IMPACT OF CLIMATE ON ROAD FOUNDATION FAILURE AND ITS IMPLICATION FOR ROAD MANAGEMENT IN NIGERIA

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01/66ME039

A THESIS TO BE PRESENTED TO THE DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL MANAGEMENT, FACULTY OF SOCIAL SCIENCES, UNIVERSITY OF ILORIN, ILORIN, NIGERIA, IN PARTIAL FULFILLEMNT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) DEGREE IN GEOGRAPHY

UNIVERSITY OF ILORIN, ILORIN

Impact of Climate on road foundation failure and its implication for road Management in Nigeria

Thesis submitted to the post Graduate School University of Ilorin, Ilorin, Nigeria, in Fulfillment of the Requirements for the Award of Doctor of Philosophy (Ph.D) Degree in Geography

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January, 2021.

DEDICATION

This thesis is dedicated to Almighty God for his guidance, protection and to Mrs. F.A. Bello-Ochende.

CERTIFICATION

This is to certify that this research work was carried out by KEKERE, Adamu Ademoh has been read and approved as meeting the requirememts of the Department of Geography and Environmental Management, Faculty of Social Sciences University of Ilorin for the award of Doctorate degree (Ph.D) in Geography.

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AKNOWLEDGEMENT

My profound gratitude goes to Almighty God for giving me wisdom and sound health to complete this thesis.

I am proud to attribute the success of this work to my supervisor, my mentor Prof. I.P Ifabiyi for his effort despite his tight schedule Sir, words are not enough to express my appreciation. May the Almighty God continue to guide, protect you and grant you your heart desires.

Lecturers in the Department are also acknowledged for their contributions and criticism all towards the success of this work, they include: Dr K. A. Iroye (H.O.D), Profs. Bisi .Adedayo, J.F.Olorunfemi, L.T. Ajibade, R.A.Olawepo, E.O.Oriola, Drs U.A Raheem, Y. A. Ahmed, S.L Tilakasri, B.A Usman, I. Orire, O.D Ajewole, E.A.Adeleke, Drs (Mrs) R.Olanrewaju, A.M.Tunde and Mrs E.Adeniyi.

I also want to extend my gratitude to my children for their patience and understanding throughout the programme.

My parent Mallam Kekere, Tijani Sule and Mrs Kekere Ramat-Ahmadu, my brother Prof H.I.Jimoh are also appreciated. I will also like to acknowledge Mrs Bello.Y.Juliet (UITH), Mrs Yusuf Janaet and Dr. Samsideen Ojoye (FUTMINA), Dr (Mrs) Grace Philips, Dr.Isaac Ocholi HOD, Department of Geography, Kogi State University, Anyigba, Dr Emmanuel Tokula Arome both of the Department of geography and environmental studies, KSU, Dr. B.E Agbano Director Health service Unit, Mrs J.L.Johnson Kogi State University Anyigba for their immense support and prayers. I also want to appreciate Sis. Dupe for the typesetting of the manuscript of this thesis..

To all my former colleagues at the Unilorin Secondary School (USS) they include: Mr. Kareem R.O, Olarenwaju Ibrahim, Dr Abiola Muhydeen, Mrs E.O.Ojapa and Mr.H.S.Ifelayo, Dr Adedoyin T.I, Mrs Adebayo Idowu Mr Raji .H. among others. Lastly, to my able Boss Alhaji Abdulrauf Oseni Ajala (former Principal Unilorin Secondary School).

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ABSTRACT

Road foundation consists of subbase and subgrade layers and is a product of earth materials. It responds to the vagaries of weather and climate. Road foundation failure may vary with climate. This variation has been observed in Nigeria. The study examined the impact of climate on road foundation failure in Nigeria and its implication for road management. The objectives of the study were to: (i) examine the pattern of road subbase and subgrade in each morphoclimatic zone; (ii) examine the relationship between climatic variables and road subbase and subgrade in different morphoclimatic zone; (iii) assess the impact of climate on road subbase and subgrade in each morphoclimatic zone; and (iv) compare the geotechnical properties of road subbase and subgrade in the study area with the Federal Ministry of Works and Housing (FMW&H) standard. Data for the study were obtained from secondary sources. Available climatic data (rainfall, maximum temperature and minimum temperature) for 36years (1980-2016) were obtained from the Nigerian Metrological Agency (NIMET). Geotechnical properties particle size distribution (PSD), natural moisture content (NMC), liquid limit (LL), plastic limit (PL), plasticity index (P), maximum dry density MDD), optimum moisture content (OMC) and California Bearing Ratio (CBR) were obtained from the Pavement Evaluation Unit, FMW&H, Nigerian Building and Road Research Institute (NBRRI) and Federal Road Maintenance Agency (FERMA). Purposive sampling technique was employed in selecting two road networks from each of the four morphoclimatic zones (namely: hot-dry, temperate-dry, hot-humid and warm-humid zones). From these, a total of 697 Kilometers of road and 516 sample points were selected. Principal component analysis, ANOVA, multiple correlations and multiple linear regressions were used to analyze the data.

The findings of the study were that:

i. significant differences (df = 0.05) exist in the spatial pattern of geotechnical properties in the morphoclimatic zones of Nigeria;
ii. many of the climate and geotechnical properties were strongly correlated with values ranging from
    r = 0.64 between rainfall and liquid limit in Brinin Yauri-Malando-Wara road to r = -0.72 between liquid limit and rainfall in Akwanga-Toto-Abuja road;
iii. rainfall, maximum temperature and minimum temperature weakly predicted foundation failure with R^2 of 1.40% in the hot humid zone to 35.2 % in the temperate dry zone;
iv. the tested geotechnical road quality parameters for subbase and subgrade materials fell short of the standard of FMW&H in 95% of the sample points; and
v. the geotechnical properties that determine road failure were PSD, NMC, LL, PL, PI, MDD, OMC, and CBR. The percentages of their explanations to road failure vary from 77.7 to 82.8 percents in the subbase category along Port Harcourt-Elele-Umanelu road and Benin-Agbor-Asaba road respectively, while in the subgrade category it ranges from, 71.4 to 82.8 percents in Akwanga-Abuja and Katchia-Kwoi-Nassarawa road respectively.

The study concluded that the influence of climate on road foundation were less severe but vary according to morphoclimatic zones. The study recommended strict compliance with standard specifications and the use of weighbridges to check excess weight on Nigeria roads.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

A subgrade is a typical natural untreated material which other road components rest upon and it serves as the foundation of road. The layer above the subgrade is subbase, it is made up of high quality materials compared to subgrade it may consist of a layer of selected borrow materials well- treated and mechanically compacted to achieve the desirable strength of foundation required for road pavement (Garber and Hoel, 2009). Among the challenges engineers face during road construction is the issue of road subgrade and poor soils materials. Road being one of the most widely used infrastructure for transportation of goods and services is being threatened by climate and problem soils. According to Hansson *et al,* (2010) an increased in the occurrence of extreme weather events will impose greater strain on facilities for dewatering and drainage of roads. Road subgrade and subbase are the most vulnerable parts of the road mostly affected by extreme weather conditions. A common incidence is when rainwater seeps through a crack surface of road and such subgrade subsequently, becomes over saturated and that further lead to deterioration of road foundation. According to Williway, Baldachin, Reeves, McHale and Nunn (2008) excessive water in the foundation of road (sub base and sub grade) will reduce the pavement's structural capacity and such pavement is liable to deformation under traffic loading. An increase in temperature has the tendency of causing road pavement bleeding and deterioration of asphalt overlay. In Nigeria, for instance all the federal roads in South East are in bad shape due to extreme weather condition. Most of the roads have been washed away by gully

erosion. Presently, Nigeria's road network is in a deplorable state, it is characterized with one form of failure to another.

Osadebe, Fakaye, Matawal and Aitaseboama (2013) maintained that the Nigerian transport system functions in a crisis situation. Opawole, Jagboro, Babatunde and Opawole, (2013) also posited that the state of our roads call for a serious concern by stakeholders, the public, policy makers and researchers. The extent of failure has generated a lot of concern. Most of these roads have become death traps which have recorded several road crashes claiming lives and property worth millions of naira, annually. According to the United Nation Decade of Action on Road Safety (2011), Nigeria is ranked 191st among the countries of the world with unsafe roads. The Federal Road Safety Corps (FRSC, 2011) revealed that 162 deaths per 1000 population occurred from road crashes in Nigeria between the 19th – 28th December 2014,193 road crashes occurred leaving 120 people dead. A total of 10380 road crashes occurred in Nigeria in 2014 alone; and 5,996 lives were lost and 32,063 people were injured (FRSC, 2015). The annual loss of property on the Nigerian road as a result of bad road and road crashes is valued at about 80 billion naira, while vehicle maintenance and operation cost is valued at about 53.8 billion naira bringing it to a total of 133.8 billion (FMW&H,2010). In 2018, the federal govevenment declared that a total of 800billion is required to fix the entire road in Nigeria (FMW&H, 2018). Most of these challenges of insesant road subgrade and subbase failure are due to bad weather and climate.

Some road networks are no longer motorable and they are no longer busy as they ought to be due to their strategic locations. Several villages and towns suffered untold hardship due to the poor state of the roads in Nigeria. Some roads in South Eastern Nigeria are in bad shape Among them are the Enugu-Okigwe-Umuahia Aba express road to Port Hacourt, Umahia-Uzuakoli –Ohafia

road, Arochukwu and Uturu Isuikuato road are aptly described as death traps due to the severe consequence of gully erosion. In Ebonyi State, six villages in Ishielu Local Government Area have been cut off from the state capital Abakiliki due to bad road and broken bridges (The Sun News paper 2014: www.sunnewsonline.org).This scenario is also peculiar to Pandogari-Birnin Gwari-Kaduna that has been taken over by kidnappers as well as Lokoja- Abuja road. However, the budget of 2018 captured about 69 road projects in South Eastern Nigeria which when completed will be a great relieve to the people in that area. In the same vien, the federal executive council in June, 2020 approved the sum of 115.5 billion naira for various roads in some part of Nigeria; according to Minister of Works, three roads were approved. These roads include: Jabi-Lamba- Bele road in Adamawa state for the sum of 26.829 billion naira, Achingali-Udobi-Udona- Umuawana road-Ubakala road including the bridge across the Imo river in Imo State for the sum of 11.540 billion naira and the Jarmai-Bashar-Zuruk-Karim Lamido road linking Plateau and Taraba State in the sum of 77.279 billion naira (The Sun News paper June 11, 2020: www.sunnewsonline.org). These roads are part of economic recovery and growth plan of the federal government to consistently improve on road transport infrastructure in Nigeria in 2020. Efforts to curb the menace of road subgrade and subbase failures in primarily the cocern of this research and in an attempt to look at the problem, this study intends to investigate impact of Climate on road foundation failure and its implication for road Management in Nigeria.

1.2 Statement of the Problem

Climatic conditions such as extreme temperature rise, extreme rainfall rising sea level and flooding among other factors have been discovered to have negative impacts on roads. Moisture

content for example influences stability of foundation materials due to the intrusion of water into the foundation of road. Similarly, excessive solar radiation may have influence on road pavement resulting to rutting, alligator cracks longitudinal and traverse cracks on road pavements in areas which are largely founded on clayey materials. In Nigerian road construction effort seems to ignore morphoclimatic conditions which could explain why the cases of road failure had been on the increase on the Nigerian road. Evidences of road sub grade failure due to extreme weather condition are common phenomenon on Nigerian roads. Failure such as potholes, erosion of road shoulders and sedimentation that may arise from subbase and subgrade owing to excessive influx of moisture content are due to rainfall events which causes instability in the strength of subbase and subgrade. In South Eastern Nigeria, most of the roads have been washed away by gully erosion as a result of excessive rainfall. Several towns cannot be assessed due to broken bridges. Roads are constructed to meet expected economy life span of at least twenty (20) years and above (High Ways Research Manuals, 2013). Despite this specified standard, some roads in Nigeria do not meet the economic life span as many of these roads had started failing as soon as they were constructed. Infrastructure and Climate Network (ICNet, 2014) emphasised the need to incorporate information on weather and climate in road pavement design and construction in order to reduce failure and the cost of maintenance. Roads constructed without proper climatic and weather information may not live the expected economic life span. Apart from climatic-induced failure some of the roads in Nigeria failed because routine maintenance were not carried out and most of the road had out- lived their economic- lifespan.

According to Central Bank of Nigeria (CBN, 2003) most of the road network in Nigeria were constructed thirty years (30) years ago and no major rehabilitation have taken place since then. As a result of this, cracks (longitudinal and transverse), depressions, broken bridges and numerous potholes characterised the road transport system. This has made transportation on Nigerian roads slow and unsafe. Nigeria has a total of 200,000Km of road network with only 16% of these roads are paved (NTP, 2017).This shows that there is a huge deficit in accessible road network across the country. With the current situation of bad roads in Nigeria, the cost of maintaining failed roads in Nigeria have become a huge financial burden to the Federal Government of Nigeria. Billions of naira is spent annually on maintenance and construction of new roads across the country. As at 2001 the cost of maintaining and replacing failed roads in Nigeria was estimated between 35-43 billion naira (NTP, 2010).In 2017, the Honorable Minister of Power, Works and Housing Babatunde Fasola declared that 900 billion naira is needed to fix Nigerian roads (www.dailytrust.com.ng. 11th December,2015). Federal government allocated 169.88 billion naira for road infrastructure in reconstruction, maintenance of our roads in 2020 budget (The punch Newspaper, 17th Oct, 2020.www.punch.com.ng) despites a lot of finanacial committement on road we still have huge deficit in road infrastructure in Nigeria.Therefor, there is need to understand the nature and causes of road subbase and subgrade failure across the morphoclimatic zones in Nigeria.This study therefore, attempt to fill this gap.

1.3 Research questions

This study seeks to address the following basic questions

i. What is the nature of the geotechnical properties over the different morphoclimatic zones in Nigeria?
ii. What is the pattern of road subbase and subgrade failure in each morphoclimatic zone?
iii. What is the nature of the relationship between morhoclimate, road subbase and subgrade failure in Nigeria?
iv. What are the impacts of these relationships?
v. What factors are responsible for road subbase and subgrade failure in Nigeria?

1.4 Aim and Objectives

The aim of this study is to examine the morphoclimatic zone and the pattern of subgrade and road failure in Nigeria. In order to achieve the aim of this study the following objectives will be pursued:

i. Examine the spatial pattern of road geotechnical properties of road subase and subgrade materials in the study area;
ii. Examine pattern of subgrade and road failure in each morphoclimatic zones in Nigeria;
iii. Examine the relationship between climate and road subbase and subgrade in different morhoclimatic zones in Nigeria;
iv. Assess the impact of climatic variables on road subbase and subgrade in each morhoclimatic zones in Nigeria ; and
v. Identify the factors responsible for road subgrade and subbase failure in the study area.

1.5 Research Hypotheses:

H_0 There is no significant differences in geotechnical properties in the morphoclimatic zones in Nigeria.

1.6 Justification of the Study

Studies on road failure have concentrated on pavement failure and faulty design which fall within the purview of engineering and geophysics (Ogundipe 2008; Hijab *et al* 2012; Osadebe *et al* 2013; Ogunribido *et al* 2016 among others), with little or no emphasis on the relationship between road subbase, subgrade failure and climate. Furthermore, some researchers in social sciences have also carried out different studies with emphasis on the economic importance of road infrastructure, impact of road failure on the socio- economy, road crashes and the need for adequate road infrastructure for economic growth (NEEDS, 2004; Arosanyin, 2004; 2006; Delany, 2008; Nworji and Oluwalaiye, 2012 among others). In many instances road infrastructure are put in place with little consideration to climate. For example, many of the policy makers are not in the know that the cost, design, construction, maintenance, duration of road varies across Nigeria. This variation is pertinent in each morphoclimatic. Hence, many serious debates ensued on the actual cost of road project at different fora .It is believed that studies of this nature will serve as an eye opener to concern individuals. Road network being the vein through which economic activities are enhanced will be properly maintained only if policy makers consider the impact of climate on road. This study will no doubt contribute to the existing studies on road infrastructure in Nigeria.

1.7 Scope and Limitation of the Study

The study examined the impact of climate on road foundation failure and its implication for road management in Nigeria. Roads under study were taken across the four (4) morphoclimatic zones namely: Hot Dry, Temperate Dry and Hot humid figure.1. The study will utilize only two variables out of the climatic data that is, rainfall and temperature (Minimum and Maximum temperature) and geotechnical data. This is because these two variables are considered major threats to road subgrade and sub base failure as pointed out by Willway *et al.* (2008), Daniel *et al* (2014). Nigeria however, falls within the tropics as results roads are threatened by these two climatic variables. Moisture condition affects the stability of sub grade while temperature affects the stability of bituminous surfacing and subbase and subgrade materials. However, some of the zones are interwoven to another zone and the choice of the four zones was to give a detailed account of the impact of clamate on foundation failure and its lmplication for road management in Nigeria. However, the study is faced with the challenges of data acquisition especially geotechnical data for road subbase and subgrade in Nigeria.

1.8 Study Area

1.8.1 Choice of Study Area

The purpose of this study is to investigate the impact of clamiate on road foundation failure and it implication for road management in Kebbi, Kano, Kwara, Kogi, Kaduna, Nassarawa, Port hacourt and Delta State of Nigeria see Figure 2. These locations were chosen because they are Federal trunk ‘A’ and ‘F’ roads and one of the busiest road networks with severe damage due to road failure. Secondly, the States fall in the four climatic zones in Nigeria (Figure.1) Hot Dry,

Temperate Dry, Hot Humid and Warm Humid for road engineering construction purpose (Highway manual, 2013).

Hot dry Morphoclimatic zone (zone 1.) Kebbi State

Physical setting

Kebbi State is located in North-western Nigeria with its capital at Birnin Kebbi Kebbi State was formed from part of Sokoto State in 1991. It has a total land area of 36,800KM^2. It lies on latitude 10^0 to 13^0 N and longitude 3^0 to 6^0 E it is bordered to the east by Sokoto State, to the south by Niger and Zamfara States and to the west by Benin Republic. Its major towns include Birnin Kebbi, Argungu and Yelwa. It population stands at 3,238,628 people, making 2.31% of the nation's population.

Kebbi State falls within the Hot Dry Climatic Zone (Zone 1). It has an annual rainfall of between 528-960mm rainy season starting from June-October and it has a single maximum pattern of rain fall regime, the dry season start from October to May which display some cold dry spells made of dusty North-East trade wind from the Sahara Desert with temperature dropping to a little bit low less than 25^{0C}. Relative humidity is very high during rainy season reaching a maximum of 75-80% in July and August. The climatology of Kebbi State is associated with Inter-Tropical Discontinuity (ITD) which migrates north to south in accordance to the dictate of the season. Kebbi State has an annual average temperature of 28.3^{0C} which makes it a very hot area. The maximum day temperature for most of the year is 40^{0C} which result to extreme dryness which makes it unbearable to its inhabitants. Kebbi State belongs to the Sudano Sahelian vegetation type. The Northern part of the State is sandy while the Southern part is generally rocky. Kebbi

State is drained by River Niger other River include River Argungu, The river passes through Ngaski LGA, Rima Argungu to Bagudo Local Government Areas, which drains into river Niger.

Socio-economic setting

The majority of the population is Muslims following the conquest of the Fulani jihad in 1804, while the minority group is Christians and traditional worshipers .Kebbi State has four major tribes which include: Hausa, Fulani, Dakarkari and Gungawal. These tribes make up the 21 Local Government Areas

Road infrastructure

Kebbi State has a total of 248,40Km of asphaltic concrete, 307.00Km of surface dressed, 286.40KM of gravel or earthly road making a total 841.00Km of road network (Table 1).

Kano State.

Physical setting

The capital of Kano State is one of the prominent ancient city and a commercial hub in northern Nigeria. The lies approximately between Latitudes 100 33'N and 120 23'N and longitudes 70 45'E and 90 29'E, with a population of 9,401,288 (NPC, 2006 census). Kano has an estimated land mass of 21,276.872 km^2 with 1,754,200 hectares of agricultural land and 75,000 hectares forest vegetation and grazing land.

The State falls in the hot dry morphoclimatic zone (zone 1) Figure 1. The movement of the Inter-Tropical Discontinuity (ITD) gives rise to two seasons (wet and dry seasons). The wet season lasts from May to mid-October with a peak in August which give rise to single maxima rain fall pattern.The dry season extends from mid-October to mid-May of every year. The annual mean rainfall is between 800 mm to 900 mm; and variations about the annual mean

values are up to 30%. The mean annual temperature is about 260C (Falola, 2002; Olofin, 2008). The area is characterized by rocks of the Basement Complex of pre-Cambrian age to the west and south, and the Chad formation to the northeast. The relief can be described under three types which are found in three zones. These are: the south and southeastern highlands, the middle and western high plains and the northeastern low Chad plains. The first two types are part of the High plains of Hausaland and the third is part of the Chad plains (Olofin, 2008).

Road infrastructure

Kano State has a total of 720.00 Km of asphaltic concrete, 165.00Km of surface dressed road making a total 885.00Km of road network in Kano State.

Temperate dry Morphoclimatic zone (zone 2.)

Kaduna State

Physical setting

The city of Kaduna is located in the northern Guinea savannah zone of Nigeria. It lies between latitudes 9^0 03^1 to $11^0 32^1$N and longitudes 6^0 05^1 to 8^0 38^1E. The city's central location makes communication with the rest of Nigeria relatively easy. Unlike any other area within the tropics Kaduna enjoys tropical climate. The rainy season in the Kaduna city region starts around March and ends in October. Annual rainfall averages around 1200 mm. The rainfall pattern is traditionally characterized with single maximal pattern of rainfall with peak precipitation between July and August. The drainage pattern is dominated by the River Kaduna with its seasonal variation between flood conditions in the wet season and almost dry exposed river beds in the dry season. Its tributaries provide useful recharge opportunities and traditional ‘‘fadama’’ development. The Kaduna area is characterized by a dry season with dry, cold conditions from

November to February. The mean monthly temperature generally varies between 26^0C and 34^0C with maximum temperatures occurring in February, March and April and minimum temperatures in the ‘‘Harmattan’’ months of November, December and January.Owing to its location in the guinea Savannah vegetation belt, a rainy season that lasts from April to October and abundance of fertile land that supports agriculture activities. Kaduna State has a population of 7,474,369 (2013 projection).The State has a total of 23 local government areas (LGAs) council.

Road infrastructure

Road and mileage covered in Kaduna State (table 2) showed that a total of 1,436.00KM of asphaltic concrete road network, 150KM of surface dressed and 8.00KM of gravel or earthly road making a total of 1,594.00KM(Table 1) of road covering the entire state.

Nassarawa State

Physical setting

Nassarawa State is located in North Central Nigeria it lies between latitudes $8^0\ 51^1$ and $8^0\ 53^1$ North of the equator and longitudes $7^0\ 50^1$ and $7^0\ 51^1$ East of the Greenwich meridian it is bordered by plateau state to the North east, Federal capital territory Abuja to the North, Kogi and Benue States to the south. Its population according to the National Population Commission (NPC 2011) is estimated at 2.04 million, It major towns include: Lafia, Keffi, Doma, Awe, Toto and Nasarawa among others.

Nassarawa State lies within temperate dry morphoclimatic zone (zone 2) with annual rainfall of 1,077-1,399mm.Temperature are generally high especially during the day, with annual temperature ranging between 20-23^{0C}.The hottest months are March and April while the coldest months are December and January (Lyam, 2000; Binbol, 2007).Unlike other parts of this

climatic Zones, the State enjoys wet and Dry seasons. The wet season starts from May and ends in October. The wettest months are July and August.

Nassarawa State is also found in the basement complex region. The rocks are mostly igneous and metamorphic in nature. However, sedimentary rocks are also found. The Maloney Hill found in Keffi is a historic relief feature. Generally, Nassarawa State is located at an average altitude of 850m above sea level. River Benue passes through Nassarawa State in the southern parts with several tributaries that drained through the State. Prominent among them is River Antau in Keffi which is the primary source of water for domestic and industrial activities. The soil in Nassarawa State belongs to the category of oxisols or tropical ferrigenous soils (Nyagba, 1995 cited in Lyam, 2000). The predominant soil parent materials in the area are derived from the cretaceous sandstone, siltstone, shale and ironstone of the Precambrian to Cambrian (Samaila and Ezeaku, 2007). According to Lyam (2000), the hilly areas in Keffi carry shallow skeletal soils and some parts of the region are heavily gullied.

