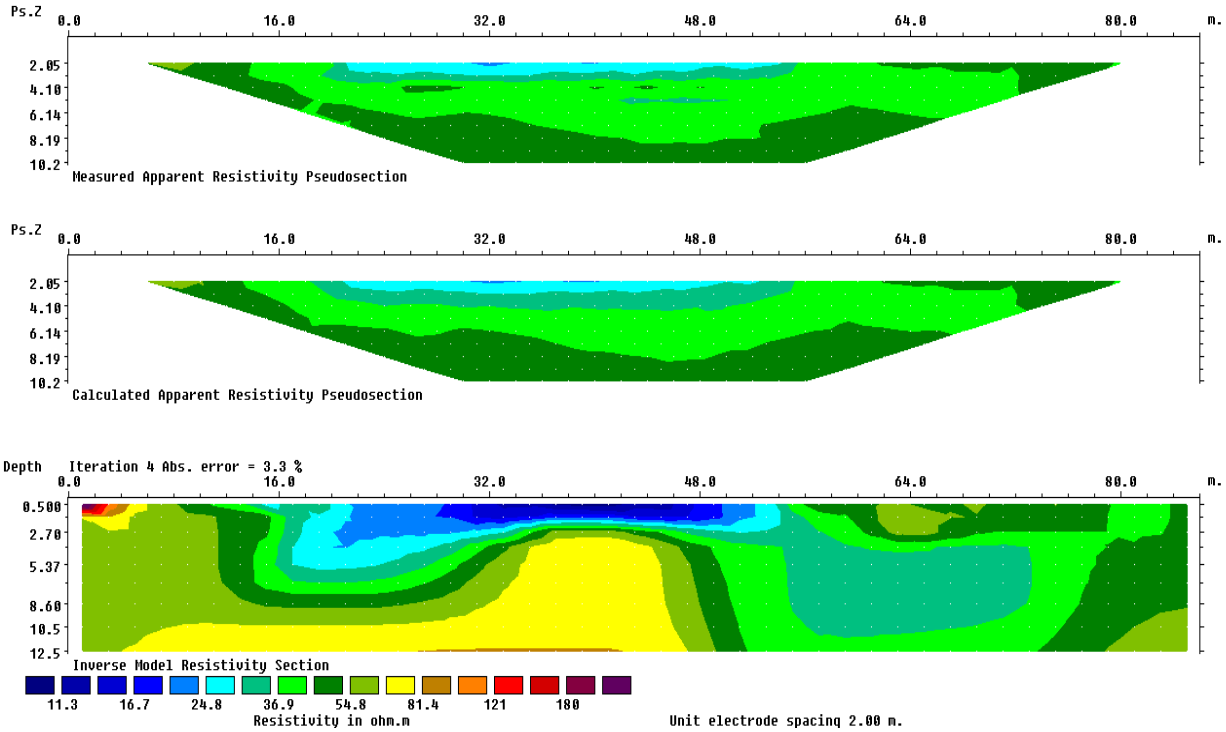

Figure 3: ERT survey results of profile 1.