Road infrastructure

Transport mode in Nassarawa State includes human portage especially in rural areas and road transport. Nassarawa State is connected to other states in the country through properly tarred Federal trunk 'A and F' roads. For example, Abuja-Keffi expressway, Keffi –Abuja-Lafia-Makurdi Road, Keffi-Akwanga-Jos Road, Keffi-Kaduna Road, keffi-Nasarawa-Toto Road, and so on (Lyam, 2000;Onosemuode, 2007).With a total of 1,795KM of road network in Nassarawa State 411.00Km of asphaltic concrete road network, 388.50Km of surface dressed roads and 560Km of gravel or earth road network. These entire road networks are maintained by federal,

State and Local Government Council Roads and mileages covered in Nigeria is presented in Table 1.

Hot humid Morphoclimatic zone (zone 3)

Kwara State

Physical setting

Kwara State lies between Longitude 8^0 and 10^0 N and Latitude 3^0 and 6^0 E. It is bordered by Niger State to the North to the south by Oyo, Osun and Ekiti States, to the East by Kogi State and Republic of Benin to the west. Due to its strategic location, Kwara State is referred to as the 'gate way' (Oyebanji, 1991) because it is located between the Northern and Southern Nigeria. The total land area is 37,700SqKm with a population density of 41 persons/SqKm (NPC 1991).Its population, according to the National Population Commission (NPC 2011) is estimated at 2,371,089(1.69%). Its major towns include: Offa, Jebba, Patigi, Erin-Ille, Illoffa, Osi, Lafiagi, Affon, and Kaiama among others. Kwara State falls into hot humid climatic zone (Zone 3).Unlike other states; Kwara State enjoys the two seasons, the dry and wet seasons with an annual rainfall of about 1,000 to 1,500mm which spread for nine months between March and October. Sometimes, it extends to November. The dry season is about four months between Novembers to February. It sometimes extends to early march. During the dry season, temperature in Kwara State rises but reduces during the rainy season. The mean maximum temperature ranges between 33^{0C} and 36^{0C} while the minimum temperature ranges between 19^{0C} and 24^{0C}.Temperature reduces as low as 15^{0C} especially in December and January.

Kwara State relief is made up of high and low land areas which rise between 60-680m above sea level, with an undulating surface in the hinterland. The highest hills are found in Ifelodun,

Irepodun and the Sobi hills in Ilorin West Local Government Areas. The State is drained by several rivers which include rivers Niger, Awon, Oshin, Teshi, Oyi and Moro. All these rivers are major tributaries of river Niger and these rivers have minor tributaries which are mostly seasonal in nature and are characterised by various drainage patterns. For instance in the downstream, it exhibited the trellis pattern, while rivers found in the hinterland exhibited a dendritic pattern. Some of the rivers are major means of transportation of goods and services within the localities. Kwara State mainly composed of furroginous soils which are underlain by basement complex rocks both primary and secondary lateritic and alluvial soils are also common. These soil deposits are weak, less resistant and prone to erosion activities.

Road Infrastructure

Kwara State has a well accessible road infrastructure with a total of 348.00Km of asphaltic concrete road 29,000Km surface dressed while gravel or earth road is 385.00Km making up a total of 102,300Km of road network in the entire area.

Kogi State

Physical setting

Kogi state is located between Latitude $6^0$28'N to 8^0N and longitude $5^0$22'E to $7^0$55'E it is located in the North-central and it is popularly referred to as the confluence of Rivers Niger and Benue is at Lokoja, the State Capital. The climate of the study area unlike other tropical environment has an average maximum temperature of 33.2^0 C and an average minimum temperature of 22.8^0 C. Lokoja, the State Capital is generally very hot between the months of October and April each year, though the intervening harmattan from late November to early February normally cushions its effects. Despite the cushioning effects of the harmattan, there are times when Lokoja the State

Capital's weather is unbearable. The land rises from 300 meters along the Niger/Benue confluence, to the heights of between 300 and 600 meters above sea level in the upland area of Agbaja Plateau and much higher in Okoro-Agbo hills in Ijumu local government area of Kogi State. Like most towns in the Niger-Benue Confluence area, Lokoja is dominated by undulating landscapes, broken by hills formed of resistant rocks and this has profound influence on the pattern of settlement in the study area. The fairly undulating terrain in the eastern region of the state has contributed to high development in such areas as against the western region that is characterized by resistant rocks. Land for development is relatively scarce in the area.

The rivers have had considerable influence on many phases of human activities including the growth of settlements, transportation and hydro-power. Rivers Niger and Benue have also contributed to the socioeconomic development of Kogi State such that most of the dry land that are not properly drained and often considered not very useful for farming due to their low organic content thus, such areas is underdeveloped. An example is the western district of the State. On the other hand there are high densities of population where there are well drained, fertile soils, human beings usually settle first in areas of fertile soils and plain land. The study area Ayingba-Dekina-Ofa road is one the federal road that linking Benue State and some eastern part of Nigeria and it is usually busy all through the year.

Road infrastrucure

Kogi State has a total of 500KM of asphaltic concrete road network, 444.00KM of surface dressed, and 232.00KM of gravel or earthly road making a total of 1,173.00KM of road network linking all the local government areas in Kogi State (Table 1)

Warm humid Morphoclimatic zone (zone 4)

Delta State

Physical setting

Delta State The state covers a landmass of about 18,050 km², The state lies approximately between Longitude 5°00 and 6°.45' East and Latitude 5°00 and 6°.30' North. It is bounded in the north and west by Edo State, the east by Anambra, Imo, and Rivers States, southeast by Bayelsa State, and on the southern flank is the Bight of Benin which covers about 160 kilometers of the state's coastline. Delta State is generally low-lying without any remarkable highland. With a population of population of 4,112,445 (males: 2,069,309; females: 2,043,136, NPC, 2006). The capital city is Asaba, located at the northern end of the state, with an estimated area of 762 square kilometers (294 Km^2), while Warri is the economic nerve center of the state and also the most populated located in the southern end of the state. The state has a total land area of 16,842 square kilometers (6,503 Km^2).The major towns in Delta State include: Agbor, Ughelli, Oleh, Ozoro, Oghara, Sapele, Koko, Burutu, Okpanam and Ogwashi-ukwu.

Delta State unlike other areas in South-south enjoys tropical climate which is marked by two distinct seasons, the dry and rainy season. The length of rainy season is throughout the year, although December to February does not have much rainfall with a total of 2000-3000 mm rainfall (Abegunde et al. 2001).The mean maximum temperature ranges from 24-27^{0C}. Delta State also has two peak periods of heavy rainfall in June to July and September to October with a brief dry spell in August commonly referred to as August break.

Delta State forms part of the gently low-lying lowland which is generally between 350-400 meters above sea level. The state has a wide coastal belt with rivulets and streams, which form part of the Niger-Delta. The vegetation comprises of the mangrove (salt water) swamp forest and fresh water swamp water forest and the rain forest. It is bounded to the South by a coastline of about 160 kilometers of the Atlantic Ocean. All the rivulets and streams drained to the river Niger to form the delta which its derived its name the Niger-Delta.

Socio-economic setting

Delta State is major oil producing state and ranked second to Rivers State. 35% of Nigeria's crude oil and some considerable amount of natural gas for refining locally and for export is supplied by Delta State. The oil producing local government areas in Delta State include: Warri North and South, Burutu, Isoko North and South, Ughelli North and South, Okpe, Ethiope East and West, Sapele and Ndokwa East and West. The nation's second refinery as well as petrochemical plant is located at Warri. The Delta state government is however making frantic effort efforts to diversify the state's revenue base from solely oil to non oil revenue base. Tourism and agricultural development are other areas which are main focus of the government in revenue generation. The state government has invested millions of naira in fisheries, agriculture, forestry, veterinary services, produce planning and research. Most local governments in the state boast of fisheries extension units which cater for advisory inputs - nets, engines ropes, lead, floats and others. Delta State is also rich in major tubers and root crops such as cassava, coco yams, yam and potatoes. There are programmes initiated to encourage agriculture in the state. These include Delta Agricultural Development Programme (DADP), Task Force on communal farming, Agricultural Loan schemes to small scale farmers; Fishermen Farm Settlement Scheme,

Tree Crop Unit and Livestock Production are also encouraged. Industries in Delta State include Glass Factory at Ughelli, the African Timber and Plywood Factory, Sapele and Asaba Textile Mills. There are several industries in the state participating primarily in the processing of raw materials such as rubber and timber, such as the African Timber and Plywood (AT&P) in Sapele, Asaba Textile Mill, Ughelli Glass Factory, Delta Boatyard, and Delta Steel Company,Ovwian Aladja (http://www.deltastate.gov.ng).There are various solid mineral deposits within state - industrial clay, silica, lignite, kaolin, tar sand, decorative rocks, limestone, etc. These are raw materials for industries such as brick making, ceramics, bottle manufacturing, glass manufacturing, chemical/insulators production, chalk manufacturing and sanitary wares, decorative stone cutting and quarrying.

Road Infrastructure

Delta state has two mode of transportation, the water transport along the coastal areas and the road transport in the hinterland. The road network comprises of 671.00Km of asphaltic concrete, 88.000Km of surface dressed stretched of road, 38.00 Km of gravel road making a total of 787+000Km of road network across the state (Table 1).

Rivers State

Physical setting

Portharcourt is a metropolitan city and capital of Rivers state, occupying approximately 1811.6 km2 area, with a population of about 1.5 million (kio-lowson and Dekor 2014). Portharcourt state's main city and has one of the largest seaports in the Niger Delta region, thus being the center of administration, commerce, and industrial activities (Weli and Efe 2015). It is situated between Latitude 4^0 and 45^0 N and 4^055^0 N, and Longitude 6^055^0 E and 7^05^0 E. occupying the

entrance of the Bonny river The city is bounded in the north by Abia and Imo states; east by Akwa-Ibom state; west by Bayelsa state; and, south by the Atlantic Ocean. Its estimated mean altitude is 300-400m above sea level, lying between the Dockyard creek/Bonny River and the Amadi creek.

Rivers State undergoes two distinct seasons they include dry and rainy seasons. The duration of rainy season is usually longer due to its closeness to atlantic ocean where the tropical maritime air originate from and its span through 12 months with a little break in august and this depict the two maximum pattern of rainfall in the area. Mean maximum and minimum temperatures are approximately 34^0C and 21^0C, respectively the months of April through October having the highest temperatures. Like other Nigerian States, the interaction between two major pressures and wind producing systems (tropical dry continental and tropical maritme air) drives the entire weather system in Rivers State.

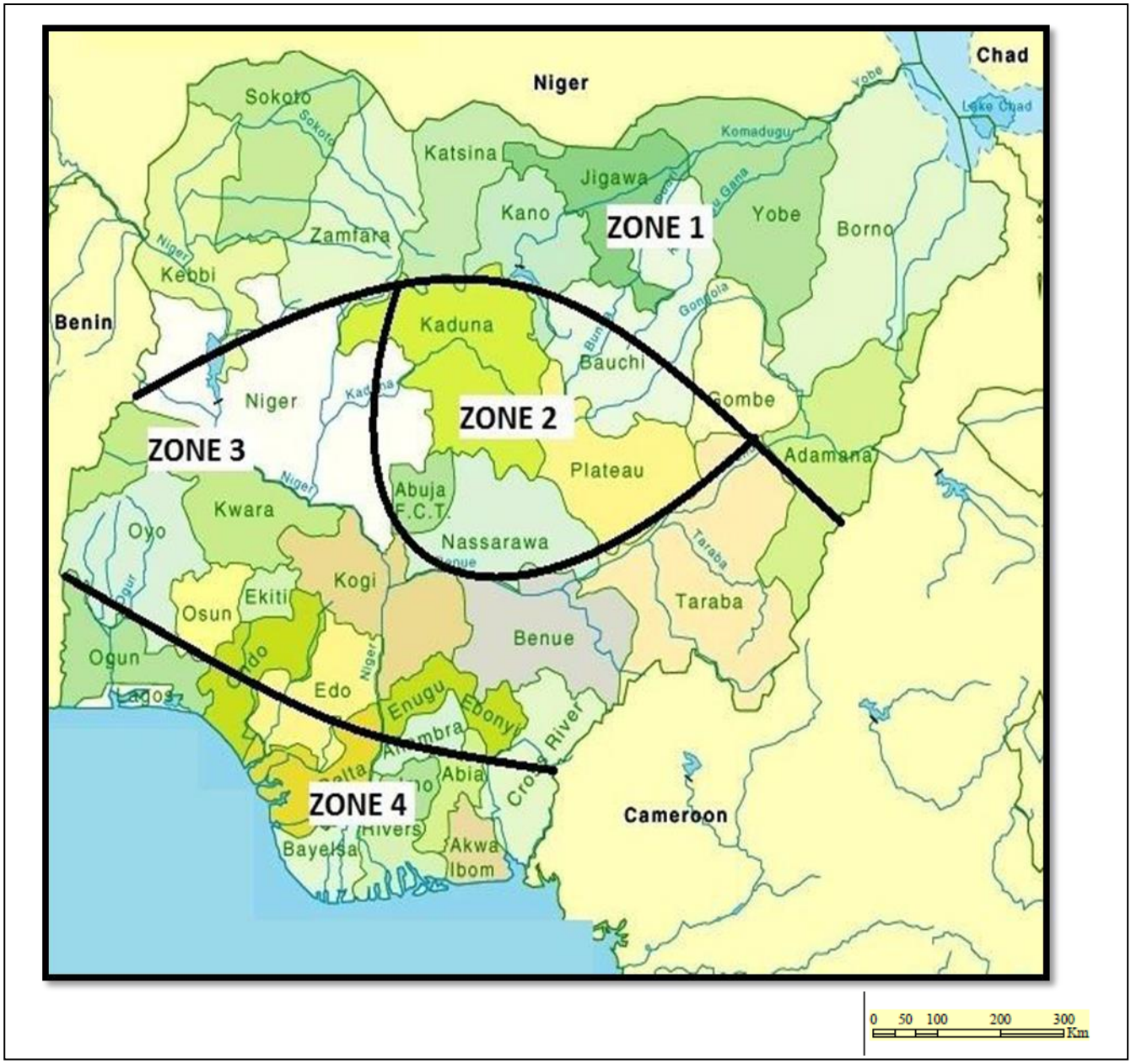


Figure 1: Morphoclimatic Zones in Nigeria.

Note: Zone 1: Hot Dry; Zone 2: Temperate Dry; Zone 3: Hot humid; Zone 4: Warm humid;
Source: Highway Manuals, (2013).

Table 1: Types of Roads and Mileages covered in Nigeria

S/NO	STATE	ASPHALTIC CONCRETE (KM)	SURFACE DRESSED (KM)	GRAVEL OR EARTH (KM)	TOTAL LENGTH (KM)
1	ABIA	376.00	343.00	29.00	748.00
2	ADAMAWA	610.00	203.00	390.00	1,203.00
3	AKWA-IBOM	293.50	204.00	40.00	537.50
4	ANAMBRA	338.90	131.00	34.00	503.90
5	BAUCHHI	1,228.00	244.00	342.00	1,814.00
6	BENUE	28.00	299.00	205.00	1,162.00
7	BORNO	1,036.00	358.00	787.00	2,181.00
8	C/RIVER	740.30	193.00	145.00	1,083.30
9	DELTA	671.00	88.00	38.00	787.00
10	EDO	749.00	101.00	-	850.00
11	ENUGU	491.40	380.00	90.00	919.50
12	IMO	308.00	198.00	5.00	511.00
13	JIGAWA	391.00	66.00	72.00	728.00
14	KADUNA	1,436.00	150.00	8.00	1,594.00
15	KANO	720.00	165.00	-	885.00
16	KATSINA	495.00	292.00	55.00	842.00
17	KEBBI	248.40	307.00	286.00	841.00
18	KOGI	500.00	444.00	232.00	1,173.00
19	KWARA	348.00	290.00	385.00	1,023.00
20	LAGOS	438.66	-	-	438.66
21	NIGER	909.00	743.00	396.00	2,048.00
22	OGUN	983.00	190.00	-	1,173.00
23	ONDO	783.00	269.00	35.00	1,042.00
24	OSUN	271.20	138.00	-	438.70
25	OYO	846.50	138.00	266.00	885.20
26	PLATEAU	411.00	388.50	560.00	1,795.00
27	RIVERS	356.00	157.00	74.70	642.70
28	SOKOTO	566.00	772.00	547.00	1,675.00
29	TARABA	343.00	356.00	656.00	1,578.00
30	YOBE	158.00	335.00	152.00	830.00
31	ABUJA	300.50	58.60	20.00	379.10

Source: Nwariaku (2009).

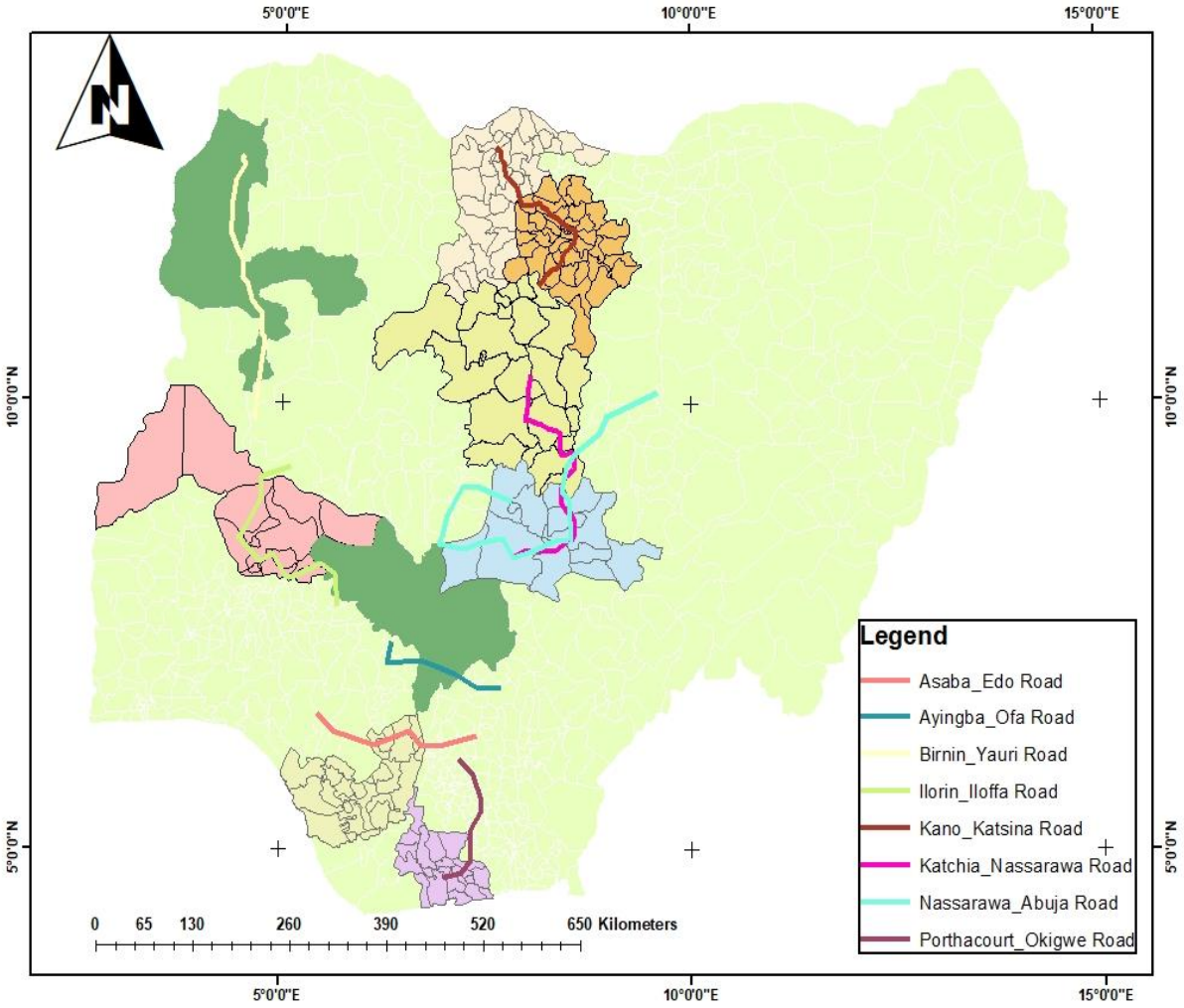


Figure.2 Map of the study areas and the roads network.
Source: www.googlemap.com

CHAPTER TWO

CONCEPTS, THEORIES AND REVIEW OF LITERATURE

2.1 Conceptual Framework

There are some basic concepts that are used in this research work based on the scope of the study; these concepts are operationalised as follows:

2.1.1 Morphoclimate

Morphoclimate is a concept in geomorphology that investigates the influence of present-day and past climate on morphogenetic processes and landforms, including their spatial and temporal distribution and the control of climatic parameters on the rates at which processes operate and landforms change. The concept of morphoclimate started during the period of European colonial expansion and exploration at the end of the nineteenth century, when peculiar landforms endemic of certain climatic environments like deserts, Polar Regions or the humid tropics, where encountered (Goudie, 2004; Gutiérrez, 2005). This period necessitated the classification of regions.

2.1.2 Morphoclimatic Zone

Troll (1944) introduced the concept of zonation in climatic geomorphology (morphoclimate). The term zonal applies to those processes or features whose geographical distribution occurs in latitudinal bands roughly parallel to the Equator, such as the equatorial forests, coral reefs and inland ice caps. Tricart and Cailleux (1965) classified morphoclimatic zones based on two main criteria which include: the large climatic and biogeographic areas that define the main zonal boundaries and some climatic and biogeographic subdivision combined with palaeoclimatic differences. In an attempt to divide the world into regions several authors divided the world into

morphoclimatic zones with distinctive processes and landform assemblages (Tricart and Cailleux, 1965; Budel, 1977). The division of the Earth surface into different morphoclimatic zones has always been a complex and controversial task. However, the main review on morphoclimatic zones in maps is those by Budel (1948, 1963, and 1977) and Tricart and Cailleux (1965). The concepts Morphoclimatic zonation explores how climatic factors such as the intensity, frequency and duration of precipitation, frost intensity, direction and power of wind, control the development of landscapes (Anhert, 1996). The relationship between climate and geomorphic systems is receiving a renewed attention due to the human-induced global warming and the predicted rapid changes in temperature and precipitation (IPCC, 2007). These two criteria are further sub divided in the following areas

i. **Cold Zone.**

a. Glacier domain.

b. Periglacial domain.

ii. **Mid-latitude Forest Zone**.

a. Maritime domain with relict Quaternary glacial and periglacial landforms.

b. Continental domain with Quaternary and present-day ice caps and the possible occurrence of permafrost.

c. Mediterranean domain with a smaller influence of relict quaternary landforms.

iii. **Arid and subarid zones**.

They are divided based on: Moisture deficit in xerophitic bush-land steppes, deserts and Temperature of cold and warm areas.

iv. **Humid intertropical zone**

a. Savannah domain, with sparse vegetation cover, intense chemical weathering although discontinuous over the time, and occurrence of significant overland flow events.

b. Forest domain, with dense vegetation covers an intense chemical weathering.

2.2 Structure of Road foundation

Road foundation consist of several structures namely: sub grade materials, subase materials, granular, surface and base course and the final structure whch is pavement course made up of asphaltic overlay. All these structures are mechanically treated and compressed one after the other to give the desirable strength for vehicular movement. Road foundation vary according to standard specification for instance in Nigerian road pavement are constructed to meet the standard specification of the Federal Ministry of works and housing (1994; 1997) to pass all the specified standard for labouratory and construction.

(i) Subgrada is a native material underneath a constructed road pavement or railway track.It is also called formation level. Subgrade is also used to refer to refer to imported materials that have been used to build embarkment. It is made up of native soils that has been compacted to withstand the load above it .It is a leyer required in many structure such as pavement and slabs.The subgrade has the capacity to absorb any weighted or load or stress coming from above layer. Road subgrade consist of earthly materials and it form the base upon which other foundation materials are laid. The nature of subgrade determines the performance of road pavements Figure 3 shows a typical structure of road pavement. According to Thagesen (1996) subgrade is the untreated natural soil acting as foundation for the pavement. It is an undisturbed local soil material excavated elsewhere

and placed as a fill where subgrades are considered for road foundation. The greater the resistance to deformation a subgrade shows the more the load it can support before reaching a critical deformation of geomorphic unit (Ekeocha and Egesi 2014).

(ii) Subbase is the layer of aggregate materials laid on the subgrade on which the base course layers are laid. It is the main load bearing layer of the pavement. The Subbase consists of three layers namely: subbase course, granula base course and surface course.

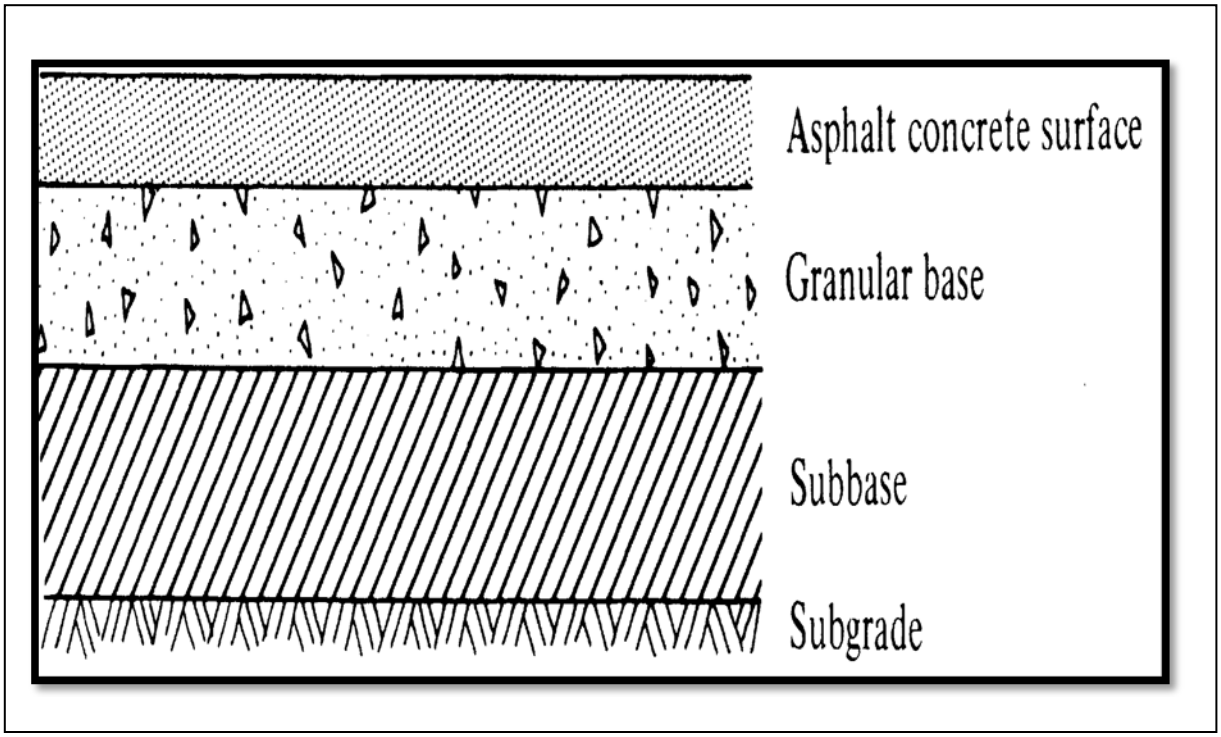


Figure.3: A typical Structure of a road foundation
Source: Garber & Hoel, 200**9)**

(iii) Subbase Course This layer is above the subgrade. It is made up of high quality materials compared to sub grade. The selection of subbase materials is made of high quality materials. Most often, subbase component of road may be omitted when subgrade

is considered to be of high quality material. Where subbase material is not available, other materials can be treated to improve on the subgrade quality. (O'Flaherty 2001; Rogers 2003; Garber and Hoel 2009). In a situation where the sub base materials are not readily available, the available materials can be treated with other materials to improve on sub grade quality. Stabilization material such as laterite are used in this act due to its good and abundance in West Africa and it is widely used as subbase course material for construction of roads (Ekwulo and Eme, 2013).The subbase material is usually the major structural element in road pavement. It is often referred to as supporting soil in pavement because of its comparatively thick highly stable layer which is stabilized mechanically to withstand high stress. It is a major load carrying component of flexible pavement (Schroeder and Dickenson, 1996; Hijab *et al*, 2012).

(iv) Base Course (Granular base) This layer in a flexible road pavement is above the subbase. It is sometimes placed immediately above the subgrade. This course usually consists of granular materials such as crushed stones, crushed or uncrushed slag, crushed or uncrushed gravel and sand. The specification for the base course requires stricter adherent to engineering construction guide particularly in respect to strength and gradation characteristics (Thagesen, 1996; Garber and Hoel 2009).In some instances where materials for sub base course are not available or do not meet the required properties, portland asphalt or lime can be used to improve the stiffness characteristics of base course in order to meet the required road construction specification.

(v) Surface Course The surface course is the final and upper course of road pavement laid above the surface base course in a road pavement. It consists of a mixture of mineral

aggregates and asphalt. Surface course or road base is constructed to withstand high tire pressure, resisting abrasive forces due to traffic loading providing a skid-resistant driving surface and preventing the penetration of surface water into underlying layers (O'Flaherty, 2001;Garber and Hoel ,2009). According to Thagesen (1996), it is the main structural layer whose main function is to withstand the applied wheel stresses and strains incident on it and distribute them in such manner that sub base materials beneath do not become overloaded. The thickness of the base course can vary from 3 inches to more than 6 inches depending on the expected traffic axle load. According to O'Flaherty (2001), a typical flexible pavement for a low-volume vehicle should be between 150-250mm thicknesses of asphalt overlay or bituminous materials of the surface course. The essence of stabilizing the surface course of the road pavement with asphalt or bituminous materials is to give the road the desired strength, prevent the surface from geomorphic events such as erosion and to withstand other forms of road failure that may occur.

2.2.1 Road Failure

According to Highway Research Board (HRB,1970) cited by Malaysian University Transportation Research Forum and Conference(MUTRFC,2009) pavement failure or distress is any situation experience when there is an indication of poor or unfavourable pavement performance or signs of impending failure, or any unsatisfactory performance of a pavement. A road is said to have failed when it is no longer able to absorb and transmit the wheel loading through the fabric of the road without causing fairly rapid further deterioration of the road (Hijab, et al. 2012). Road pavement failure is a very common phenomenon on Nigerian roads. Road get deteriorated after few years of performance and most often before attaining the

designed age. Pavement failure can either be functional (surface pavement failure) or structural (deep-seated pavement failure) (Akintorinwa, et'al 2011). The structural failure describes the pavement structure incapable of carrying the traffic loads imposed, while functional failure describes pavement structure incapable of carrying out their function at the intended serviceability thereby causing discomfort to passengers or high stress to vehicle given it excessive roughness (Latif, 2009). A road pavement deteriorates under combined actions of traffic loading and environmental factors thus reducing quality of ride (Haas et al 1994).

Nurul, et al. (2010) identified two causes of pavement failure: internal and external pavement failure. The internal failure of pavement occurs due to poor pavement mixture, weakness of component materials and poor construction, while external failure of pavement occurs due to overloading, diesel spillage, flooding, sink holes and other natural causes such as earthquake and volcanoes. In the same vein, Rani, (2007) categorises flexible pavement failure into four these are surface deformation, surface defects, cracking, patching and potholes. However, other factors which influence road pavement failure include: geological, geomorphological, geotechnical, design, materials, poor construction practices and maintenance and usage factors.

2.2.2 Road Physical Condition

Road physical condition can be described in terms of road roughness or smoothness. Road roughness refers to an expression of irregularities in the longitudinal profile of pavement surface that adversely affects the ride quality of vehicles, thus causing discomfort to users (Sayer and Karamihas, 1998). Garber and Hoe, (2009) defined pavement roughness as irregularities in the pavement surface that affects the smoothness of the ride. According to the American Society of Testing Materials (ASTM, 2005), road roughness is the deviation of a surface from a true

planned surface with a characteristic dimension that affects vehicle ride quality, dynamic load and drainage. For example, longitudinal profile, transverse profile and cross slope, while road smoothness describes the opposite which is regarded as being perfect in terms of comfort and safe for road users. Roughness is an important factor in pavement characteristics because it affects ride quality, causes vehicle delay, fuel consumption and maintenance cost of vehicles.

Basically, pavement roughness can be measured subjectively or objectively. In subjective measurement using Present Serviceability Index (PSI), a set of road users can be asked to rate the riding quality of road based on a scale 0-5 on ASTM standard, while the objective measurement of roughness is indicated in terms of cumulative measure of vertical displacement as recorded by a recording wheel due to the unevenness of the longitudinal profile of the road. The unevenness of the road can be measured in terms of roughness index (Garber and Hoel, 2009; Rousan et'al, 2010; Subagio et'al, 2013). The need for a smoother road cannot be overemphasized because a smooth road provides quality ride, comfort and safety for road users. It reduces the operating cost of vehicle, fuel consumption, tire wear and maintenance. Furthermore, it reduces road crashes and it enhances smooth ride for vehicle.

2.2.3 Climate and Road foundation Failure

Climate largely influences pavement construction, maintenance and failure. According to Willway, *et al.* (2008), past climate records are used to plan construction and maintenance activities. With the trend in the changing climate, construction of new high way must be designed to meet a normal design of a life span up to 20years. Subsequently, there should be the need for periodic replacement of surface course that have experienced failure or complete replacement of surface course after 10-20years.The extent to which climate affect the pavement

also depend on many other factors such as the characteristics of pavement (materials, structure and condition), traffic, underlying Geology and Geography (Willway et al, 2008). Francoise and Hande, (2012) observed that road pavement also deteriorate as a result of traffic load together with weather condition.

Similarly, Jo Sias, et al (2014) opined that changing climate can impact the properties of the pavement layer making them susceptible to accelerated damage under traffic loading reducing their serviceable life-span and increasing maintenance cost. Road pavement failure may also occur as a result of the intrusion of moisture due to extreme precipitation. Khosla, et al (1999) pointed out that pavement failure due to moisture damage starts at the bottom of an asphalt layer or at the interface of the two layers which could lead to the emergence of potholes or pavement ravel or ruts. Water intrusion to this water- damaged area coupled with traffic loading further degrades the structural integrity of pavement layer and possibly the underlying layer which, if not repaired, can lead to substantial localized failure of pavement structure.

2.3 Theoretical Framework

2.3.1 Theory of Road Hierarchies

According to Eppel, et al (2001) a road hierarchy is a means of defining each roadway in terms of its function such that appropriate objectives for that roadway can be set and appropriate design criteria can be implemented. These objectives and design criteria are aimed at achieving an efficient road system whereby conflicts between the roadway and the adjacent land use are minimised and the appropriate level of interaction between the roadway and land use is permitted. Eppell and Zwart (1997) revealed that the notion of hierarchy is deeply embedded within the planning of transport networks. One of the key aims of road hierarchy is to optimize

accessibility, connectivity, amenity and safety for all road users including motor vehicles, bicycles pedestrians, and public transport patrons. To do so, the relationship between road hierarchy and the land uses serves needs to be considered. Eppell and Durham, (1989) developed a four level road hierarchy for Network Planning and Management they include: Purpose, Function, Management and Design.

(i.) Purpose: Traffic volume on a roadway is proportional to the number of destination meant to serve. The relationships between the importance of the access function, the traffic carrying function and the number of destination served. The greater number of accessibility, the greater need there is for a roadway to serve a traffic carrying purpose. Table 2 below shows a four level road hierarchy framework which has been developed by Eppell et'al (2001). In level 1 of the road hierarchy defined the basic purposes of road network as follow:

(a)Roads – to carry through traffic, serving a longer distance purpose;

(b) **Streets** – to provide access to properties and local areas.

(ii) Function: Within the two broad groups of roads and streets, the functions of roadways vary depending on the land use type. This has necessitated the identification of four functional categories of road net work which are enumerated below:

(a) **Arterial roads** – to carry long distance through traffic external to specific areas;

(b) Sub arterial roads – to carry through traffic between specific areas and arterial roads on a supporting role to the latter;

(c) Collector streets – to provide connectivity between the environmental cells and the traffic carrying road; and

(d) **Local streets** – to provide direct property access.

(iii) Management: Road hierarchy plans form the basis for the roadway management and planning initiatives of government and proper instruments in the legislation on road design. The designation of a roadway in a particular category is useful only when there are complementary management policies to implement the designation. In other words, there must be a means to achieve the road hierarchy plan. These management policies form the third level of the hierarchy. Levels 1 and 2 of the hierarchy framework derive purely from functional considerations. It is these levels of the road hierarchy that are traditionally used to assist in planning the road network and the land use that is serves. Ideally, within each category of level 2, all roadways would be treated in the same manner. Whilst this may be achievable in a new design, often an existing situation or other constraint may dictate that a variety of treatments may need to be available. These situations may arise for a number of reasons, not the least of which is the mixture of access and traffic functions already prevalent on many roadways. Level 3 includes management sub categories within each of the four classifications of function which relate to more particular attributes of the roadway. It is this level of the hierarchy that fulfills the road management role. For each sub category, Table 2 addresses objectives that are more specific than level 2. Section 6 discusses this most innovative level of the hierarchy in detail.

(iv) Design: The fourth level of the hierarchy framework relates to specific design criteria that are applicable to each road. These design criteria should be developed using relevant documents, including local government development guidelines, state guidelines and national guidelines network and the land use that is serves. Ideally, within each category of level 2, all roadways would be treated in the same manner. Roads are arranged in different categories (hierarchies)

based on its uses, importance, purpose and functions as described by epell, *et al* (2001). Road transport infrastructure is a kind of infrastructure that determines the development of a region. It is the spillover effects of infrastructural investment on economic growth in the region which does not only affect them but also has impact on the surrounding areas or neighbors (Calderon and Serven, 2004). Road infrastructure opens up more places because the more the road networks, the more open the area for social economic activities and the interconnectivity between one or more areas.However, designs and construction guidelines vary from one country to another for instance in Nigeria roads are construction to standard specification according to FMW&H,(1997).

Table 2: Four levels of a road Hierarchy

<table>
<tr><th colspan="10">LEVEL 1: PURPOSE</th></tr>
<tr><th colspan="5">ROAD</th><th colspan="5">STREET</th></tr>
<tr><td colspan="5">• To carry through traffic</td><td colspan="5">• To provide local property access
• To collect local traffic</td></tr>
<tr><th colspan="10">LEVEL 2: FUNCTION</th></tr>
<tr><th colspan="3">ARTERIAL ROAD</th><th colspan="3">SUB ARTERIAL ROAD</th><th colspan="2">COLLECTOR STREET</th><th colspan="2">LOCAL STREET</th></tr>
<tr><td colspan="3">• Through traffic movements
• Longer distance traffic
• Movements
• Line haul public transport
• task
• Primary freight and dangerous
• goods routes</td><td colspan="3">• Connections between local
• areas and arterial roads
• Connections for through traffic between arterial roads
• access to public transport
• Through movement of public transport
• Regional – local cycle movement (off road)
• Pedestrian movement</td><td colspan="2">• carry traffic having a trip end within the specific area
• direct access to properties
• access to public transport
• pedestrian movements
• local cycle movements</td><td colspan="2">• Direct access to properties
• Pedestrian movements
• local cycle movements</td></tr>
<tr><th colspan="10">LEVEL 3: MANAGEMT</th></tr>
<tr><td colspan="10">The aim of management policies for these categories will be to facilitate</td></tr>
<tr><td>• Longer distance traffic movement
• Regionally and nationally significant movement</td><td>• Longer distance traffic movement</td><td>• Longer distance traffic movements
• Access to commercial properties</td><td>• Connection of local areas to arterial roads</td><td>• Connection of local areas to arterial roads
• Access to properties (certain existing cases). Treatment may control some local aspect of operation to ameliorate impacts</td><td>• Connection of local areas to arterial roads
• Access to commercial properties. Treatment may involve preservation of local amenity in balance with traffic operation</td><td>• Connection of residential streets with traffic carrying roads
• Access to grouped, commercial properties and community facilities</td><td>• Connection of residential streets with traffic carrying roads
• Access to individual adjacent properties</td><td>• Access to individual to adjacent properties
• Access to local area</td><td>• Access to individual adjacent properties</td></tr>
<tr><th colspan="10">LEVEL 4: DESIGN</th></tr>
<tr><td colspan="10">• According to relevant guidelines and codes including council subdivision guidelines, AUSTROADS Guides, Queensland Street, AMCORD, Australian Standards</td></tr>
</table>

Source: Eppell, et *al* (2001).

2.3.2 Models of Road Failure studies in Nigeria

Adebayo, et al. (2012) developed a model to explain performance of a typical flexible road pavement in Nigeria. The model emphasized that deterioration process of road pavement is a continuous process over time and road condition is rated according to scale. This model include: Pavement Condition Index (PCI), Present Serviceability Index Rating (PSR), and International Roughness Index (IRI). This model has been applied to Nigerian roads (Lagos and Ibadan express way), and some major cities in Nigeria. The study also presented an index for Pavement Condition Rating (PCR). Thus, if a road condition is rated 80-100% it can be regarded as excellent, 65-75% very good, 55-64% good, 45-54% fair, 35-44% poor and 1-34% unacceptable. The model attempted rating of quality of road pavements.

Ekwulo and Eme (2013) also developed regression equation model to establish a relationship between expected traffic pavement loading and pavement thickness, rutting and fatigue. The study concluded that, there exists a close relationship between expected traffic loading and pavement thickness and fatigue strain and pavement thickness and rutting strain

Eluzo (2013) developed a mathematical model to exhibit an approach that can precisely predict the resilient modulus on bituminous mixtures that influence the causes of pavement failure. The model concluded that road deformation is proportional to the applied load (high traffic load) which are considered as a major factor responsible for most pavement failure.

2.4.0 LITERATURE REVIEW

Studies of road failures in Nigeria have mostly concentrated on the use of geophysical and geotechnical apprpoaches with little or no emphasis on the influence of climate on road failure.

2.4.1 Studies on geotechnical methods.

Okechukwu and Celestine (2011) while conducting geotechnical assessment of road failure in Abakaliki area in South-Eastern Nigeria. The recorded a lot of road defects problems associated with foundation materials. The study showed that, medium to high values of liquid limit (LL), plasticity index (PI) and Maximum Dry Density (MDD) values compared to other parts of the Asu River with shale composition which have LL less than 40% and PI less than 20%. A situation which suggests that, the shale contains clay materials which are considered poor foundation materials. The study also identified the occurrences of illite and smecitetite/illite mixed layer clay minerals in some areas. The shale samples identified were classified as A-7-6 according to American Association of State Highway and Transport Official (AASHTO) and CH according to Unified Soil Classification system (USCS). Analytical results showed that soils samples recorded appreciable linear shrinkage value of 18-22% which showed it's higher than other shale recorded in Nigeria. Maximum Dry Density (MDD) and California Bearing Ratio (CBR) showed relatively high content of clay. This implies that, road is founded on poor foundation materials. However, the study also observed relatively scarce construction materials and wide coverage of Abakaliki area by shale. This has resulted in the utilisation of shale formation in all components of highway pavements (i.e. subgrade, sub-base and base course) materials in this zone. The analytical results classified the foundation materials as CH soils

which are associated with poor compaction characteristics, very high compressibility and expansion, poor to very poor value as pavement subgrade which is responsible for road failure problems encountered in this road corridor.

Alayaki (2012) studied water absorption properties of lateritic soils in road pavement along Ife-Ilesha highway, south western Nigeria. The study was divided into two: the stable and unstable parts. More than 60% of the soil samples were classified as inorganic sandy clays of low to medium plasticity (CL) and inorganic micaceous silty soil (MH). Correlation and regression models were established and it showed that a positive linear correlation exists between clay content and natural moisture content. There was also positive correlation with high significant value between shrinkage limit and liquid limit (LL), and between shrinkage limit and plasticity index (IP). On the other hand, these results however agreed with that of a similar study reported by Gidigasu (1976). This positive correlation(R=0.826 and R=0.939) showed that, the higher the clay content, the higher the water contents. This phenomenon was as well explained in a study by McCarthy (2007) that the surface of clay particles has a net negative electrical charge and the edges have positive and negative charges, as a result of their molecular grouping and ions arrangement. The study further concluded the non-availability of side drains to take-out surface run-off after each rainfall events as responsible for direct increase of water below pavement. This phenomenon further contributed to instability of road which invariably leads to further erosion of road shoulders as well as defects on pavement structures resulting to deformation such as cracks, potholes among other road pavement failures.

Ifabiyi and Kekere (2013) in a study of road failure along Ilorin-Ajase-Ipo Road Kwara State observed failure of road pavement was due to the presence of high level of clay content, especially montmonillonite clay type of the ratio 2:1, most of which were found on unstable portions on the road. Results from the analysed soil samples from the foundation showed that, moisture content of stable and unstable portion ranges from 10-14% and 11-12%, plasticity 17-26% and 18-24% respectively. The study found out that foundation materials were characterized by clayey soils of intermediate plasticity (CI) and clay soil of high plasticity (CH) which are recorded in both unstable and stable foundation of the road. This is responsible for the consistent failure rate of the road even when maintenance is carried out. The study also reported poor engineering construction as part of the problem s of road failure along the road corridor. The study reported that, pavement structure of the road did not meet the required standard specification for flexible pavement of road construction in Nigeria.The IN SITU measurement showed that the pavement measures 45mm which falls far below 150-250mm, according to British specification. . In addition, they observed that, some portions of the road were founded on sandy soils which could not enhance a good compaction and the absence of side drainage facility which were absent in greater parts of the road and where drainages were provided it was blocked by sediments.

Bayewu and Adewoye (2013) investigated permeability characteristics of some sub-grade along part of the Sagamu-Ore high way in South Western Nigeria. The study was also divided into two (2) parts: the stable and unstable segments. The study observed that Liquid Limit (LL) ranges between 26.5-44% and plasticity index (IP) 9.95-18-95%.This empirical analysis maintained the

maximum recommended value of tropical soils in the stable locations of the road. However, results from the unstable portion of the road indicated that values derived from the test showed an abnormal range of result, which exceeded the normal requirements. Hence, it was unstable and this could enhance pavement failure on the road corridor. Secondly, soils found in the unstable location was made up of fines (clay and silt) which were likely to have poorer geotechnical properties of the highway sub grade; this explains the failure observed in the unstable location of the Sagamu highway.

Hijab, *et al. (*2012) studied road pavement failure induced by poor soil properties along Gombi-Biu highway Nigeria. The soil samples were classified according to America Association of State Highway and Transport Officials (AASTHTO) as A samples (A-2-6) for base and A-2(A-2-4) for subbase. These indicated that soils ranges from fine sand silt or clayey gravel and sand. Empirical analysis showed that liquid limit (LL) and plasticity index (PI) were greater than 35% and 12%, suggesting that subbase materials of the foundation were mainly inorganic clay moisture content. Value presented were 7.0-17.7%, 5.1-15.9% and 6.9-13.4% suggesting moisture content being normal, while the Maximum Dry Density (MDD) suggested low compaction rates which could be responsible for failure such as rutting, potholes and other geomorphic events. The study concluded that foundation materials were sub-standard and the road did not conform to the required standard specification (Federal Ministry of Works and Housing FMWH, 1970).

Akintorinwa and Olorunfemi (2011) carried out a comparative analysis on the causes of pavement failure along the Ilesa-Akure highway in southwestern Nigeria using remotely sensed

and geotechnical data. Results for geotechnical analysis suggested that moisture content (4-31%) from the stable segments of the road were controlled and classified as stable, while the failed segment indicated 4-28%. Soil classification ranges from A-4 to A-7(AASHTO) which can be regarded as poor subgrade high way materials. Similarly, liquid limit (LL) for stable and failed portions ranges from 24-55% and 20-66% and 10-41% for Plastic Limit (PL), while the compaction characteristics of stable and unstable segment presented were 7-28% and 10-20% for Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), which equally presented poor compaction characteristics and California Bearing Ratio (CBR). Values for both segments ranges from 38-35% for stable segment. This can be referred as normal for stable segment. For failed segment, it ranges between 20-70% and 25-84% which was regarded as being high. This explained the reasons for the failed segment of the road with poor sub-grade soils capable of causing perpetual failure.

2.4.2 Studies on geophysical methods.

Aigbedion (2007) investigated road failure using electromagnetic profiling along Opoji, Uwenlenbo and Illeh in Ekpoma, Nigeria. The study was divided into two sections: the stable and unstable sections. The study revealed that profile 1 along Ipoji road recorded fairly stable condition from 0 – 70m, while on profile 2 he observed that 0 – 36m is stable and non – conductive, while 40 – 116m have fairly stable road and nonconductive zone. However, the study concluded that the failed portion of the road could not be linked to the geologic materials alone but other factors such as the absence of drainage facilities and qualities of materials used for construction. These are also the reasons why the unstable parts of the road experience failure.