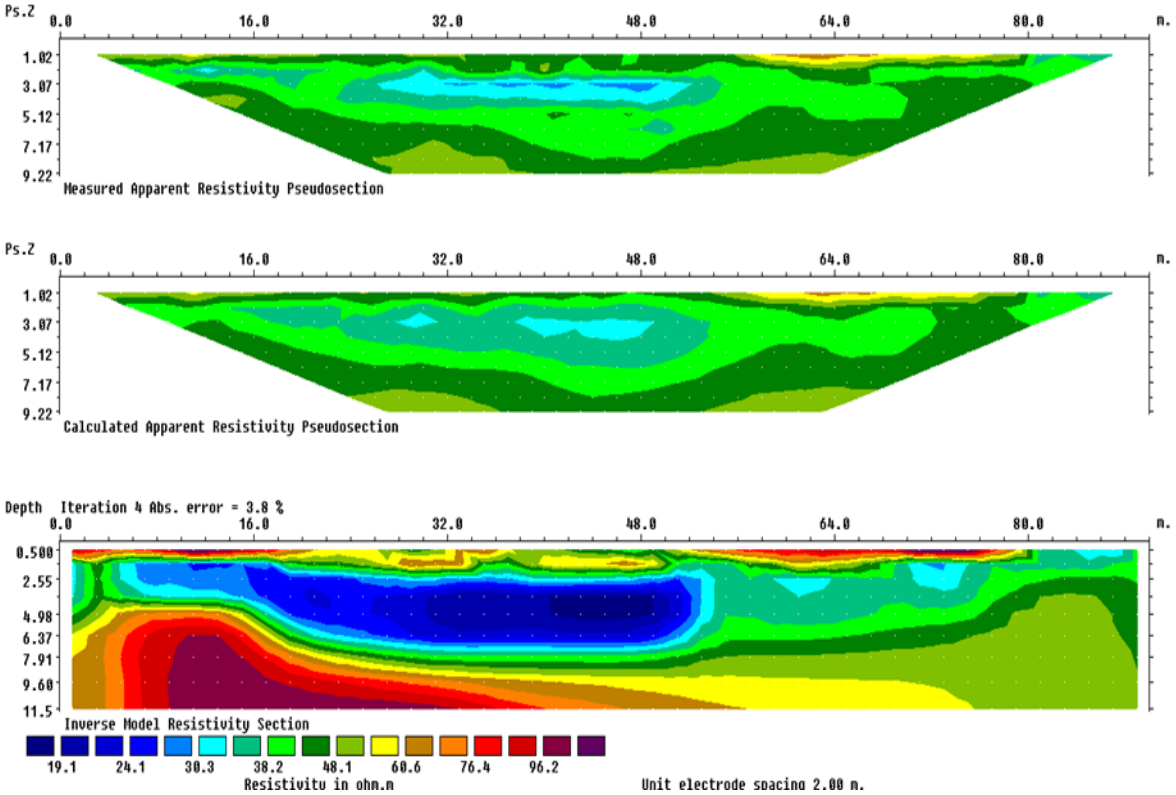

Figure 4: ERT survey results of profile 2.

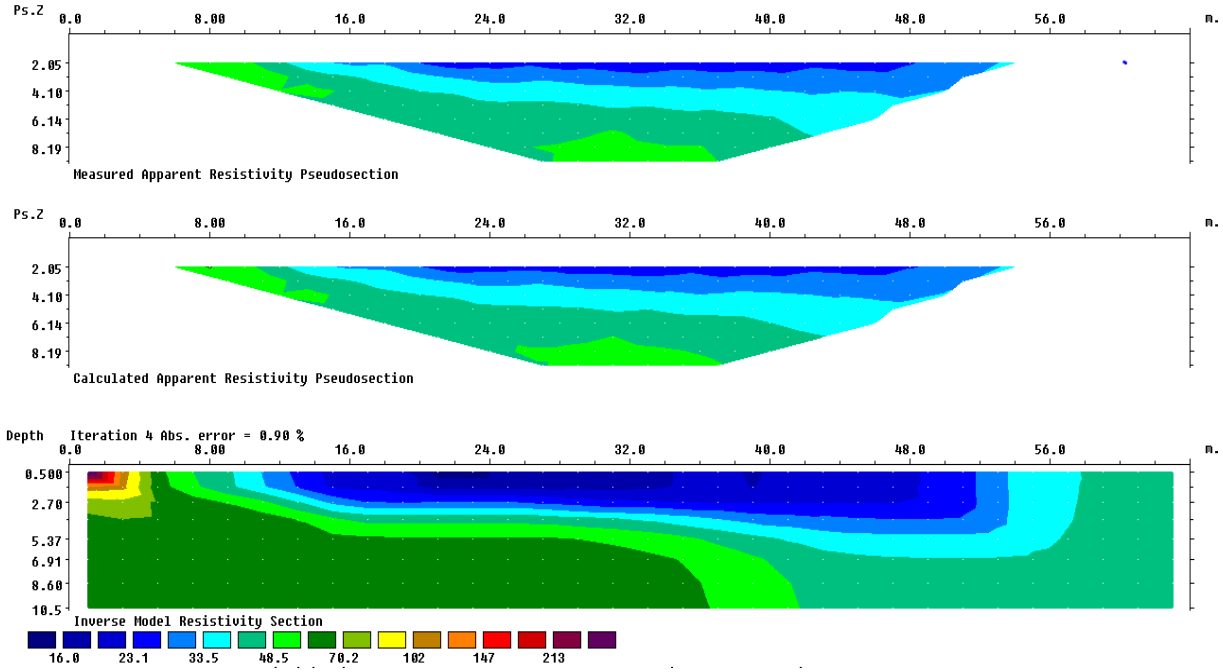

Figure 5: ERT survey results of profile 3.

The Vertical Electrical Sounding survey defined geoelectric layers including topsoil, clay, sand, and sandy-clay in the study area. The majority of the geoelectric curves derived from the study area are HA curves (Figure 6).