Adiat, et *al* (2009) examined the relevance of geophysics in a study of road investigation in a typical Basement Complex in Western Nigeria. The study identified four (4) subsurface layers, which include: top soil, the sand, literite sand, the weathered layer and fresh basement. The study observed that the clayey nature of the top soil/subgrade soil thickness ranges between 88–553/ohm which the road pavement is founded retains water without releasing it. As a result, swells occur on the road surface and the exertion of pressure from vehicular movement subsequently causes the road to experience failure. Secondly, the study observed some faulty, fractured zone, fissures and joint which create structurally weak zone that enhance ground water accumulation and hence pavement failure and absence of drainage causing ponding or pool of water to accumulate on the road.

Akintorinwa, *et al* (2010) investigated pavement failure in a basement complex terrain along Ilesa–Akure high way, South–Western Nigeria. The study observed that failed segment of the road 1-10 consist of both top soil and the sub-soil in the upper zone 0–8m were clayey with characteristics of low resistivity value less than 100/ohm-m. The result showed that this soil type absorbs water, swells and collapses under imposed traffic load stress and thereby leading to pavement failure. Secondly, geological features such as faults, fracture, and lithological contacts beneath the high way pavement. This feature act as zone of weakness which also enhances the accumulation of water which is capable of causing unstability on the road pavement on the road investigated.

Emujakporue (2012) investigated the causes of high failures in Niger Delta sedimentary Basement in the eastern part of Nigeria. The study was carried out in six (6) locations along Port

Harcourt high way. Out of the six (6) points identified 3 portions were in stable conditions, while the other four portions failed. Results in the study showed that the failed portions were highly associated with low resistivity value and they were mainly due to the presence of high clay content in the sub–grade at different depths. This unstable seasonal behaviour of clay makes pavement to lose its integrity within a short time after construction and this leads to the deteriorating nature of the road. The study employed the soil profile to analyse the road foundation materials. The top soil layer is characterised with clay to sandy silt with resistivity value varies between 28.8ohm-m at VES 2. (Failed portion) and 348.47-m at VES 6(stable section). The value recorded is lower than the stable portion. This indicated that failed segment possesses clay materials which was capable of causing road failure at the unstable segment. The second layer presented resistivity value of between 108.1/ohm-m at VES 4 and 1247.9/ohm-m at VES 6 for stable and unstable portion of the road. The low resistivity value recorded in the unstable portions of road is also an indication that the segment is made of clay and silt, sand constituent, soil materials which could be responsible for the failure. The third layer has a resistivity value of 237.5/ohm-m at VES 4 to 2997.2/ohm-m at VES 6. The layer is made of fine medium sand. And this segment is considered stable because the value is greater than value obtained in other failed portions. The fourth layer has a resistivity value of between 418ohm-m and 1419.08/ohm-m. This layer according to the results is made up of coarse sand in the failed portions that is why it is considered as failed portions because the value is less than the stable portion and the coarse sand which has low compaction rate and contributed to the failure of the

unstable segment and the fifth layer has a resistivity value between 511.3/ohm-m to 921.05/ohms-m which is considered stable.

Adeyemo and Omusuyi (2012) reported geophysical investigation of road pavement instability along the part of Akure-Owo road, southwestern Nigeria. The study sampled 10 portions from Oloko junction to Owo and further divided these points into two 5 points stable and 5 unstable points. It used soil profiling to examine both the stable and unstable segments. The two segments showed conductive zones at distances of 240m and 350-360m which are indicative of fractured zone or conductive clay materials. The 2-D geoelectric section showed a bedrock depressions at a distance 80-160/m(stable segment) and 240-360/m (unstable segment) while the bedrock fractured was delineated beneath VES point 1,3,5 and 10 corresponding distances of 0,80/m,160/m and 400/m, respectively. The topsoil resistivity value varies from 83-865/ohm-m while resistivity in the weathered layer materials ranges from 182-1139/ohm-m along the stable segment and 27-262/ohm-m along the unstable segment. Therefore, the low resistivity value observed beneath the unstable segment is as a result of typical expansive clay present. Thus, the instability of the road pavement along the studied portion of the road is probably precipitated by the presence of near surface bedrock depression occupied by low resistivity weathered materials typical of expansive clay and sandy clay which are unsuitable and very poor construction materials for construction. These soil materials are capable of causing road failure along the unstable segment of the road under investigation according to the study.

2.5 Soils for Road Construction

Soil is a major component of the environmental system and it is derived from rocks by physical, chemical and biological processes (Faniran and Areola, 1978, Ogidiolu, 2003). Soil is one of the major earth resources with a lot of potentials. Ahn (1970) described soil as the basis of human civilization. It supports plant life and provides nutrition for man and his livestock. Soils studies cut across various disciplines such as: Geography, Agriculture, Biology, and Engineering, among others. Geography or pedology is concerned with the distribution, pattern, and use and soil sustainability. Engineers view soil as construction materials that vary widely in its physical composition and behaviour from location to location. Soils are further subjected to various tests by geotechnical engineers to enhance sustainability of engineering structures. However, problem soils have been a major concern to engineers, particularly for the purpose of construction of infrastructural facilities such as roads, dams, bridges, and houses to mention but few. Soils, which are normally refered to as foundation are exposed to problems, soils may result to reduction in the life span of facilities (Menasseh and Olufemi, 2008). Rezae et al (2012) posited that there are various types of problem soils but three basic ones are noted in engineering construction. They include: expansive, disperse and collapsible soils.

i. **Expansive Soils**

Expansive soil types undergo slow volume changes. When in contact with water content that occurs independently, it can lead to swelling and shrinkage which give rise to ground movement which can cause damage to low-rise building that does not have sufficient weight to resist (Bell,2007;Yenes *et al* 2010;Ozer *et al,* 2011). Expansive soils cause swelling due to the

presence of swelling clay minerals such as montmorrillonite content. The swelling is governed by initial moisture content, void ratio and vertical stress as well as the amount and type of clay minerals.

ii. **Dispersive Soils**

Dispersion occurs in soils when the repulsive forces between clay particle exceeds the attractive forces, thus bringing about deflocculating so that, in the presence of relatively pure water, the particle repel each other to form colloidal suspension (Umesh *et al*, 2011).The more disperse the soil system is, the greater the swelling (Rezael et'al, 2012; Umesh et'al, 2011).This situation can cause failure problem to physical infrastructure such as road, buildings, among others.

iii. **Collapsible Soils**

Collapsible soils are moisture sensitive in that increase in moisture content is the primary triggering mechanism for the volume reduction of the soil (Bell, 2000).Soils such as loess and certain wind-blown silt may have the potentials to collapse. Studies conducted by geotechnical and geological engineers agree with this assertion (Azam, 2000; Bell, 2000; Yakov 2007). However, collapsible soils also have the tendencies to destroy physical structures especially when in contact with moisture content during wet season, this situation is capable of causing damages to foundation, walls of building, and roads among other civil engineering structures.

2.6 Problem Soils in Nigeria

In Nigeria, a lot of structural defects have been reported because of problem soils. Damages to infrastructures such as roads, buildings, dams, swimming pools, foundations among other physical infrastructures are caused by problem soils. According to Fatokun and Bolarinwa

(2012), one of the major problems of road infrastructure in Nigeria is problem soils. A lot of studies have identified problem soils as a major threat to physical structures such roads, buildings among others. These problem soils range from the structurally unstable residual lateritic soils and clay soils which several works have reported (Ola, 1983; Madedor and Lal, 1985; Adesunloye, 1987; Madedor and Adekale, 1987; Ifabiyi and Kekere, 2013 among others). Clay soil, for example, is predominantly the most subgrade material in Nigeria which poses a serious problem to foundations of buildings, highways, water retaining structures and dams (Ola, 1987). Some of the major problem soils identified across Nigeria include the following:

i. **Peat, organic silt clays:** it consists of decayed vegetation in various stages of decomposition. It is dark in colours and strong odour made of mainly soft peat organic silt and clays (Ajayi, 1985). A study by Adesunloye (1987) identified this type of problem soils in Lagos and Port Harcourt areas as peaty clay. They occur as clayey peat over the mud plain, they are also found in the Niger-Delta area, along the lagoon and creeks.

ii. **Black cotton soils:** They are noted to be very bad construction materials because of their poor performance (Fatokun and Bolarinwa, 2012).Black cotton soils are dark coloured, expansive clay materials rich in kaolinite and expansive montmorrillonitic clay minerals. They are found in the Northeastern part of Nigeria. These soils swell and shrink when in contact with water especially during rainy season. Structures founded on this soil type will encounter severe forms of crack and other forms of deformation which could further result to collapse of such structures

iii. **Sokoto soft clay shale (Attapulgite) of North-western Nigeria:** This soil covers large area of the Sudano-Sahelian region along the North-Western Nigeria along Sokoto plain. They contain active clay minerals of montmorrillonite or illite types that can be very sensitive to humidity (Adesunloye, 1985). Ola (1983; 1987) observed that Sokoto soft clay shale is very unpredictable engineering materials because they shrink on drying. However, three problems are associated with it, they include collapsing sand, sink hole and caverns in the limestone deposit and swelling of the clay shales.

iv. **Soft Deposit in the Niger-Delta Region of Nigeria:** These problem soils type are found in Bayelsa, Cross River, Delta, Edo, the swampy mangroves of Rivers and Imo states in the South-South zone of Nigeria. The general geology consist of various types of quaternary deposits (gravel, sand silt and clay) overlaying three main tertiary lithostratigraphic units of Benin, Agbada and Akata formation (Akpokodje, 1987). These soils are regarded as problem soils because they expand, collapse, disperse and any structure founded on such soil risk failure problems see (figure 4).

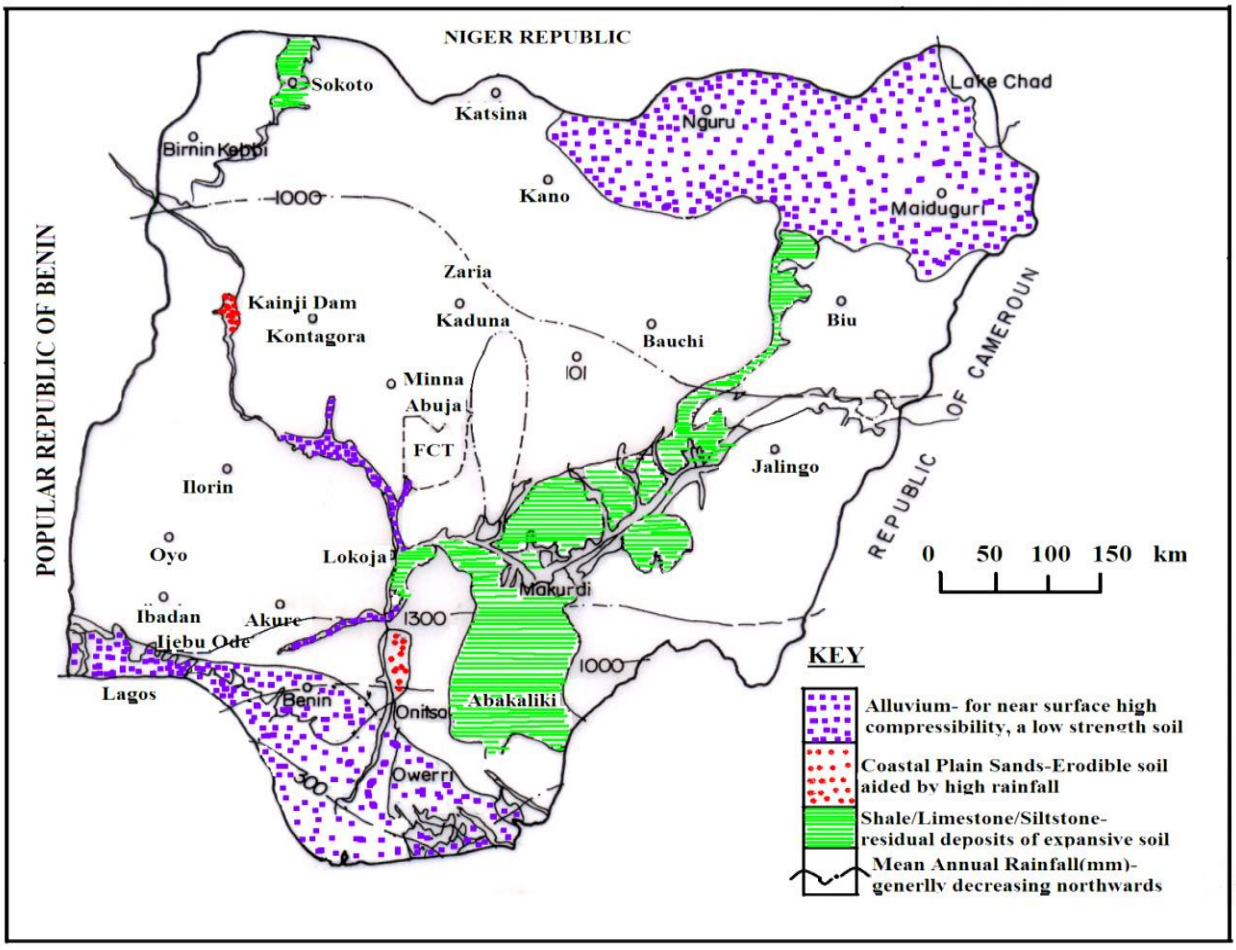


Figure 4 Map of geological composition of problem soils in Nigeria
Source: Adesunloye (1987)

2.7 The Case of Poor Road Infrastructure in Nigeria

According to World Bank (1994), infrastructure can deliver major benefit in economic development, poverty reduction and economic sustainability. Malik (2009) also reiterated the significant role of available and affordable set of infrastructure in poverty reduction and achievement of the Millennium Development Goal (MDG). Therefore, infrastructure plays a central role in facilitating economic growth and international competiveness. According to

Akeem (2010), the development of a society depends on the availability of infrastructure at home or industries. Inadequate infrastructures constitute a great threat to human survival. Okoye and Okoye (2004) posited that the persistent acute shortage of infrastructure in Nigeria is associated with the decade of dictatorship and the adoption of neo-liberal reforms after successful transition from military to democracy in the 1980 and 1990, respectively**.** According to Central Bank of Nigeria (CBN 2003), most roads during the British colonial administration lacked standard design and were in single lane with poor drainage system this also contributed to the road failure we are experiencing today.

However, improvement on road construction began in 1950 with the construction of bituminous road pavement with a total 15,785km, and earth/gravel surface of 75,200km. In the early 70s, road construction received a major boost in Nigeria. Owing to the increase in government revenues after the discovery of crude oil, road network grew from its initial total length 6,500km in 1960, to 10,000km in 1970 to 29,000km in 1980. According to National Transport Policy (2010), it rose to 66,000Km. And in 2010, there were 200,000km of federal, state and local roads with 50,000Km paved (CBN, 2003; Nwariaku, 2009).Table 4 shows the distribution of road network under different tiers of government.

A survey on the state of highways in Nigeria as indicated in several reports showed that most of the roads required complete rehabilitation due to major cracks, depression, broken down bridges and numerous potholes, which make road transportation slow and unsafe (CBN, 2003;Ngim and Udosen, 2007). The deplorable state of Nigerian road network today is as a result of neglect and lack of maintenance of roads. This situation has caused the total collapse of integrated transport

system and this has affected commodity flow and cost of goods and services (Nworji and Oluwalaiye, (2012). Nigeria is ranked 95th in the world behind countries such as Botswna and Namibia with poor infrastructure (World Bank, 2007). Road infrastructure, in the report, is considered as the second pillar, Nigeria is ranked 114th out of 131 countries of the world with poor road infrastructure. Delaney (2008) asserted that identifying the extent of decay in Nigeria's infrastructure is not a difficult task; from transport to health, from energy to utilities, decades of Malaise and under investment have taken over their toll on the nation's infrastructure. According to National Economic Empowerment Development Strategy (NEEDS, 2004), infrastructure needs cut across all sectors and is central to economic development; the state of infrastructure in the country is far from meeting the expectations of an average investor in Nigeria's economy. In the light of this recognition, the strategy to adopt is to complete ongoing construction of 3,000km network of road and embark on any road construction if and when fund-specific assistance or finance is available to facilitate economic growth and development across the geo-political zones of the nation. Additional road maintenance agency should be set up to undertake rehabilitation and maintenance.

However, in an effort to maintain and construct more roads in Nigeria, funds were being disbursed to execute more road projects across the country and contractors were mobilized across the six geopolitical zones (appendix 1-iv). As some of the roads were completed while work is ongoing in some of the road after so many years of the projects was awarded. Nonetheless, some were completely abandoned. Wasike (2000) observed that the major problem culminating in the poor state of the Nigerian road is that construction standard has always been

compromised and ineffectively co–ordinated. Eboh, et al. (2005) expressed similar opinion that most roads in Nigeria were not constructed with the required standard specification and without the necessary furniture such as like drainages provided, which led to the degradation of the road networks. The case of poor and inadequate road transport infrastructure was as a result of inconsistencies in the transport infrastructure and capital investment in Nigeria by various regimes since independence. For instance, the 1960 capital investment plan on transport infrastructure takes significant share of the national budget on public capital expenditure during the first development plan (Table 2).The percentage share witnessed a sharp rise from 15.2% - 27% and it suddenly declined from 11.6%-8.6 due to underfunding by different regimes; this decline affected the progress recorded in transport development in Ngeria. Between 1986 and 2007, capital investment in transport sector increased tremendously from N516 million to N19.24 billion and it rose to N35.23 billion in the years 2007 (NBS, 2010). The Nigeria transport sector contributes less than 3% of the real GDP, with road transport accounting for over 83% of the total share allocated for transport sector. The sector's output and the number of vehicles has increased tremendously by more than 30% transversing a mere 200,000 km of roadways with 50,000 paved surface roadways (CBN 2003; Nworji and Oluwalaiye 2012).

Table 3. Percentage Share of public Sector Expenditure on Transport Sector (1962-1998)

Plan	Plan Period	%Share of the Transport
First National development plan	1962-1968	21.3
Second National Development Plan	1970-1974	23.7
Third National Development Plan	1975-1980	22.2
Fourth National Development Plan	1981-1985	15.2
First National Rolling Plan	1990-1993	11.6
Second National Rolling Plan	1994-1996	8.6
Third National Rolling Plan	1996-1998	10.1

Source: Onokala, 2012.

CHAPTER THREE

METHODOLOGY

3.0 RESEARCH METHODS

Research Design

The following steps were the procedures employed in executing this work.

3.1 Data Required

The data employed in this study were completely secondary in nature. They included the following:

i. Climatic data namely: rainfall amount, maximum temperature and minimum temperature from 1980-2016 (36 years);

ii. Data on kilometer/ mileages of road network in each study areas and;

iii. Information on the geotechnical properties of sub base and sub grade: such as Particle Size Distribution, Liquid limit, Plastic limit, Plasticity index, Maximum Dry Density, Carlifornia Bearing Ratio, and Optimum Moisture Content.

3.2 Sources of Data Collection

The study employed secondary sources of information.The geotechnical properties of soil were obtained from the Nigerian Building and Road Research Institute (NBRRI , Abuja), and the Pavement and Evaluation Unit the Federal Ministry of Works and Housing (FMW&H, Kaduna). Information on road networks in Nigeria was obtained from Nigerian Highways Manuals

(2013). Information on climate indices were obtained from the Nigerian Metrological Agency (NIMET,Abuja) Also information on capital project across Nigeria were gotten from the Central Bank of Nigeria (CBN,2003).

3.3Sampling

3.3.1 Selecting Road Corridors

The Purposive sampling techniques were employed in the study, the sampling points were chosen from the exiting test conducted by established government agencies this was simply because of the massive logistics involved in geotechnical analysis and secondly of the relatively available data in the records of the public agencies such as NBRRI, FERMA and FMW&H .Nigeria lies within 4 morpho-climatic characteristics.Hence, morphogenetic processes found to differ from one part to the order. In each of these zones two road networks were sampled this is reflected in Table 3. The number of sample points varies from road to road. For example Ilorin-Idofian-Iloffa road data from 54 points were used. The morphoclimatic zones and the road segments are hot dry: Birnin-Yauri Malando-Wara road in Kebbi State and Kano-Gwarzo-Katsina road in Kano State, temperate dry: Abuja-Akwanga-Nassarawa road in Nassarawa State and Kachia-Kwoi-Nassarawa road in Kaduna State; hot humid : Ilorin- Omuaran- Illoffa road in Kwara State and Ayingba-Ankpa-Ofa road in Kogi State and warm humid: Edo- Agbor-Asaba road in Delta State and Portharcourt-Elele-Umanelu road in Rivers State. Altogether in the 4 morphoclimatic zones, a total 8 roads corridors 417 sampling points along 697 Kilometres of road stretches were examined in this study.

Table 4: Morphoclimatic zones and Road sections

Morphoclimatic zones	States	Road sections	KM	Sample points
Zone 1	Kebbi	Birnin-Yauri-Malanda-Wara Rd. 10(F.201)	89	54
	Kano	Kano-Gwarzo-Katsina Rd. 368(F.128)	90	54
Zone 2	Kaduna	Katchia-Kwoi-Nassarawa Rd. 346(F.238)	80	48
	Nassarawa	Nassarawa-Toto-Abaji-Abuja Rd. 301(F.124)	98	54
Zone 3	Kwara	Ilorin-Umuaran-Illoffa Rd. 45(A.125)	89	54
	Kogi	Ayingba-Ankpa-Ofa Rd.45(A.233)	94	54
Zone 4	Delta	Asaba-Agbor-Edo(SB) Rd. 25(A.232)	85	54
	Rivers	Porthacourt-Elele-Umanelu Rd. 414(F.229)	72	45
Total			697	417

Source: Author's field work, (2018).

3.4 Methods of Data Analysis

3.4.1 Instrumentation and Laboratory Analysis

Secondary data were used in the study.However, ASTM laboratory procedures were used to anayze these geotchincal data. The procedures are discussed below.

3.4.2 Particle Size Distribution (PSD)

This entails the separation of soil into different particle size or fractions. This will be done to determine grain size of sandy and gravel materials of subgrade. This laboratory test will be carried out in accordance with BS 1377(1990) to enable us to see the variations in sub grade materials of the road under investigation. From the anticipated results, coefficient of uniformity (Cu) and co-efficient of curvature (Cc) will be evaluated to classify soil based upon the Unified Classification System (USCS) using the following relationships.

$$Cu = \frac{D60}{D10}$$

$$Cc = \frac{[D30]^2}{D60 \times D10}$$

Where, Cu = Uniformity of coefficient

Cc = Coefficient of curvature

D60 = the diameter corresponding to 60% finer in particle size distribution

D30 = Diameter corresponding 30% finer

D10 = Diameter corresponding to 10%

Instrumentation:

Test Sieves [BS] 1377 [1990]. Mechanical Sieve shaker, Balance, sieve brushes and metal tray.

Procedure:

The selected sieves with varying degrees of sizes will be cleaned and arranged from the bigger opener to the smallest opener. The sample soils are then poured carefully and poured into the sieve and shall be covered and placed in the mechanical sieve shaker. The sample of soils retained on each sieve and percentage passage were calculated thus:

i. **Percentage retained on sieve** =

$$\frac{\text{Weight of soil retained}}{\text{Total weight of sample}} \times 100\%$$

ii **Percentage passing on each sieve** =

$$\frac{\text{Weight of total sample} - \text{weight retained}}{\text{Total sample}} \times 100\%$$

iii **Specific gravity**: The test will be carried out in accordance with BS 1377(1990)

$$\text{Specific gravity} = \frac{\text{Density of soil particle}}{\text{Density of water}}$$

iv **Moisture Content(%)** The test will be carried out in accordance with BS1377 (1990)

$$= \frac{Ww}{WD} \times 100\%$$

Where,

Ww = weight of water

WD= weight of dry soil

iv A graph will then be plotted to show the various sieve size diameter [mm] and percentage passage soil samples.

3.4.3 Consistency Limit:

The liquid limit [LL] and plastic limit [PL] were routinely determined for cohesiveness of soil and strength correlations. The test was carried out in accordance with BS1377 (1990).

$$\text{Linear shrinkage\%} = \frac{Lo - Lf}{Lo}$$

Where,

L_0= Length of wet soil bar

Lf= Length of dry soil bar

Plasticity index= Liquid Limit (LL)-Plastic Limit (PL)

Instrumentation:

i. BS [1377, 1990] sieves

ii. A glass plate about 9.5 mm thick

iii. A small spatula

iv. A piece of apparatus for liquid limit, a brass cup and carriage mounted on a tuber base 18cm x 13cm x 5cm approximately.

v. A standard grooving tool with gauge handle.

3.4.4 Compaction Test:

This test will be carried out to determine the variation that existed between dry densities with moisture content. The test was carried out in accordance with BS (1999)

$$\text{Bulk density } \ell \text{ (kg m}^{-3}) = \frac{Ma - Mb}{\text{Volume of mould}}$$

Where,

Ma= Weight of mould + compacted soil

Mb= Weight of mould

$$\text{Dry density (kg m}^{-3}) = \frac{\ell}{1+w}$$

Where,

ℓ = Bulk density

w = Moisture content.

Instrumentation:

i. Compaction mould Rammer (2.5kg)

ii. 4mm sieves

iv. Spatula measuring cylinder

v. Balance

vi. Drying oven

vii. Mixing pan and Drying cans

Procedure:

An air- dried soil samples will be weighed on a balance after sieving with a 20mm sieve. A 2.5 kg rammer will be used in soil compaction mould and a spatula was used to remove the excess soil. Two cans were used in the moisture content determination. As soon as wet and dry was determined, the value for the compaction test was obtained from the formula stated above.

3.4.5 California Bearing Ratio [CBR] Test:

The CBR test was originally devised by O.J. Porter of the California state Highways Department, following an investigation of flexible pavement failures in California (cited in O'Flaherty 2001). The principle behind the CBR is to determine the relationship between force when a cylindrical plunger of a standard cross-sectional area is made to penetrate a compacted soil sample at a given rate.

Instrumentation:

i. CBR mould

ii. CBR rammer

iii. CBR machine

iv. Perforated plates, spatula, mixing pan

viii. Measuring cylinder and soaking tank

Procedure:

Soil samples were air-dried and calculation of moisture content from the compaction test was obtained; water will be measured in a cylinder according to each sample used in compact soil. The mixed soil was divided into three [3] parts. The first part was put inside the CBR mould and compacted with 25 blows with a rammer of 4.4kg. The second and third part was then put inside the mould with the extension collar and compaction of each layer at 25 blows each. Spatula was used to remove the excess soil sample from the top of the mould to allow for reading of the CRB machine. After reading the value, the whole mould was soaked completely together with compacted soil in water for 24 hours to determine the worst condition of tested soil sample. To obtain the plunger value of soaked and unsoaked soil sample was followed. CBR is determined through the following equation.

$$CBR = \frac{\text{Load on plunger}}{\text{Standard load}} \times 100\%$$

3.5 Statistical Methods

The study employed the use of descriptive and inferential statistics to analyse the data in this study. The Mean, standard and Standard Deviation were used to calculate samples of the road under investigation. Erosion of road shoulders, gully along road network, soil loss and gully surface area were computed.

(a) Descriptive Analyses

Descriptive analyses such as table, co-efficient of variation, mean, ranges and percentage were used to describe the secondary data.

(b) Inferential statistics

i. One Way Analysis of Variance (ANOVA).

The technique was used to compare wherether or not there is significant differences exist among the geotechnical properties of four morphoclimatic zones.

Table 5 Analysis of Variance Table

Source of Variation	Sum of Square	DF	Mean Square	F-Ratio
Treatment	SS_{TR}	K-1	SS_T/K-1=A	A/C
Block	SS_B	n-1	SS_b/n-1=B	B/C
Residual	SS_R	(n-1)(K-1)	SS_R(n-1)(K-1)=C	
Total	SS_T	Kn-1		

Source: Olubosoye *et al* (2002).

ii. *Multiple Correlation*

Correlation was used to measure the degree of linear association between two or more variables, when a movement in one variable is associable either in the same direction.This statistics was used to measure the degree of association between extreme temperature, rainfall and road

subbase and subgrade failure to establish if any relationship existed between them. The statistics was generated to treat object two which seek to investigate the relationship sub grade and temperature and rainfall data.

Thus the model is expressed as follows:

$$Rxy = \frac{n\sum x_1 Y - \sum x_1 \sum Y}{\sqrt{n\sum X_1^2 - (\sum X_1)^2}\sqrt{n\sum Y^2 - (\sum Y)^2}}$$

Where$_{xy}$ is the Correlation Co-efficient
Y = is the degree of road failure
X = is the climatic Variables
n = number of Samples

iii Multiple linear regression analysis

This study used this statistical tool to examine the magnitude of relationship (R^2) between climatic variables (rainfall, Maximum and Minimum Temperature) and geotechnical properties. The following equation will be used to derive (R^2) as follows.

Multiple linear regression models is expressed as follows:

$$\hat{y} = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + \ldots\ldots\ldots\ldots b_n x_n + e$$

Where

Y= geotechnical properties

X_1= rainfall

X_2= maximum temperature

X_3= minimum temperature

iv Principal Component Analysis:

Principal component analysis was in the study to reduce variety of data matrix comprising 'n' variables and 'N' observation to form few selected component variables derived to form a true representative of its original sets. The factor analysis was used in this research to identify both

physical and engineering properties of foundation soils of the road and to remove the multi-co linearity from variables identified. For this study as the Factor Defining Variables [FDV] for the rotated component matrix therefore, Factors greater than 0.6 from the rotated matrix formed the major variance in each components identified.

CHAPTER FOUR

4.0 PATTERN OF GEOTECHNICAL PROPERTIES OF ROAD SUBBASE AND SUBGRADE OF THE STUDY AREA

4.1INTRODUCTION

This chapter discusses the Geotechnical properties of road foundation.The result from sections of each road understudy in each morphoclimatic zone were analysed. Assesmemnt were based on The Federal Ministry of Work and Housing (FMWH, 1997) standard specification and it is presented in Table 6.

Table 6: Benchmark for consturction of Road and Bridghes in Nigeria.

S/N	Geotechnical properties	Subgrade(SG)	Subbase(SB)
1.	Particle Size Distribution (PSD)	>35%	>35%
2.	Liquid Limit (LL)	>50%	>35%
3.	Plastic Limit (PL)	>30%	>12%
4.	Plasticity Index (PI)*	-	-
5.	Carlifornia Bearing Ratio(CBR) soaked	>30%	>30%
	Carlifornia Bearing Ratio(CBR) unsoaked	>80%	>80%
6.	Maximum Dry Density (MDD)*	-	-
7.	Optimum Moisture Content (OMC)*	-	-

Source: FMW&H, (1997)

* Not available

4.2 Geotechnical Properties of subbase and subgrade for Zone 1, (Hot Dry) Birin Yauri – Malando-Wara Road

Particle Size Distribution (PSD) Subgrade

PSD for subgrade presented in Tables 7, ranges from 5- 69% in 54 locations. This suggests that, in all these locations almost 70% were not retained. The mean PSD is 45.4% which is greater than the acceptable value of 35% of the FMW&H (1997). 20(37%) sample location passed the

FMW&H, (1997 Table 6) PSD value while 34(63%) failed the benchmark less than 35% as stipulated by FMW&H, (1997) (Table 7). This is in view of the high clay contents in many part of the study area. This is similar to the distribution of soil samples in the foundation of the road as stipulated by the American Association of State Highway and Transport Official (AASHTO) which falls into A-2-4,A-2-4, A-7-6,2-7, A-4,A-7-5(sandy-clayey soil materials) for subgrade indicating that road that is underlain by the Sokoto soft clay shale (Attalpugite) which comprises of clayey material, fine sand, silt or clayey gravel and sand about 63.7% of samples did not passed N0.200 BS sieve analysis to meet the Nigerian General Specification Requirement of materials to be used for subbase, while other sections were greater than 35% passing BS200 sieve (FGN, 1997).

Particle Size Distribution (PSD) Subbase

PSD as presented in Table 7, PSD values in the subbase category ranges from 2-69%. Out of the 54 locations 30(70%) locations passed the benchmark for road and construction of FMW&H,(1997) standard, while 24(30%) failed. This is expected in view of high clayey content in the study area. This is classified in to AASHTO classification of A-2-4, A-2-6 and A-2-7 which is often describe as dangerous engineering materials for engeneering construction.

Liquid Limit (LL) Subgrade

The value of Liquid limits (LL) ranges from 17-77% (Tables 7) in the study area. This implies that, 49 (91.1%) sample points passed the acceptable standard of < 50% standard specication of FMW&H, (1997) while 5(8.9%) failed (Table 7). This implies that the soil in this road axis is

cohesive, consisitent, consolidation and the toughness of the size. This explain a relative stable soil in this axis.

Liquid Limit (LL) Subbase

The value of Liquid limits (LL) ranges from 18-55% (Table 7) in 54 locations. This suggest that, in all these locations only 25(46.3%) out of 54 locations conforms to the acceptable values and 29(53.7%) locations failed (Table 7) the acceptable limit of 35% bench mark for the construction of road and bridges of FMW&H,(1997).This implies that foundation failure will be recorded in 53.7% of the section of the road and the subbase materials are relatively low in stability.

Plastic Limit (PL) Subgrade

The PL ranges from 22-35% (Table 7) in 54 locations. Out of the value obtained only 12(22.2%) passed the standard specification for the construction of road and bridges in Nigeria (FMW&H, 1997) while 42(77.7%) locations failed the bench mark of >30% for road and bridges in Nigeria. The limit is an indication of the amount of water in clayey materials and then ease of low clay soil form plastic.Hence, there is likelyhood that, the subgrade materials will swell and shrink and crack according to the seasons, failure will be imminent in this subgrade.

Plastic Limit (PL) Subbase

The value of PL in subbase in Table 6 ranges from 9-29% in the value obtained only two were below the benchmark value of >12% this road section passed the test for the construction of road and bridges of the FMW&H, (1997) at 2(4%) sample points (KM 0-2+000, and KM38+000) in all other 52(96%) sample points of the PL were above the benchmark hence,

they failed the test .This suggest that a large section of the road did not pass the PL test in Malando-Wara Birnin Yauri road. This indicated that road failure is expected on the subbase as the subbase will responds to pressure of water especially during rainy seasons and failure rate on the road foundation expected.

Maximum Dry Density (MDD) Subgrade

MDD for subgrade (Table 7) ranges from 1.60-1.94g/cc along various sample points in the 54 location. MDD does not have acceptable value because of the complexity and variation of clay soil types in Nigeria as presented in figure 4. This variation in clayey materials in Nigeria makes it difficult to have a clear cut range or bench mark for construction of road and bridges in Nigeria however, Affonime and Anniekan (2005) make a clear categorization of MDD into low (< 1.80g/cc), medium (1.80-1.85g/cc), hgh (1.85-1.90g/cc) and very high (>1.90g/cc). Therefore, results in the study will determine the clay type and its effects on road and each point in the road. Out of the 54 locations MDD in 21(38.9%) location ranges < 1.80g/cc which indicated low clay contents, 24(44.5%) locations ranges from 1.80-1.85which indicated medium clay contents, 3(5.6%) locations ranges from 1.85-1.90g/cc indicated high clay contents whle other 6(11.1%) locations ranges from in >1.90g/cc (Table 7), which is an indication of high clay content. This is an indication that at each location constitutes a particular clay content which could also causes the road section to fail failure experience at the road under study. The MDD is simply an index of how much compactions surface is required. The value indicated a relativelyacceptable level of compaction.

Maximum Dry Density (MDD) Subbase

MDD for subbase (Table 7) ranges from 1.80-2.09g/cc in the 54 locations in the study area 1(1.9%) locations range < 1.86g/cc indicating that, they were in the category of low low clay contents, 6(11.1%) locations also have MDD ranging between from 1.80-1.85g/cc which is medium clay types, 13 (24.1%) locations ranges from 1.85-1.90g/cc suggesting high clay contents and 34 (63%) locations range > 1.90g/cc implying the presence of very high clay contents. This showed that the magnitude of road failure caused by MDD will be be higher, since majority of the sampled points have value greater than 20. This will impact on the rate at which road are compacted.

California Bearing Ratio (CBR) Subgrade

The CBR considered in the study is the soaked type and it ranges from 5.3-20.5% in the 54 sample locations. The prescribed values for CBR in subgrade for Nigerian road are 30%. A comparison of the value obtained in the study and FMW&H (1997) standard showed that, the value is higher than the specified >30% standard in only 6(11.1%) locations indicating that they failed the test in (KM8-10+000,KM16-18+000,KM24-26+000,KM28-30+000, KM32-34+000,KM52-54+000 and KM68-70+000) while only48(88.9%) location passed the prescribed standard of FMW&H,(1997) of all 54 sampled points.This suggest in almost 89.9% of the samples were retained while only 6 sample location failed the standard specifications (Table 7).Ths implies that materials for subgrade are good for road construction along the road except in few locations that are bad. The CBR test is a measure of resistant of a material to prenetration of standard plunger and it is a test of how stable the soil could be. The results obtained in this study

showed that, when soil is wet foundation of the road would become less stable and this explain the failure rate along the road road network.

California Bearing Ratio (CBR) Subbase

The CBR in subase category presented in (Table 7) ranges from 5.1-31.1% for soaked sample in 54 locations also showed that, 5(9.3%) locations in (KM4-6+000, KM8-10+000,KM44-46+000,KM48-50+000 and KM64-66+000) were higher than the prescribed standard specification for the construction of road and bridges in Nigeria (FMW&H,1997). Results obtained in the study also suggest that, out of 54 location 49(90.7%) failed hence they failed passed the value for > 30% for the construction of road and bridges in Nigeria according to the bench mark FMW&H,(1997) with a mean of 13.4% (see Table 7d). They values largely fall short of 30% required specification hence, the subbase materials are largely unstable.

Table 7: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Birnin Yauri-Malando-Wara Rd 10(F.201)

Soil properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8 – 10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM20-22+000KM			FMW&H (1997)
Sample locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	64	20	58	34	20	32	30	35	6	43	66	32	05	64	64	58	52	6	>35%
(%)	SG	36	69	42	2	47	69	69	65	40	57	34	69	2	36	34	42	48	69	>35%
*LL	SB	53	18	20	45	30	25	53	50	55	19	50	25	43	53	19	20	25	40	>35%
(%)	SG	77	25	35	38	17	20	17	35	29	35	40	20	25	25	30	36	77	37	>50%
*P L	SB	09	12	15	22	20	27	15	29	27	15	29	20	15	18	15	29	28	20	>12%
(%)	SG	32	30	32	30	32	22	30	32	22	30	32	38	30	25	35	30	18	36	>30%
*PI	SB	44	28	44	42	40	47	48	40	40	42	44	47	43	42	45	50	50	44	----
(%)	SG	15	10	26	16	16	12	14	15	19	21	13	12	10	15	16	17	19	08	
**MDD	SB	2.80	2.03	1.80	1.90	1.88	1.94	2.09	2.29	2.01	2.40	2.30	1.94	1.87	1.81	1.88	2.70	1.90	1.90	----
g/cc	SG	1.80	1.70	1.80	1.82	1.88	1.94	1.70	1.80	1.80	1.60	1.70	1.94	1.80	1.81	1.88	1.70	1.90	1.70	
**OMC	SB	12	10	16	10	12	10	12	11	15	10	12	11	10	13	12	12	10	10	-----
(%)	SG	13	10	14	14	15	12	13	12	10	12	13	12	14	14	13	10	14	15	
**CBR	SB	5.45	20.5	34.5	13.4	13.0	5.45	5.45	34.5	13.4	5.45	13.41	5.45	13.0	13.00	5.1	12.45	14.01	13.0	>30%
(%)	SG	15.2	15.1	5.3	15.3	20.5	31.1	20.3	5.1	15.5	20.2	5.12	31.1	15.3	20.1	15.1	13.5	15.1	20.1	>30%
*(ASHTO)								A-2-4						A-26 A-2-7						
Soil Class								A-2-4						A-7-6 A-2-7 A-4 A-7-5						

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 7: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Birnin Yauri-Malando-Wara Rd 10(F.201)

Soil properties		KM 24 – 26+000KM			KM 28-30+000KM			KM 32 – 34+000KM			KM 36-38+000KM			KM 40 – 42+000KM			KM44-46+000KM			FMW&H (1997)
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	20	32	30	43	66	32	52	64	64	58	52	6	64	20	6	43	66	58	>35%
(%)	SG	47	69	69	57	34	69	48	36	34	42	48	69	36	69	40	57	34	42	>35%
*LL	SB	30	25	53	19	50	25	25	53	19	20	25	40	53	18	55	19	50	20	>35%
(%)	SG	17	20	17	35	40	20	77	25	30	36	77	37	77	25	29	35	40	35	>50%
*PL	SB	20	27	15	27	15	29	09	15	18	15	09	12	15	22	27	15	29	15	>12%
(%)	SG	32	22	30	22	30	32	32	30	25	35	32	30	32	30	22	30	32	32	>30%
*PI	SB	40	47	48	42	44	47	50	42	45	50	50	44	44	28	40	42	44	44	----
(%)	SG	16	12	14	21	13	12	19	15	16	17	19	08	15	10	19	21	13	26	
**MDD	SB	1.88	1.94	2.09	1.89	2.30	1.94	1.90	1.81	1.88	2.01	1.90	1.90	1.94	2.03	2.01	2.40	2.30	1.80	----
g/cc	SG	1.88	1.94	1.70	1.60	1.70	1.94	1.90	1.81	1.88	1.70	1.90	1.70	1.80	1.70	1.80	1.60	1.70	1.80	
**OMC	SB	12	10	12	13	12	12	12	10	13	12	12	10	10	16	15	10	12	16	-----
(%)	SG	15	12	13	14	13	10	10	14	14	13	10	14	10	14	10	12	13	14	
**CBR	SB	13.0	5.45	5.45	5.45	13.41	5.45	14.01	13.00	5.1	12.5	14.1	13.0	5.45	20.5	13.4	5.45	13.4	34.5	>30%
(%)	SG	20.5	31.1	20.3	20.2	5.12	31.1	15.1	20.1	15.1	13.5	15.1	20.1	15.2	15.1	15.5	20.2	5.12	5.3	>30%
*(ASHTO)	SB						A-2-4						A-26	A-2-7						
Soil Class	SG						A-2-4						A-7-6	A-2-7	A-4	A-7-5				

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 7: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Birnin Yauri-Malando-Wara Rd 10(F.201)

Soil properties		KM 48 – 50+000KM			KM 52-54+000KM			KM 56 – 58+000KM			KM 60-62+000KM			KM 64 – 66+000KM			KM68-70+000KM			Mean
Sampled locations		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
*PSD	SB	30	35	6	43	66	32	05	64	64	58	52	6	64	20	58	34	20	32	38.2
(%)	SG	69	65	40	57	34	69	2	36	34	42	48	69	36	69	42	2	47	69	45.4
*LL	SB	53	50	55	19	50	25	43	53	19	20	25	40	53	18	20	45	30	25	35.7
(%)	SG	17	35	29	35	40	20	25	25	30	36	77	37	77	25	35	38	17	20	34.3
*PL	SB	27	15	29	27	15	29	20	15	18	15	09	12	15	22	20	27	15	29	
(%)	SG	22	30	32	22	30	32	38	30	25	35	32	30	32	30	32	22	30	32	
*PI	SB	48	40	40	42	44	47	43	42	45	50	50	44	44	28	44	42	40	47	43.3
(%)	SG	14	15	19	21	13	12	10	15	16	17	19	08	15	10	26	16	16	12	15.3
**MDD	SB	2.09	1.79	2.01	1.89	2.30	1.94	1.87	1.81	1.88	2.01	1.90	1.90	1.94	2.03	1.80	1.90	1.88	1.94	2.01
g/cc	SG	1.70	1.80	1.80	1.60	1.70	1.94	1.80	1.81	1.88	1.70	1.90	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.89
**OMC	SB	12	11	10	13	12	12	11	10	13	12	12	10	10	16	10	12	10	15	23.5
(%)	SG	13	12	14	14	13	10	12	14	14	13	10	14	10	14	14	15	12	10	21.7
**CBR	SB	5.4	34.5	13.4	5.45	13.41	5.45	13.0	13.0	5.1	12.45	14.0	13.0	5.45	20.5	34.5	13.4	13.0	5.45	13.4
(%)	SG	20.3	5.1	15.5	20.2	5.12	31.1	15.3	20.1	15.1	13.5	15.1	20.1	15.2	15.1	5.3	15.3	20.5	31.1	16.6
*(ASHTO)							A-2-4						A-26 A-2-7							
Soil Class							A-2-4						A-7-6 A-2-7 A-4 A-7-5							

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table7: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Hot Dry (Zone 1) and Temperate Dry (Zone2)

Mophoclimatic Zones	State	Road section	Geotechnical Properties	Sub base		Sub grade		Sample Location	Road KM
				Passed	Failed	passed	Failed		
Hot Dry (zone 1)	*Kebbi	Birnin-Yauri-Malanda-Wara Rd. 10(F.201)	PSD	30	24	20	34	54	89
			LL	25	29	49	5	54	89
			PL	02	52	12	42	54	89
			MDD*	-	-	-	-	54	89
			CBR	49	5	48	6	54	89
Hot Dry (zone 1)	*Kano	Kano-Gwarzo-Katsina Rd. 368(F.128)	PSD	32	22	10	34	54	90
			LL	11	43	51	3	54	90
			PL	13	41	54	-	54	90
			MDD	-	-	-	-	54	90
			CBR	6	48	19	25	54	90
Temperate Dry (Zone 2)	*Kaduna	Katchia-Kwoi-Nassarawa Rd. 346(F.238)	PSD	20	28	14	34	48	80
			LL	05	43	37	11	48	80
			PL	---	48	27	21	48	80
			MDD	---	--	---	---	48	80
			CBR	42	6	35	13	48	80
Temperate Dry (Zone 2)	*Nassarawa	Nassarawa-Toto-Abaji-Abuja Rd. 301(F.124)	PSD	24	30	8	46	54	98
			LL	--	54	50	4	54	98
			PL	-----	54	33	21	54	98
			MDD	---	---	---	---	54	98
			CBR	49	5	16	38	54	98

Source: Author's compilation, (2018). *FMW&H (1997) Highway Manuals, (2013)

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^3/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005).