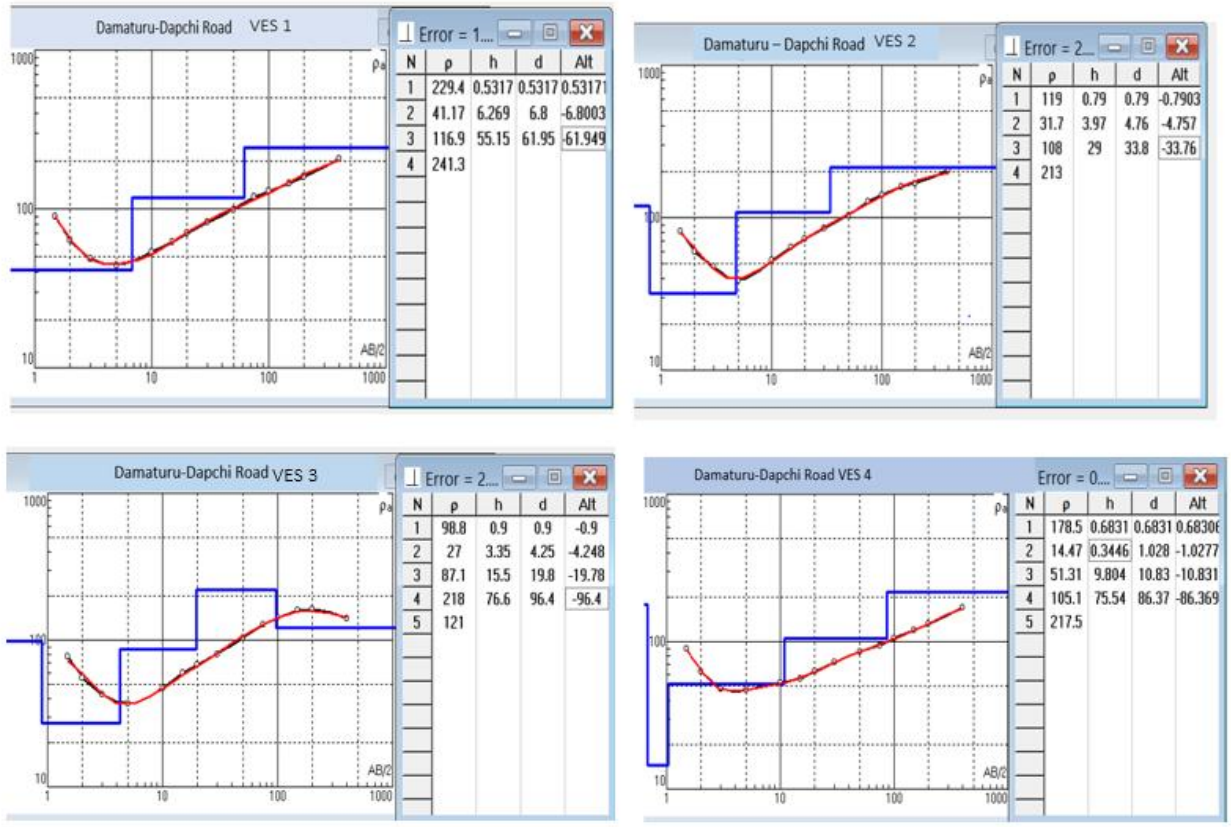

Figure 6: Typical curves obtained from the study area.

The resistivity characteristics of the second geoelectric layer suggested that in several regions of the study area, the second layer is made up of clay with resistivity values ranging from 27 to 41. 2 Ωm, while in other regions of the study area, the second geoelectric layer exhibits resistivity values varying from 145 to 231. 7 Ωm, indicating that it consists of sandy formation (Table 1).

Table 1. Vertical Electrical Sounding (VES) survey results.

VES No.	Resistivity (Ωm)					Thickness (m)				Remark
	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5	h_1	h_2	h_3	h_4	
1	229.4	41.2	116.9	241.3	------	0.5	6.3	55.1	-------	Unstable Portion
2	119.0	31.7	108.0	213.0	------	0.8	4.0	29.0	-------	Unstable Portion
3	98.8	27.0	87.1	218.0	121.0	0.9	3.4	15.5	76.6	Unstable Portion
4	178.5	14.5	51.3	105.1	217.5	0.7	0.3	9.8	75.5	Unstable Portion
5	234.3	145.0	211.0	317.7	245.0	1.0	7.5	21.6	38.9	Stable Portion
6.	129.8	231.7	187.7	265.6	311.7	0.9	8.2	43.5	34.8	Stable Portion

The resistivity characteristics of the second geoelectric layer indicated that in many parts of the study area, the second layer is composed of clay whose resistivity value ranged from 27 to 41.2 Ωm and in other parts of the study area, the second geoelectric layer has resistivity values which varied from 145 to 231.7 Ωm indicating that it is a sandy formation (Table 1).

The variation between clay and sand deposits within the second layer throughout the study area allowed for the identification of both stable and unstable sections of the road (Table 1).

This finding aligns with the ERT results, which demonstrated that the spatial distribution of the clay material in the second layer within the study area is not uniform but varies from one part of the road to another (Figures 3, 4, and 5).