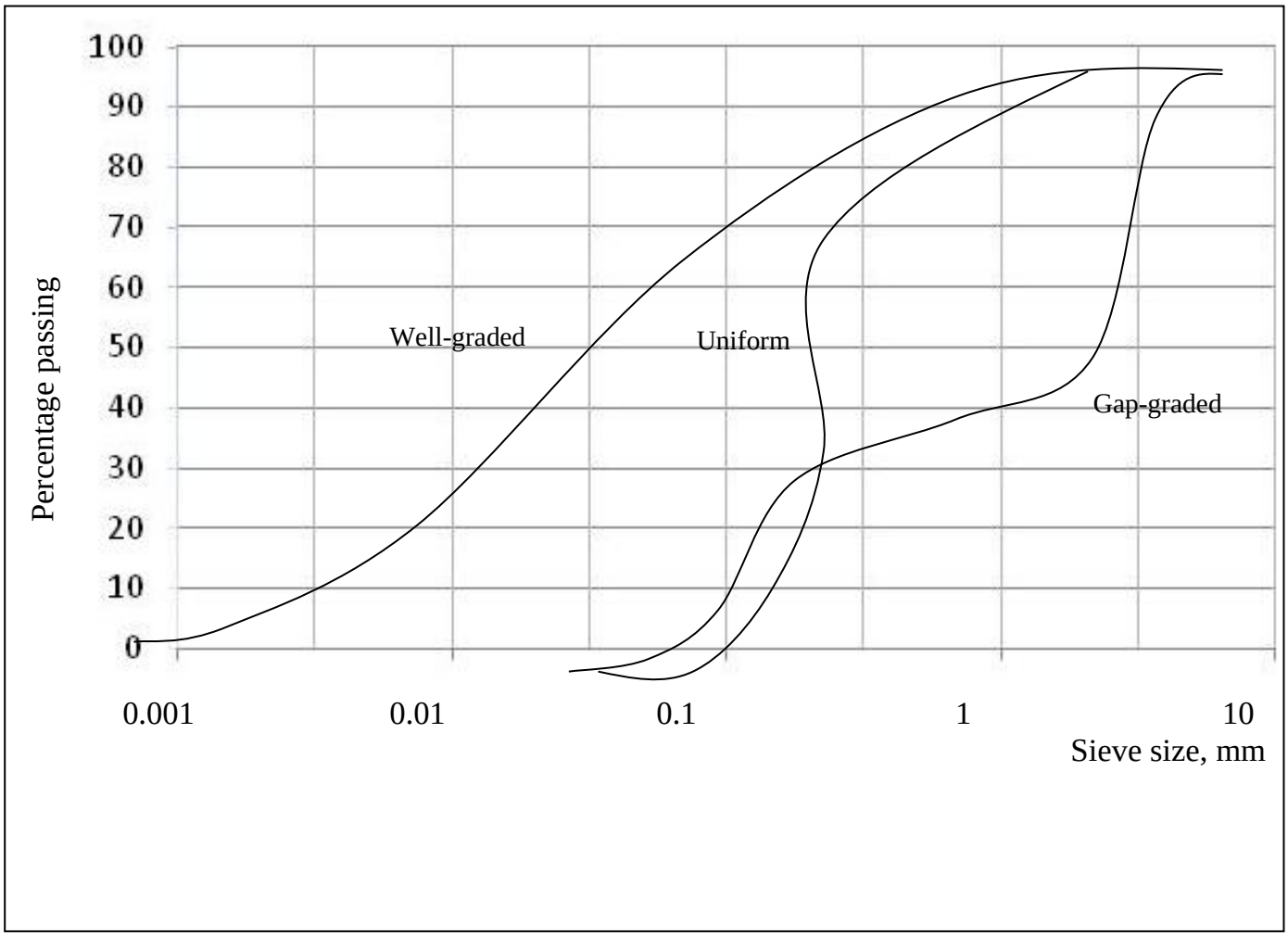


Figure 5: Particle Size Distributions for Birnin Yauri-Malando-Wara Road
Sorce: Garber and Hoel (2009)

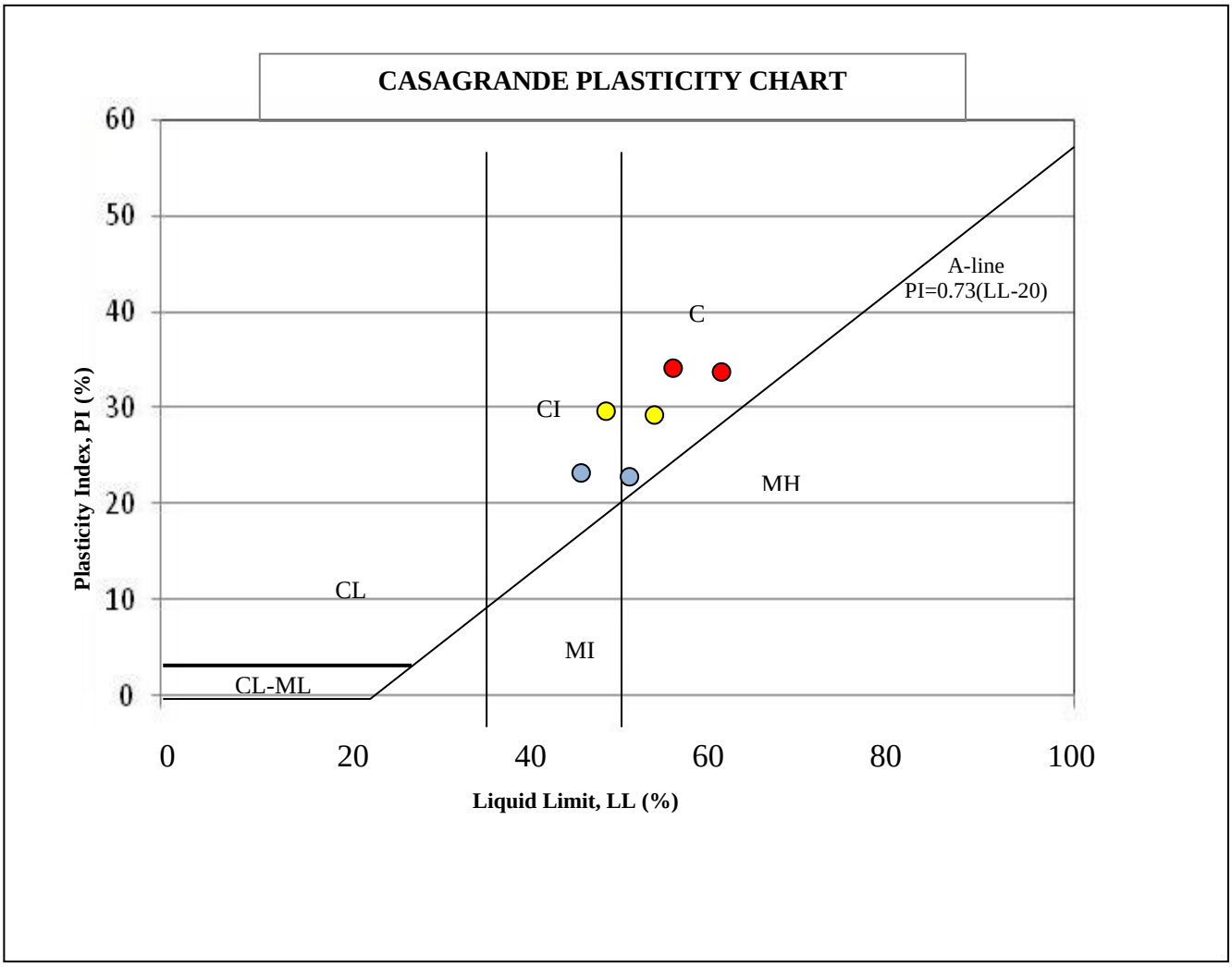


Figure 6: Plasticity Chart for Birnin Yauri Road
Source: Garber and Hoel (2009)

4.3 Geotechnical Properties of Zone 1, (Hot Dry) Kano-Gwarzo-Katsina Road (F.128) 90KM

Particle Size Distribution (PSD) Subgrade

PSD in subgrade is presented in Table 8, it ranges from 9-65% in the 54 sample point's locations. Out of this locations 44 (81.5%) failed the bench mark of > 35%. The percentage of clay is less greater than 35% only in 10 locations passed the standard specification for the construction of road and bridges in Nigeria. This suggests that the values were satisfactory in only 18.5% of the road section, where PSD value is less than 35%. Where ever clay contents retained were higher than 35% road failure will be expected. This is in view of the high clay contents in the study area. Soil distribution along the road is classified into A-2-4, A-2-6, A-7-5 for subgrade (Table 8) according to American Association of State Highway and Transport Official (AASHTO).

Particle Size Distribution (PSD) Subbase

PSD subbase category ranges from 8-45% in this road section. In the 54 locations of the study area almost 32(59.3%) locations recorded values less than 35% of the the benchmark for construction road and bridges of FMW&H, (1997). Hence they passed the PSD test. A bout 40.7% of the road stretch of the road did not complied with the standard suggesting that this sections of the road have high clay contents. Clay materials are generally distructive to civil engineering structures especially road.. The implication of the clay contents of 40.7% of the road is that, this road section will be exposed to road failure in some of these areas. The road section is classified into A-2-4, A-2-6, A-4 of AASHTO soil classifications.

Liquid Limit (LL) Subgrade

The value of Liquid limit (LL) in the study area ranges from 19-65% in subgrade category (Table 8). Out of 54 sample points 51(94%) were greater than 50% which is the standard specification (FMW&H, 1997) .It was less than 50% in 3 locations namely : chainages KM12-14+000, KM28-30+000 and KM60-62+000. The overall average record in the Kano-Gwarzo Road is 33.8% . This suggests that a greater part of the road sections will be cohesive and consistent even in the presence of water. The LL on the other hand is a measure of the level of cohesiveness, consistency, consolidation and toughness of soil which are exhibited on other section of the road.

Liquid Limit (LL) Subbase

Liquid limit (LL) the subbase material ranges from 28-70% (Table 8). When compared with benchmark of 35% for subbase were less 35% in only. The subbase materials were less than 35% in only 11(20.4%) locations in this road axis suggesting that it did not met the required specification for road and bridges (FMW&H, 1997). In most sample locations in 43(79.6%) were greater than 35% suggesting the soil largely passed the specification in greater parts of this section? This implies that large part of the foundation of the road section could hold water and as such less plastic. The subbase materials can be said to be largely consolidated.

Plastic Limit (PL) Subgrade

The values of PL ranges from 8-26% as presented in (Table 8) in the subgrade. PL values benchmark is >30%. This suggests that, all values along the road section were lower than 30%. This suggests that, they did not conform to the acceptable standard of >30%. The plastic limit is an indicator of quantity of water in the soil and measures of how soil can flow or becomes

plastic. The results obtained showed that, in the presence of water the subgrade materials of Kano-Gwarzo high way will become plastic and can therefore failed.

Plastic Limit (PL) Subbase

PL in subbase in (Table 8) ranges from 28-50% in along the 54 locations; all the sample locations were greater than 12%. This shows the materials did not passed the plastic limit test for the construction of road and bridges in Nigeria (FMW&H, 1997). The mean of PL is 34.5% which is greater than the benchmark of 12% acceptable standard for road. Hence, the subbase materials were not largely fit into benchmar of FMW&H.

Maximum Dry Density (MDD) Subgrade

This is the extent of engineering compaction required by a geotechnical properties in road construction. MDD for subgrade (Table 8a) ranges from 1.60-2.20g/cc in all the 54 sample locations along the road. Results shows that, out of 54 locations 18(33.3%) location ranges into < 1.80g/cc which indicated low clay contents, 22(40.7%) locations ranges from 1.80-1.85which indicated medium clay contents, 6 (11.1%) locations ranges from 1.85-1.90g/cc indicated high clay contents other 8(14.8%) locations ranges from in >1.90g/cc which is an indication of very high clay content. This is an indication that, at each sample locations they are various types of clay materials responsible to road failure along the road sections. The value recorded supports that, the earth materials will yield to moderate level of compaction.

Maximum Dry Density (MDD) Subbase

MDD for subbase (Table 8) ranges from 1.70-2.28g/cc in the 54 locations. In all these location sampled 12(22.2%) locations range < 1.80g/cc .which falls under low clay materials, 19(35.2%) locations ranges from 1.80-1.85g/cc also an indication that materials composed of medium clay types, 9(16.7%) locations ranges from 1.85-1.90g/cc suggesting that materials consist of high clay contents and 14(25.9%) locations range > 1.90g/cc indicating that, there is a presence of a very high clay contents. This shows that, the magnitude of road failure vary according to the clay types along the road. The values obtained also showed that, the materials will yield to compaction by engineering equipment.

California Bearing Ratio (CBR) Subgrade

The soaked CBR test is measure of how stable an earth materials will be when such materials are wet. CBR soaked in the subgrade category ranges from 5.10-50.30% in 54 sampled locations. The benchmark for CBR for the construction of road and bridges in Nigeria is > 30%. Hence the benchmark value were reached in only in 19(35.2%) sample locations and failed in 25(46.3%) locations where values lower were recorded. This suggests stable surface will be expected in only 35.2% of the road.

California Bearing Ratio (CBR) Subbase

CBR in the subase category as presented in Table 8 ranges from 5.45-34% for soaked samples along the 54 sampled points. The benchmark for CBR for the construction of road and bridges in Nigeria is > 30%. Hence, this condition was met in 6(11.1%) points. Suggesting that, only 11.1% of the road sections passed the FMW&H, (1997) standard, whereby 88.9% of the road will be

less stable especially when they become wet. This condition simply explains reasons for the road failure in the rainy season in Kano-Gwarzo-Katsina road.

Table 8: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Kano-Gwarzo-Katsina Road 368 (F.128)

Soil Properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8 – 10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM20-22+000KM			FMW&H 1997
Sampled locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	30	35	8	43	45	40	30	35	25	34	20	32	08	45	18	45	30	10	>35%
(%)	SG	09	65	50	57	34	42	36	65	42	40	45	65	55	36	34	42	48	65	>35%
*LL	SB	35	65	55	25	70	35	64	65	34	68	58	28	30	59	35	68	66	65	>35%
(%)	SG	28	35	29	35	44	30	30	25	35	19	36	65	25	25	30	36	44	37	>50%
*PL	SB	48	40	40	42	44	43	44	28	44	42	40	47	43	42	45	50	50	44	>12%
(%)	SG	14	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	>30%
*PI	SB	48	10	40	12	44	43	44	28	44	42	40	47	43	12	45	10	50	44	----
(%)	SG	14	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.97	1.80	1.80	2.28	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.90	1.90	1.70	----
g/cc	SG	2.20	1.80	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	
**OMC	SB	18	16	15	15	18	12	16	12	16	15	15	14	13	15	15	14	18	12	-----
(%)	SG	20	18	20	18	20	20	18	15	20	15	20	20	15	16	20	15	20	14	
**CBR	SB	10.45	34.0	13.01	10.50	25.50	12.40	5.45	25.4	34.5	13.4	25.0	5.45	13.00	13.00	10.0	12.0	14.0	13.0	>30%
(%)	SG	40.00	50.20	45.30	30.20	15.70	20.21	35.60	25.30	10.30	5.10	15.0	10.2	12.40	50.50	13.3	31.6	5.10	40.5	>30%
*(ASHTO)							A-2-4	A-2-6	A-4				A-2-4				A-2-6	A-4		
SB SG							A-2-4						A-2-6				A-7-5			

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 8: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Kano-Gwarzo-Katsina Road 368 (F.128)

Soil properties		KM 24-26+000KM			KM 28-30+000KM			KM 32 – 34+000KM			KM 36-38+000KM			KM 40 – 42+000KM			KM44-46+000KM			FMW&H 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	30	35	25	34	20	32	08	45	18	45	30	10	30	35	8	43	45	40	>35%
(%)	SG	36	65	42	40	45	65	55	36	34	42	48	65	09	65	50	57	34	42	>35%
*LL	SB	64	65	34	68	58	28	30	59	35	68	66	65	35	65	55	25	70	35	>35%
(%)	SG	30	25	35	19	36	65	25	25	30	36	44	37	28	35	29	35	44	30	>50%
*PL	SB	43	44	28	44	42	40	47	43	48	40	40	42	44	43	45	50	50	44	>12%
(%)	SG	15	15	10	26	16	16	12	10	14	15	19	21	13	15	16	17	19	08	>30%
*PI	SB	44	12	44	10	40	47	43	42	45	12	50	44	48	40	40	10	44	43	----
(%)	SG	12	10	26	16	16	12	10	15	12	17	19	08	14	12	19	21	13	15	
**MDD	SB	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.90	1.90	1.70	1.97	1.80	1.80	2.28	1.70	1.70	----
g/cc	SG	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	2.20	1.80	1.80	1.60	1.70	1.70	
**OMC	SB	20	12	25	15	15	20	25	20	15	10	18	12	35	25	32	25	35	12	-----
(%)	SG	30	35	30	30	25	35	32	37	25	35	32	35	20	15	30	15	20	30	
**CBR	SB	5.45	25.40	34.50	13.4	25.0	5.45	13.00	13.00	10.0	12.0	14.0	13.0	10.45	34.00	13.01	10.50	25.50	12.40	>30%
(%)	SG	35.60	25.30	10.30	5.10	15.0	10.2	12.40	50.53	13.3	31.60	5.10	40.50	40.00	50.20	45.30	30.20	15.70	20.21	>30%
*ASHTO				A-2-4	A-2-6	A-4				A-2-4				A-2-6	A-4					
Soil Class				A-2-4					A-2-6					A-7-5						

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
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SG: Sub grade

Table 8: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Kano-Gwarzo-Katsina Road 368 (F.128)

Soil Properties		KM 48 – 50+000KM			KM 52-54+000KM			KM 56 – 58+000KM			KM 60-62+000KM			KM 64-66+000KM			KM68 70+000KM			Mean
Sampled locations		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
*PSD	SB	35	30	8	43	45	40	30	35	25	34	20	32	45	18	45	30	10	30	30.8
(%)	SG	09	65	50	57	34	42	36	65	42	40	45	65	36	34	42	48	65	09	39.4
*LL	SB	35	65	55	25	70	35	64	65	34	68	58	28	59	35	68	66	65	35	51.7
(%)	SG	28	35	29	35	44	30	30	25	35	19	36	65	25	30	36	44	37	28	33.9
*PL	SB	42	40	47	43	48	40	40	42	44	40	40	44	43	45	50	50	44	43	43.1
(%)	SG	16	16	12	10	14	15	19	21	13	15	19	13	15	16	17	19	08	15	15.5
*PI	SB	12	40	10	42	10	43	44	28	44	12	40	47	42	45	50	50	44	48	43.4
(%)	SG	14	15	19	21	13	15	15	10	26	16	16	12*	15	16	17	19	08	14	15.1
**MDD	SB	1.97	1.80	1.80	2.28	1.70	1.70	2.20	1.70	1.80	1.82	2.18	1.94	1.81	1.88	1.90	1.90	1.70	1.97	1.89
g/cc	SG	2.20	1.80	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.81	1.88	1.70	1.90	1.70	2.20	1.83
**OMC	SB	35	20	18	20	18	12	20	12	20	15	15	20	20	15	10	18	12	18	21.2
(%)	SG	20	15	30	15	20	30	30	35	30	30	25	35	37	25	35	32	35	20	26.1
**CBR	SB	10.5	34.05	13.01	10.5	25.50	12.40	5.45	25.40	34.50	13.4	25.0	5.45	13.00	10.0	12.0	14.0	13.00	10.45	17.5
(%)	SG	40.05	50.25	45.30	30.2	15.70	20.21	35.60	25.30	10.30	5.10	15.0	10.2	50.50	13.3	31.60	5.10	40.50	40.00	26.9
*ASHTO Soil Class							A-2-4 A-2-4	A-2-6 A-4					A-2-4 A-2-6				A-2-6 A-4 A-7-5			

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 8: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Hot Dry (Zone 1) and Temperate Dry (Zone2)

Mophoclimatic Zones	State	Road section	Geotechnical Properties	Sub base		Sub grade		Sample Location	Road KM
				Passed	Failed	passed	Failed		
Hot Dry (zone 1)	*Kebbi	Birnin-Yauri-Malanda-Wara Rd. 10(F.201)	PSD	30	24	20	34	54	89
			LL	25	29	49	5	54	89
			PL	02	52	12	42	54	89
			MDD*	-	-	-	-	54	89
			CBR	49	5	48	6	54	89
Hot Dry (zone 1)	*Kano	Kano-Gwarzo-Katsina Rd. 368(F.128)	PSD	32	22	10	34	54	90
			LL	11	43	51	3	54	90
			PL	13	41	54	-	54	90
			MDD	-	-	-	-	54	90
			CBR	6	48	19	25	54	90
Temperate Dry (Zone 2)	*Kaduna	Katchia-Kwoi-Nassarawa Rd. 346(F.238)	PSD	20	28	14	34	48	80
			LL	05	43	37	11	48	80
			PL	---	48	27	21	48	80
			MDD	---	--	---	---	48	80
			CBR	42	6	35	13	48	80
Temperate Dry (Zone 2)	*Nassarawa	Nassarawa-Toto-Abaji-Abuja Rd. 301(F.124)	PSD	24	30	8	46	54	98
			LL	--	54	50	4	54	98
			PL	-----	54	33	21	54	98
			MDD	---	---	---	---	54	98
			CBR	49	5	16	38	54	98

Source: Author's compilation, (2018). *FMW&H (1997) Highway Manuals, (2013) Vol.II

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^3/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005).

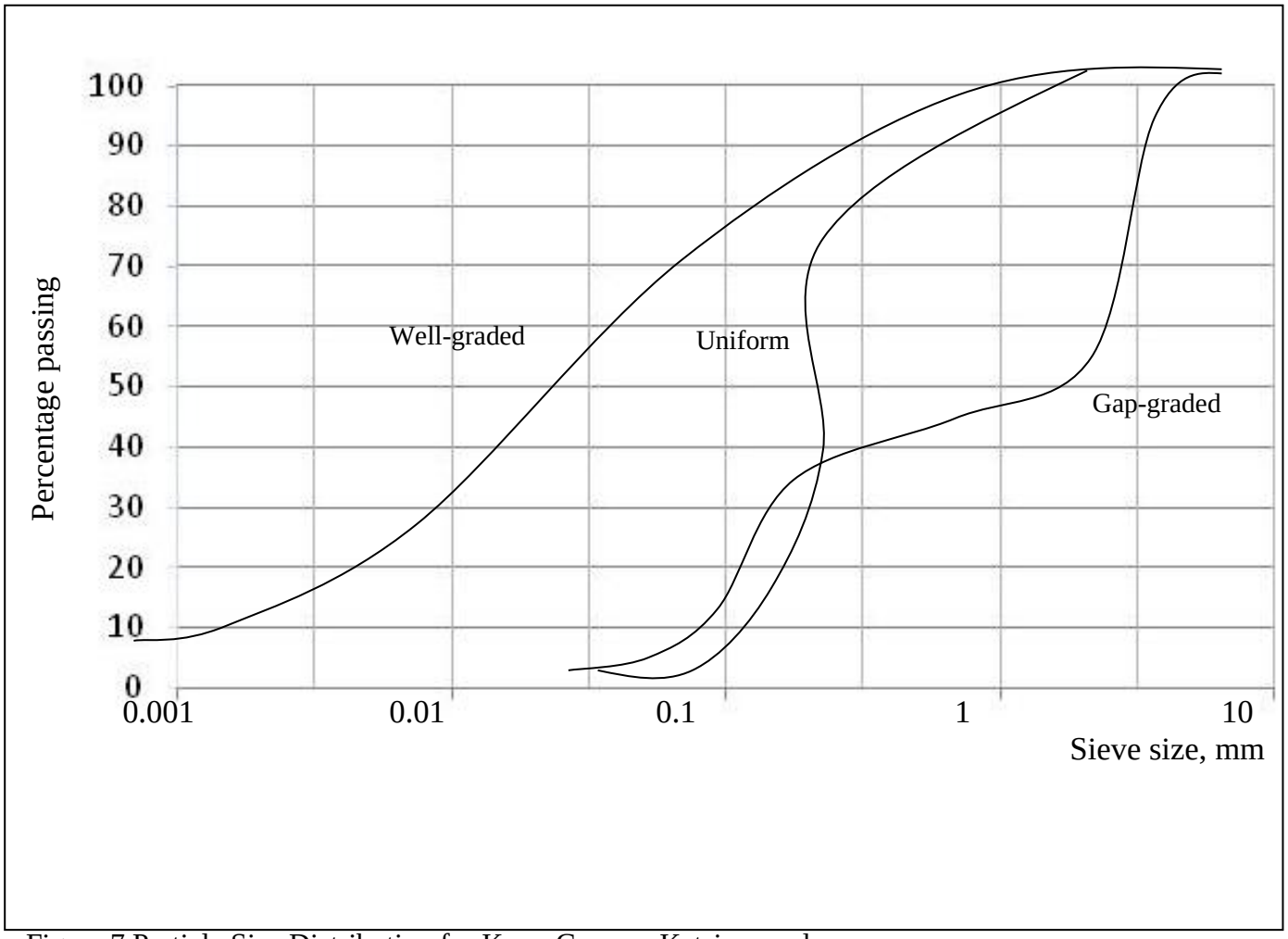


Figure 7 Particle Size Distribution for Kano-Gwarzo-Katsina road
Source: After Garber & Hoel (2009)

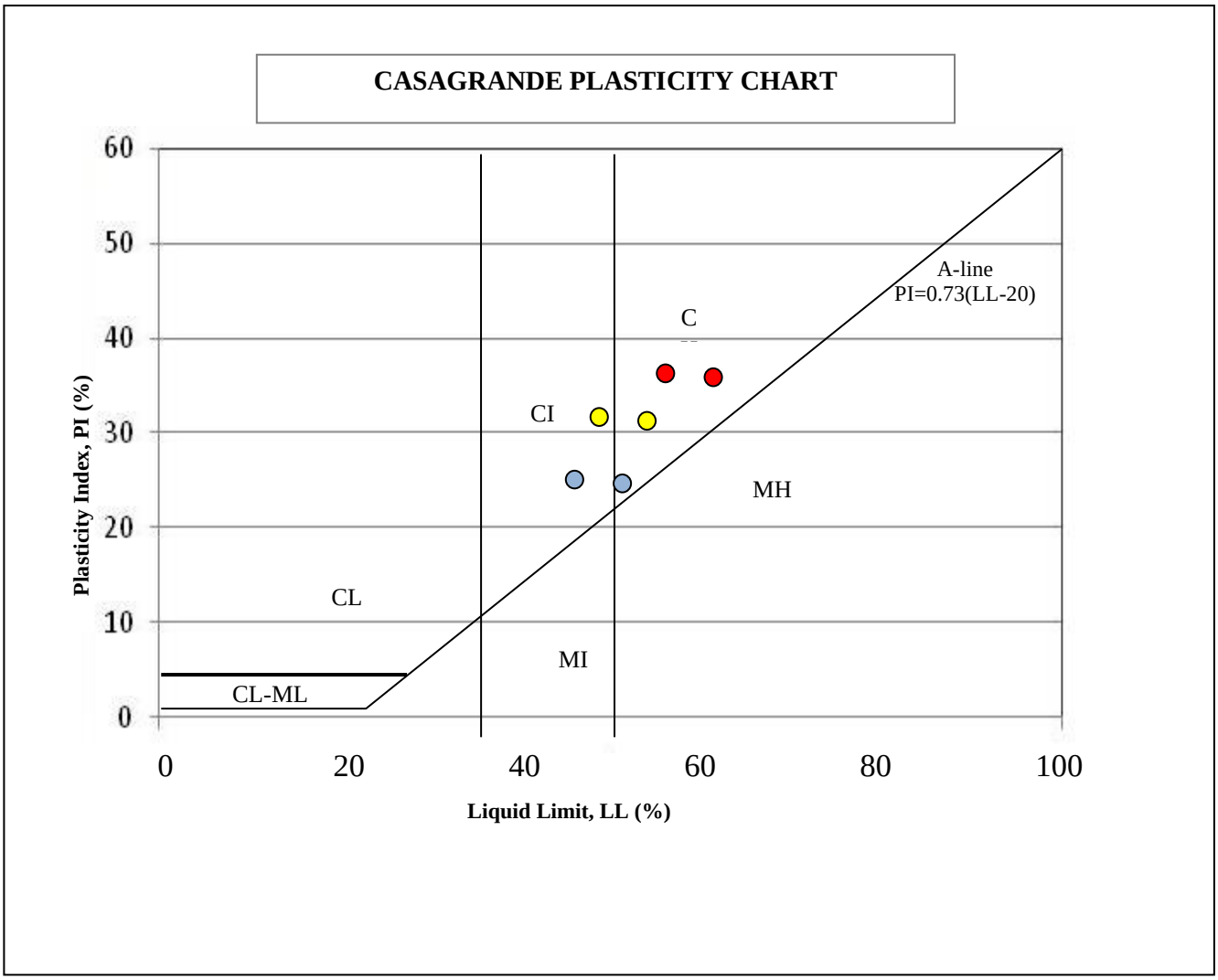


Figure 8: Plasticity Chart for Kano-Gwarzo road
Source: Garber & Hoel (2009)

4.4 Geotechnical Properties of Zone 2, (Temperate Dry) for Katchia- Nassarwa-Kwoi road 346(F238).

Particle Size Distribution (PSD) Subgrade

The Particle size distribution plays important role in geotechnical studies, most especially the percentage of clay retained.The FMW&H has stipulated parcentage of clay retained should not be greater than 35% for road surface. PSD in subgrade presented in (Tables 9) ranges from 13-89% in 48 locations. The results shows that, in 34(70.8%) locations out of the 48 sample location PSD value were greater than 35%. This implies that, for 70.8% of the sections of the road under study, higher percentage of clay were retained when compared with FMW&H standard. Only 14(29.2%) sample points complied with the PSD road failure is expected.

Particle Size Distribution (PSD) Subbase

PSD subbase category presented in (Table 9) ranges from 22-89% in the 48 locations of the study areas in the 48 sample collected, 28(58.3%) sample locations were greater than 35% benchmark set by the FMW&H. Hence, about 58.3% of the road sections have higher values of clay contents. Only 20(41.7%) sample locations passed the acceptable value of < 35% for Nigerian road FMW&H, (1997). The PSD has a mean of 18.1%. This showed that about 41.7% of the road complied with the standard ofn FMW&H standard. This showed that it is only this section that is likely to be stable.

Liquid Limit (LL) Subgrade

The soil liquid is an indication of the low cohesive, consisitent, and consolidated the soil is the pattern of liquid limit (LL) recorded 19-70% in (Table 9) in 48 different locations. The results

showed that, liquid limit was less than 50% in 37(77.1%) locations out of 48 sample locations. This implies that LL in these 37 locations did not complied with the FMW&H standard and in 11(22.9%) of the road studied did not meet the benchmark for construction of road and bridges (FMW&H, 1997) hence, these section of the road foundation failed.

Liquid Limit (LL) Subbase

In the subbase category liquid limit (LL) ranges from 5-70% (Table 9) all the 43(89.6%) sampled points along the road did not confirmed with the standard specification of >35% for the construction of road and bridges(FMW&H,1997) except in 5(10.4%) sampled locations (KM0-2+000; 4-6+000;44-46+000; 48-50+000; 56-58+000) out of the 48 sampled points passed the standard specification for road construction. This showed that, LL for subbase was largely followed.

Plastic Limit (PL) Subgrade

The plastic limit is as an indicator of the quantity of water and how plastic the soil can be. PL in suggrade ranges from 18-35% presented in (Table 9). The value for PL was obtained in 27(56.3%) locations out of the 48 locations in the study area. This showed that 56.3% rate of compliance in the study area. The low percentage experienced is as a result of the high clay contents in the soil in this area. Out of 48 locations 21(43.8%) locations failed the bench mark of ≥30% as stipulated by FMW&H, (1997).Hence; 43.8% of the subgrade materials is substandard and therefore subgrade materials will be subjected to failure.

Plastic Limit (PL) Subbase

PL in the subbase category (Table 9) ranges from 17-41% this suggest that PL in all locations were above ≥ 12% benchmark of FMW&H, 1997. This implies that, results in all 48 locations

(Table 9) met the benchmark. The subbase materials along this road section are completely suitable for road construction. Plastic limit is an indication of the amount of water in the materials and a measure of how such materials respond to water. The mean of PL is 34.5%.

Maximum Dry Density (MDD) Subgrade

MDD is a measure of the level of compaction that a material required. This is because there are materials that cannot be compacted. MDD for subgrade in Table 9a-c ranges from 1.60-1.94g/cc in all 48 the locations. MDD does not have acceptable value because of the complexity and variation of clay soil types in Nigeria as presented in figure 4 which makes it difficult to have a clear cut range or bench markfor MDD for construction of road and bridges in Nigeria however, Affonime and Anniekan (2005) make a clear categorization of MDD into low (< 1.80g/cc), medium (1.80-1.85g/cc), hgh (1.85-1.90g/cc) and very high (>1.90g/cc). Therefore, results in the study will determine the clay type and this also have effects on road failure at each point in the road and this suggest that, out of 48 locations 16(33.3%) location ranges into < 1.80g/cc which indicated low clay contents,20(41.7%) locations ranges from 1.80-1.85g/cc which indicated medium clay contents, 7(14.6%) locations ranges from 1.85-1.90g/cc indicated high clay contents whle other 5(10.4%) locations ranges >1.90g/cc which is an indication of high clay content. The mean of MDD in the study is 1.80g/cc (table 9). This is an indication that at each point they are various types of clay contents which could also translated to the type of failure experience at the road under study. The results indicated above showed thus materials can easily be compacted.

Maximum Dry Density (MDD) Subbase

MDD for subbase category (Table 9) ranges from 1.60-1.90g/cc in all 48 sample locations in the study 19(39.6%) locations range < 1.80g/cc suggesting that, these locations are categorized under low clay contents, 22(45.8%) locations ranges from 1.80-1.85g/cc which is confirms the sections of road comprises medium clay types, 4(8.3%) locations ranges from 1.85-1.90g/cc which is also an indication of a high clay type and 3(6.3%) locations comprises of very high clay contents. This shows that the magnitude of road failure vary according to the clay types along the road section.

California Bearing Ratio (CBR) Subgrade

CBR is a measure of soil stability. CBR soaked in subgrade presented in Table 9 ranges from 5.21-31.54% in the 48 locations of the study area. The results showed that, 35(72.9%) locations out of the 48 in the Katchia-Kaduna road passed the standard specification for road and bridges in Nigeria (FMW&H, 1997) suggesting that the road section have good foundation materials. Only 13(27.1%) locations failed the standard specification suggesting 27.1% did not complied with FMW&H, 1997 stanadard that explains why these sections failed and ths implies that materials for subgrade are substandard. Minimal rate of compaction is expected.

California Bearing Ratio (CBR) Subbase

CBR in subase category (Table 9) ranges from 5.41-34.54% for soaked sample in all the 48 location. Out of the 48 sampled locations 42(87.5%) passed the standard of >30% value of FMW&H,(1997) except in 6(12.5%) locations (KM 0-2+000;8-10+000; 32-34+000; 40-42+000;

56-58+000 which did not confirms with the standard specification. Suggesting that, about 87.5% of the materials in Kaatchia-Nassarawa-Kwoi road is suitable for subbase materials.

Table 9: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Katchia Kwoi-Nassarawa Road 346(F, 238)

Soil Properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8 – 10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM20-22+000KM			FMW&H 1997
Sampled locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	22	35	30	43	66	25	89	50	58	34	23	32	89	70	66	58	52	25	>35%
(%)	SG	70	13	89	57	18	42	36	80	42	16	89	68	50	13	34	42	89	40	>35%
*LL	SB	35	5	53	30	53	65	53	65	65	50	58	62	45	59	70	53	50	65	>35%
(%)	SG	19	35	29	35	40	60	30	25	35	65	70	58	25	25	30	36	39	37	>50%
*PL	SB	41	25	17	19	22	20	18	17	18	20	25	17	18	24	18	19	24	23	>12%
(%)	SG	35	34	20	35	32	30	35	32	19	21	29	32	18	22	19	22	20	29	>30%
*PI	SB	05	40	26	42	25	43	20	26	25	26	30	22	15	26	45	50	50	44	----
(%)	SG	09	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.70	1.80	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	----
g/cc	SG	1.70	1.80	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	
**OMC	SB	18	15	12	15	15	12	15	15	12*	15	18	18	15	12	14	14	15	20	-----
(%)	SG	20	18	20	20	32	30	30	25	20	20	25	20	25	20	25	20	24	25	
**CBR	SB	10.45	34.54	5.41	10.4	13.41	13.0	5.45	5.45	34.5	13.4	13.0	5.45	15.1	13.00	10.00	12.0	14.00	13.00	>30%
(%)	SG	31.55	20.15	30.15	5.70	20.14	15.1	20.10	31.5	10.5	12.5	5.21	31.5	21.40	10.20	5.31	31.50	5.31	15.10	>30%
*ASHTO Soil Class					A-2-4 A-2-4	A-2-6 A-2-6	A-4 A-2-6	A-2-4 A-2-7	A-2-6 A-2-7		A-2-7 A-5		A-7-6 A-4				A-4 A-7-5 A-7-5			

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 9: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Katchia Kwoi-Nassarawa Road 346(F, 238)

Soil properties		KM 24-26+000KM			KM 28-30+000KM			KM 32 – 34+000KM			KM 36-38+000KM			KM 40–42+000KM			KM44-46+000KM			FMW&H 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	89	70	66	58	52	25	89	50	58	34	23	32	22	35	30	43	66	23	>35%
(%)	SG	50	13	34	42	89	40	36	80	42	16	89	68	70	13	89	57	18	89	>35%
*LL	SB	45	59	70	53	50	65	53	65	65	50	58	62	35	65	53	30	53	58	>35%
(%)	SG	25	25	30*	36	39	37	30	25	35	65	70	58	19	35	29	35	40	70	>50%
*PL	SB	20	25	17	18	24	18	19	24	23	41	25	17	19	22	20	18	17	18	>12%
(%)	SG	21	29	32	18	22	19	22	20	29	35	34	20	35	32	30	35	32	19	>30%
*PI	SB	15	26	45	50	50	44	20	26	25	26	30	22	05	40	26	42	25	30	----
(%)	SG	10	15	16	17	19	08	15	10	26	16	16	12	09	15	19	21	13	16	
**MDD	SB	1.80	1.81	1.88	1.70	1.90	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.70	1.80	1.80	1.60	1.70	1.88	----
g/cc	SG	1.80	1.81	1.88	1.70	1.90	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.70	1.80	1.80	1.60	1.70	1.88	
**OMC	SB	12	15	15	12	15	18	15	12	15	15	12	12	14	14	15	20	12	15	-----
(%)	SG	30	30	25	20	20	25	18	20	20	32	30	20	25	20	24	25	20	20	
**CBR	SB	15.1	13.00	10.00	12.0	14.00	13.00	5.45	5.45	34.55	13.4	13.0	5.45	10.45	34.5	5.41	10.41	13.41	13.0	>30%
(%)	SG	21.40	10.20	5.31	31.55	5.31	15.10	20.10	31.5	10.50	12.5	5.21	31.5	31.53	20.15	30.15	5.70	20.14	5.21	>30%

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
SB: Sub base
SG: Sub grade
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 9: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Katchia Kwoi-Nassarawa Road 346(F, 238)

Soil properties		KM 48-50+000KM			KM52-54+000KM			KM 56–58+000KM			KM 60-62+000KM			Mean
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	
*PSD	SB	58	34	23	32	22	35	30	43	66	23	89	70	18.1
	SG	42	16	89	68	70	13	89	57	18	89	50	13	49.3
*LL	SB	65	50	58	62	35	65	53	30	53	58	45	59	55.3
(%)	SG	35	65	70	58	19	35	29	35	40	70	25	25	38.5
*PL	SB	18	24	18	19	24	23	41	25	17	19	22	20	21.4
(%)	SG	18	22	19	22	20	29	35	34	20	35	32	30	27.8
*PI	SB	25	26	30	22	05	40	26	42	25	30	15	26	31.5
(%)	SG	26	16	16	12	09	15	19	21	13	16	10	15	15.1
**MDD	SB	1.80	1.82	1.88	1.94	1.70	1.80	1.80	1.60	1.70	1.88	1.80	1.81	1.79g/cc
g/cc	SG	1.80	1.82	1.88	1.94	1.70	1.80	1.80	1.60	1.70	1.88	1.80	1.81	1.80g/cc
**OMC	SB	25	35	50	30	35	25	32	25	35	50	25	45	34.5
	SG	30	30	25	35	40	30	35	29	32	25	32	37	32.1
**CBR	SB	34.56	13.4	13.0	5.45	10.45	34.54	5.41	10.41	13.41	13.0	15.1	13.00	13.4
(%)	SG	10.50	12.5	5.21	31.54	31.50	20.15	30.1*	5.70	20.14	5.21	21.4	10.20	17.9
*ASHTO Soil Class				A-2-4 A-2-4	A-2-6 A-2-6	A-4	A-2-4 A-2-7	A-2-6	A-2-7 A-5		A-7-6 A-4			

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 9: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Hot Dry (Zone 1) and Temperate Dry (Zone2)

Mophoclimatic Zones	State	Road section	Geotechnical Properties	Sub base		Sub grade		Sample Location	Road KM
				Passed	Failed	passed	Failed		
Hot Dry (zone 1)	*Kebbi	Birnin-Yauri-Malanda-Wara Rd. 10(F.201)	PSD	30	24	20	34	54	89
			LL	25	29	49	5	54	89
			PL	02	52	12	42	54	89
			MDD*	-	-	-	-	54	89
			CBR	49	5	48	6	54	89
Hot Dry (zone 1)	*Kano	Kano-Gwarzo-Katsina Rd. 368(F.128)	PSD	32	22	10	34	54	90
			LL	11	43	51	3	54	90
			PL	13	41	54	-	54	90
			MDD	-	-	-	-	54	90
			CBR	6	48	19	25	54	90
Temperate Dry (Zone 2)	*Kaduna	Katchia-Kwoi-Nassarawa Rd. 346(F.238)	PSD	20	28	14	34	48	80
			LL	05	43	37	11	48	80
			PL	---	48	27	21	48	80
			MDD	---	--	---	---	48	80
			CBR	42	6	35	13	48	80
Temperate Dry (Zone 2)	*Nassarawa	Nassarawa-Toto-Abaji-Abuja Rd. 301(F.124)	PSD	24	30	8	46	54	98
			LL	--	54	50	4	54	98
			PL	-----	54	33	21	54	98
			MDD	---	---	---	---	54	98
			CBR	49	5	16	38	54	98

Source: Author's compilation, (2018). *FMW&H (1997) Highway Manuals, (2013) Vol.II

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^{3}/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005)

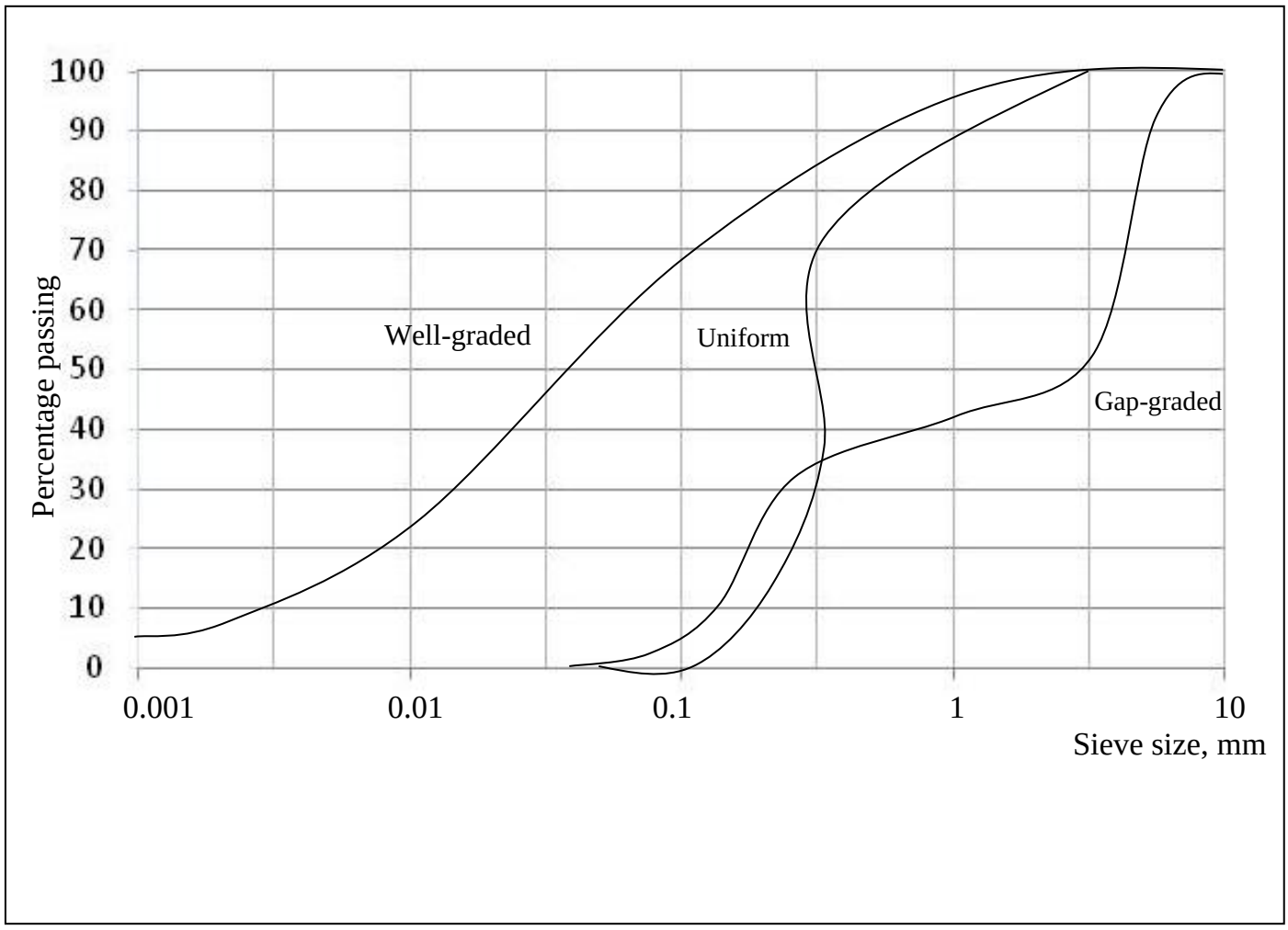


Figure 9: Particle Size Distribution for Katchia-Nassarwa-Kwoi-road
Source: Garber & Hoel, (2009).

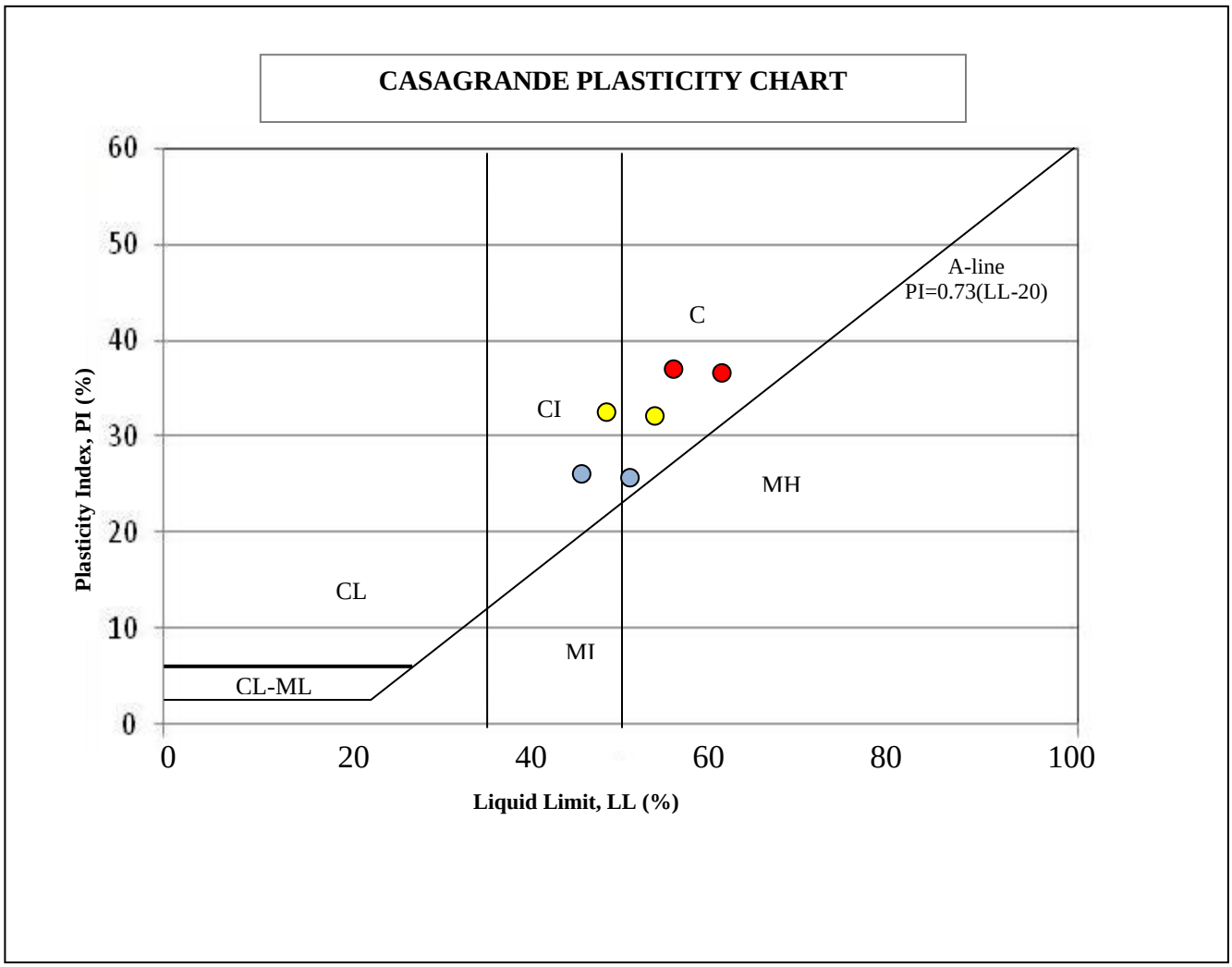


Figure 10 Plasticity Chart for Katchia-Kwoi Road
Source: Garber & Hoel, (2009).

4.5 Geotechnical Properties of Zone 2, (Temperate Dry) Nassarawa –Toto-Abaji-Abuja Road 346 (F.238).

Particle Size Distribution (PSD) Subgrade

PSD for subgrade is presented Tables 10 the values ranges from 8- 94% in the 54 locationsof the study area. Only 8(14.8%) sampled locations passed the FMW&H,(1997) standard for road in Nigeria and 46(85.2%) failed the test. About 85.2% of the road sections have more than 35% materials retained. This is in view of the high clay contents in many part of the study area. This is similar to the distribution of soil samples in the foundation of the road as stipulated by the American Association of State Highway and Transport Official (AASHTO) which falls into A-2-4,A-2-4,A-2-6,A-2-7, A-2-7-4, A-7-6 (sandy-clayey soil materials) for subgrade indicating that road is underlained by mixture of high to medium clay material, fine sand, silt or clayey gravel and sand.