In certain areas of the study region, the clay materials are located beneath the topsoil (Figure 4), whereas in other areas, they are visible at the surface (Figure 7).

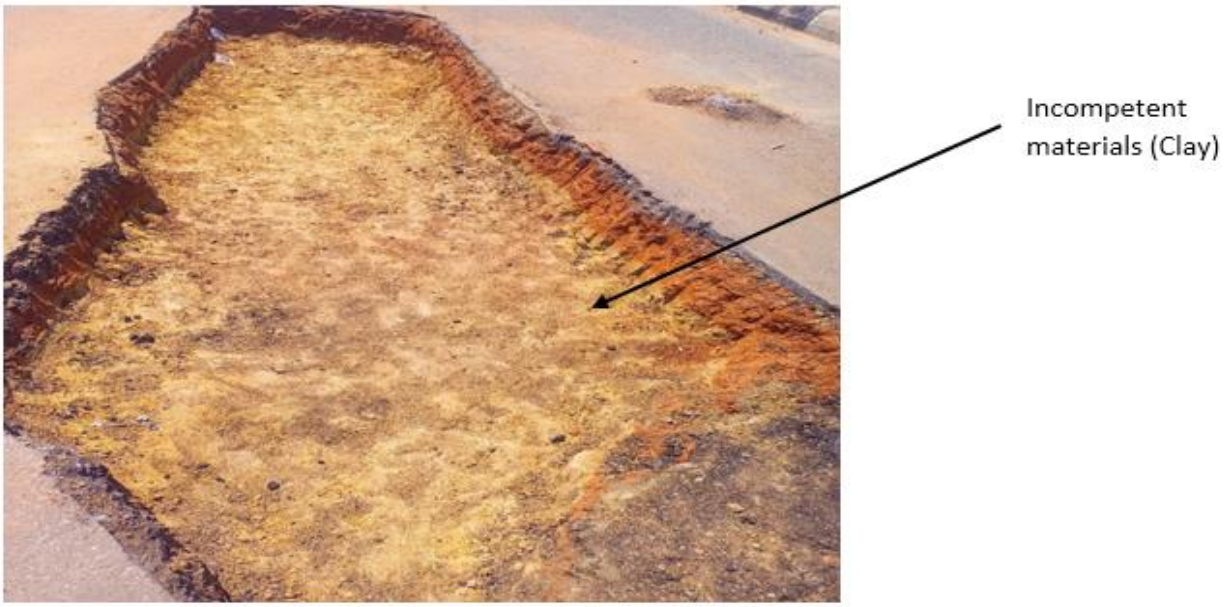

Figure 7: Clay materials underlying the Pavement of the road.

The shrinking and swelling of clay materials are significant contributors to road failures in the Chad Basin due to their closeness to the earth's surface. The swelling pressure causes deformation or elevation of near-surface structures, while the shrinking results in differential subsidence of the road surface (Figure 1).

The horizontal layering of the clay formation along the highway and its nearness to the surface in certain areas of the study region, as revealed by both the ERT and VES results, indicates that the road failures in the study area are exacerbated by the dynamic responses of the clay materials to varying hydrological conditions in the area.

Roads in the study area experience prolonged failures characterized by the emergence of potholes, fracturing, swelling, and depressions along the highway. Inadequate rock materials like clay are unsuitable for supporting road pavement due to their inconsistent reactions to subsurface moisture dynamics. Subgrades that include clay materials are often linked with frequent expansion and contraction that lead to the formation of folds, fractures, and potholes. Road failures are a major contributor to road accidents in the study area and throughout Nigeria. Seasonal fluctuations in subsurface moisture levels increase the frequent swelling and shrinking of roads in the study area, which results in their failures. The results of this study is in consonance with the report of Emmanuel *et al*. (2021) as stated in the literature.

CONCLUSION

This research examined road failures in the Chad Basin region, utilizing Damaturu as a case study within Nigeria. The outcomes of this research indicated that the closeness of clay formations to the surface of the Earth in the study area significantly contributes to road

failures in the Zone. Both the ERT survey outcomes and the VES findings pinpointed unsuitable materials such as clay as a factor in the recurrent road failures observed in the study area. It was noted that the longevity and reliability of the roads in the Chad Basin region depend on the quality of the subgrade materials that support the road pavements. The application of geophysical survey techniques in road construction endeavors should be strongly emphasized in this region to prevent recurrent road failures in the Chad Basin and to reduce expenses. It is thus advised that sections of roads with incompetent subgrades should be removed and substituted with more solid and competent materials that possess the necessary stability and load-bearing capacity. In addition, road construction should be supplemented with thorough geophysical surveys to detect areas on the road that are identified by less competent subgrades, ensuring that sufficient attention is given to them.

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