Particle Size Distribution (PSD) Subbase

PSD in the study area as presented in Table 10 PSD value in the subbase category ranges from 15-75%. In the 54 locations in the study area almost 24(44.4%) locations recorded values less than 35% of the benchmark for construction of road and bridges FMW&H, (1997). Hence they passed the PSD test. About 30(55.6%) of the road stretch of the road did not complied with the standard suggesting that, this sections of the road have high clayey materials which are distructive tocivil engineering structures especially road. The soil materials of the road are is classified in to AASHTO category of A-2-7, A-7, A-2-4, A-2-5,A-2-7,A-7-5,A-7-6.

Liquid Limit (LL) Subgrade

The liquid limit is a measure of levels of cohesiveness, consistency, consolidation and toughness of soil materials. The value of liquid limits (LL) in subgrade ranges from 25-5677% (Tables 10) in all the 54 sampled locations in the study area 50(92.3%) locations were less than 50% benchmark as stipulated by FMW&H, (1997). This suggest that 50% part of the road were cohesive and consistent even in the presence of water. 4 locations namely in chainages (KM 20-24+000; 26+28+000; 42-44+000; 64-66+000) were higher than the stipulated 50% bench mark and they failed the test of LL in subgrade category.

Liquid Limit (LL) Subbase

The value of Liquid limit (LL) in subbase category ranges from 49-70% (Table 10). The results of LL in subbase category when compared with the benchmark in 54 locations showed that, all the sampled locations were higher than the stipulated benchmark of less than 35% (FMW&H, 1997). This suggesting that, all the sampled location of the road under study failed the LL test. Hence, the subbase materials were unconsolidated, and are very poor for road subbase.

Plastic Limit (PL) Subgrade

The value of PL ranges from 18-35% (Table 10) in 54 locations in the subgrade. The PL values benchmark of less than 30% is required to pass the PL subgrade test. The plastic limit is an indication of the quantity of water in the soil and a measure of how soil can become plastic. The results obtained showed that, only 33(61.1%) passed the standard specification for the construction of road and bridges in Nigeria (FMW&H, 1997). Subgrade materials in 21(38.8%)

were greater than 30% hence they are non plastic materials and they failed the PL subgrade category. Suggesting that, 61.1% of samples locations are very good foundation materials.

Plastic Limit (PL) Subbase

The values of PL in subbase in Table 10 range from 17-25%. The values obtained for subbase in all the 54 sampled locations were greater than the benchmark value of >12% hence all locations failed the test for the construction of road and bridges of the FMW&H, (1997). Hence, subbase materials not fit for road materials along Nassarawa-Toto-Abaji-Abuja road.

Maximum Dry Density (MDD) Subgrade

This is a measure of the extent of engineering compaction required by a geotechnical surface. MDD for subgrade (Table 10) ranges from 1.60-1.94g/cc along various sample points in the 54 location. MDD does not have acceptable value because of the complexity and variation of clay soil types in Nigeria as presented in figure 4. This variation in clayey materials in Nigeria makes it difficult to have a clear cut range or bench mark for construction of road and bridges in Nigeria however, Affonime and Anniekan (2005) make a clear categorization of MDD into low (< 1.80g/cc), medium (1.80-1.85g/cc), hgh (1.85-1.90g/cc) and very high (>1.90g/cc). Therefore, results in the study will determine the clay type in the road. Out of the 54 locations MDD in 21(38.9%) locations ranges < 1.80g/cc suggesting materials composed of low clay contents, 21(38.9.5%) locations also ranges from 1.80-1.85 also an indication of medium clay contents, 6(11.1%) locations ranges from 1.85-1.90g/cc indicating high clay contents whle other 6(11.1%) locations ranges from in >1.90g/cc (Table 10), which also indicate a very high clay content. This is an indication that at each location constitutes a particular clay content which

could also causes the road section to fail failure experience at the road under study. The results showed that, materials will yield tomcompaction by engineering equipments.

Maximum Dry Density (MDD) Subbase

MDD for subbase category presented in Table 10, ranges from 1.60-1.94g/cc in the 54 locations in the study area. Of all the sampled locations 20(37.4%) out of the 54 locations range < 1.86g/cc this implies materials are low clay contents, 21(38.9%) locations also have MDD ranging between from 1.80-1.85g/cc which is medium clay types, 6(11.1%) locations ranges from 1.85-1.90g/cc suggesting high clay contents and 7 (12.9%) locations range > 1.90g/cc implying the presence of very high clay contents. This showed that the magnitude of road failure caused by MDD was determined by the levl of cclayey materials various magnitude as shown in figue 12..

California Bearing Ratio (CBR) Subgrade

The soaked CBR test is a measure of how stable an earth materials will be when materials are wet. The CBR considered in the study is soaked in the subgrade category in Table 10 ranges from 5.45-34.56% in 54 sample locations. The prescribed values for CBR in subgrade for Nigerian road should not be greater than >30%. Hence, the benchmark values were reached in 38(70.4%) of the road and the standard were not attained in 16(29.6%) along the road. This suggesting that, almost 70.4% of the samples were good materials for construction of road and bridges in Nigeria as stipulated by FMW&H, (1997).

California Bearing Ratio (CBR) Subbase

The CBR in the subase category as presented in Table 10 ranges from 5.45-34.56% for soaked samples along the 54 points. The benchmark for CBR for the construction of road and bridges as

stipulated by FMW&H,(1997) must not be higher than 30%. Hence these conditions were met in 41(75.9%) locations. Suggesting that, 75% of the larger part of the road complied with the standard specifications for the road and bridges in Nigeria. While results also showed that, 13(24.1%) of the road sections failed the test hence, they less stable locations especially when they becomes wet. This condition simply explain reasons for the road failure in rainy season in the Nassarawa –Toto-Abaji-Abuja area.

Table 10: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Nassarawa-Toto-Abaji-Abuja Road 301(F.124)

Soil Properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8–10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM20-22+000KM			FMW&H 1997
Sampled locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	15	64	66	58	52	15	75	20	58	34	20	32	30	35	15	43	75	58	>35%
(%)	SG	94	36	34	42	48	94	36	80	42	66	08	68	08	65	94	57	34	42	>35%
*LL	SB	63	52	70	68	66	65	64	55	65	68	55	62	62	65	53	60	70	49	>35%
(%)	SG	25	25	30	36	39	37	30	25	35	38	36	26	28	35	29	35	56	30	>50%
*PL	SB	20	25	17	18	24	18	41	25	17	19	22	20	18	24	18	19	24	23	>12%
(%)	SG	21	29	32	18	22	19	35	34	20	35	32	30	35	22	19	22	20	29	>30%
*PI	SB	43	42	45	50	50	44	44	28	44	42	40	47	48	40	40	42	44	43	----
(%)	SG	10*	15	16	17	19	08	15	10	26	16	16	12	14	15	19	21	13	15	
**MDD	SB	1.80	1.81	1.88	1.70	1.90	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.70	1.80	1.80	1.60	1.70	1.70	----
g/cc	SG	1.80	1.81	1.88	1.70	1.90	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.70	1.80	1.80	1.60	1.70	1.70	
*OMC	SB	25	45	35	40	42	37	35	30	25	35	50	30	35	25	32	25	35	40	-----
(%)	SG	32	37	25	35	32	35	30	35	30	30	25	35	40	30	35	29	32	30	
**CBR	SB	13.0	30.07	5.10	12.0	14.0	13.0	31.07	5.45	34.56	13.4	13.0	5.45	5.45	34.58	13.4	20.1	13.4	13.0	>30%
(%)	SG	20.1	5.71	20.3	31.1	31.5	30.2	5.10	20.3	5.45	20.1	20.5	13.10	20.5	31.5	15.5	25.4	31.1	30.1	>30%
*ASHTO Soil Class		A-2-7. A-4 A-2-4. A-2-5. A-2-4. A-2-6.A-2-7.								A-2-6 A-2-7 A-4 A-7-5. A-2-7. A-4.									A-7-6 A-6. A-7-6	

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 10: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Nassarawa-Toto-Abaji-Abuja Road 301(F.124)

Soil Properties		KM 24 – 26+000KM			KM 28-30+000KM			KM 32-34+000KM			KM 36-38+000KM			KM 40– 42+000KM			KM44-46+000KM			FMW&H 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	75	20	58	34	20	32	15	64	66	58	52	15	43	75	58	30	35	15	>35%
(%)	SG	36	80	42	66	08	68	94	36	34	42	48	94	57	34	42	08	65	94	>35%
*LL	SB	64	65	65	68	50	62	63	55	70	68	66	65	60	70	65	62	65	50	>35%
(%)	SG	30	25	35	38	36	26	25	25	30	36	39	37	35	56	30	28	35	29	>50%
*PL	SB	20	25	17	18	24	18	41	25	17	19	22	20	18	24	18	19	24	23	>12%
(%)	SG	21	29	32	18	22	19	35	34	20	35	32	30	35	22	19	22	20	29	>30%
*PI	SB	44	28	44	42	40	47	43	42	45	50	50	44	42	44	43	48	40	40	----
	SG	15	10	26	16	16	12	10	15	16	17	19	08*	21	13	15	14	15	19	
**MDD	SB	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	1.60	1.70	1.70	1.70	1.80	1.80	----
g/cc	SG	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	1.60	1.70	1.70	1.70	1.80	1.80	
**OMC	SB	35	30	25	35	50	30	25	45	35	40	42	37	25	35	40	35	25	32	-----
	SG	30	35	30	30	25	35	32	37	25	35	32	35	29	32	30	40	30	35	
**CBR	SB	30.4	5.45	34.58	13.4	13.0	5.45	13.0	30.0*	5.10	12.0	14.0	13.00	20.1	30.48	13.0	5.45	34.56	13.4	>30%
	SG	5.10	20.3	5.45	20.1	20.5	13.1	20.1	5.71	20.3	31.1	31.5	30.20	25.4	31.1	30.1	20.5	31.5	15.5	>30%
*ASHTO Soil Class		A-2-7. A-4 A-2-4. A-2-5. A-2-4. A-2-6.A-2-7.								A-2-6 A-2-7 A-4 A-7-5. A-2-7. A-4.									A-7-6 A-6. A-7-6	

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 10: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Nassarawa-Toto-Abaji-Abuja Road 301(F.124)

Soil Properties		KM 48–5 0+000KM			KM 52-54+000KM			KM 56-58+000KM			KM 60-62+000KM			KM 64 – 66+000KM			KM68-70+000KM			Mean
Sampled locations		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
*PSD	SB	30	66	58	34	20	32	15	64	66	58	52	15	43	75	58	30	35	15	40.3
(%)	SG	08	34	42	66	08	68	94	36	34	42	48	94	57	34	42	08	65	94	49.7
*LL	SB	62	70	65	68	50	62	63	55	70	68	66	65	60	70	65	62	65	50	61.5
(%)	SG	28	30	35	38	36	26	25	25	30	36	39	37	35	56	30	28	35	29	30.4
*PL	SB	19	17	17	18	24	18	41	25	17	19	22	20	18	24	18	19	24	23	21.4
(%)	SG	22	20	32	18	22	19	35	34	20	35	32	30	35	22	19	22	20	29	27.8
*PI	SB	48	45	44	42	40	47	43	42	45	50	50	44	42	44	43	48	40	40	40.4
	SG	14	16	26	16	16	12	10	15	16	17	19	08*	21	13	15	14	15	19	16.4
**MDD	SB	1.70	1.88	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	1.60	1.70	1.70	1.70	1.80	1.80	1.89
g/cc	SG	1.70	1.88	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	1.60	1.70	1.70	1.70	1.80	1.80	1.77
**OMC	SB	35	35	25	35	50	30	25	45	35	40	42	37	25	35	40	35	25	32	30.6
	SG	40	25	30	30	25	35	32	37	25	35	32	35	29	32	30	40	30	35	28.9
**CBR	SB	5.45	5.10	34.58	13.4	13.0	5.45	13.0	30.0*	5.10	12.0	14.0	13.00	20.1	30.48	13.0	5.45	34.56	13.4	15.5
	SG	20.5	20.3	5.45	20.1	20.5	13.1	20.1	5.71	20.3	31.1	31.5	30.20	25.4	31.1	30.1	20.5	31.5	15.5	20.9
*ASHTO Soil Class		A-2-7. A-4 A-2-4. A-2-5. A-2-4. A-2-6.A-2-7.								A-2-6 A-2-7 A-4 A-7-5. A-2-7. A-4.									A-7-6 A-6. A-7-6	

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 10: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Hot Dry (Zone 1) and Temperate Dry (Zone2)

Mophoclimatic Zones	State	Road section	Geotechnical Properties	Sub base		Sub grade		Sample Location	Road KM
				Passed	Failed	passed	Failed		
Hot Dry (zone 1)	*Kebbi	Birnin-Yauri-Malanda-Wara Rd. 10(F.201)	PSD	30	24	20	34	54	89
			LL	25	29	49	5	54	89
			PL	02	52	12	42	54	89
			MDD*	-	-	-	-	54	89
			CBR	49	5	48	6	54	89
Hot Dry (zone 1)	*Kano	Kano-Gwarzo-Katsina Rd. 368(F.128)	PSD	32	22	10	34	54	90
			LL	11	43	51	3	54	90
			PL	13	41	54	-	54	90
			MDD	-	-	-	-	54	90
			CBR	6	48	19	25	54	90
Temperate Dry (Zone 2)	*Kaduna	Katchia-Kwoi-Nassarawa Rd. 346(F.238)	PSD	20	28	14	34	48	80
			LL	05	43	37	11	48	80
			PL	---	48	27	21	48	80
			MDD	---	--	---	---	48	80
			CBR	42	6	35	13	48	80
Temperate Dry (Zone 2)	*Nassarawa	Nassarawa-Toto-Abaji-Abuja Rd. 301(F.124)	PSD	24	30	8	46	54	98
			LL	--	54	50	4	54	98
			PL	-----	54	33	21	54	98
			MDD	---	---	---	---	54	98
			CBR	49	5	16	38	54	98

Source: Author's compilation, (2018). *FMW&H (1997) Highway Manuals, (2013) Vol.II

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^{3}/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005).

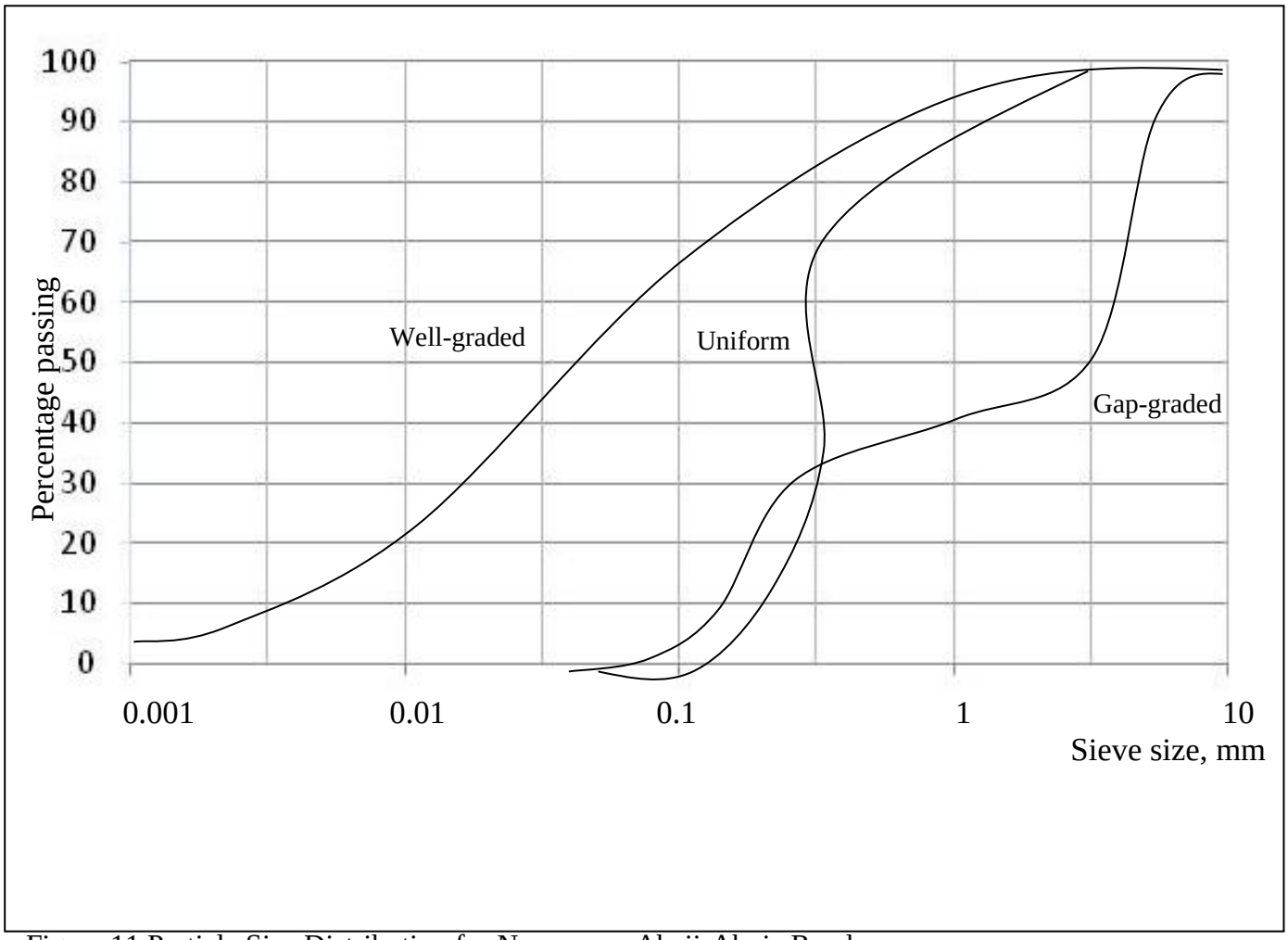


Figure 11.Particle Size Distribution for Nassarawa-Abaji-Abuja Road

Source: Garber & Hoel,(2009)

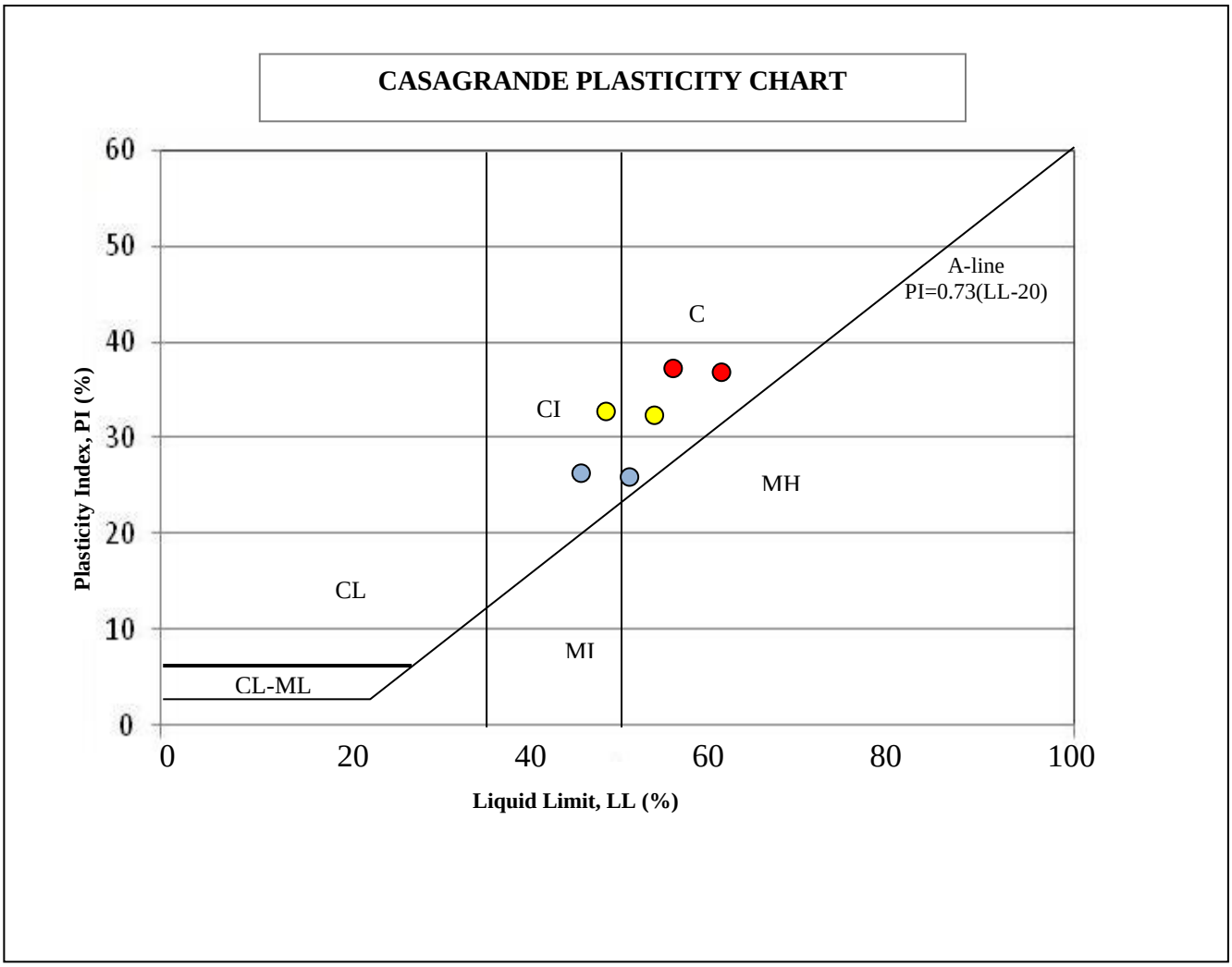


Figure 12 Plasticity Chart for Nassarawa-Toto-Road
Source: Garber & Hoel,(2009)

4.6 Geotechnical properties of subgrade and sub base of zone 3,(Hot Humid) Ilorin-Ajase-Ipo- Umuaran-Iloffa Road 45 (a123.) 89.3KM,Width 7.3

Particle Size Distribution (PSD) Subbase

PSD subbase category ranges from 5-66% as presented in Table 11 in this road section of the study area. In the 54 locations sampled collected in 25(46.3%) locations of the total sample points recorded the values were less than 35% and hence, they complied with the the benchmark for construction road and bridges of FMW&H, (1997). Only 29(53.7%) of the road stretch of the road did not complied with the standard suggesting that the section of the road have higher clay contents which is very distructive to Civil Engineering structure especially road. The mean of PSD in subbase is 43.1%. The foundation materials are classified in to AASHTO classification of A-7-6.

Particle Size Distribution (PSD) Subgrade

The particle size distribution plays important role in geotechnical studies most especially the percentage of clay retained. According to FMW&H, (1997) percentage of clay retained should not be greater than 35% for road surfaces. PSD in subgrade is presented in Table 11 its ranges from 16-68% in 54 locations. Results showed that, 48(88.9%) were higher than the stipulated value and they were not retained hence, they failed the bench mark of > 35%. The percentage of clay is less than 35% in only 6(11.1%) locations therefore, they passed the standard specification for the construction of road and bridges in Nigeria. Suggesting that, the PSD value in the subgrade category was retained in few locations along Ilorin-Ajase-Ipo-Illoffa road. This suggests that the values were satisfactory in only 11.1% of the road section where PSD value is less than 35%. Whenever clay contents retained were higher than 35% road failure will be

expected. The soil distribution of the road according to American Association of State Highway and Transport Official (AASHTO) falls into A-2-6, A-5-7 for subgrade (Table 11).

Liquid Limit (LL) Subbase

The soil liquid limit is an indication of how cohesive, consistent and consolidated the soil is. Liquid limit (LL) of the subbase materials ranges from 55-70% (Table 11). The subbase materials were above than 35% in all locations sampled locations in this road axis suggesting that, LL did not met the required specification for road and bridges (FMW&H, 1997). In almost all the 54 sampled locations failed the test. This implies that large part of the road section could hold water. Hence the road is likely to shrink. Liquid limit is an explanation of how much water a materials could hold

Liquid Limit (LL) Subgrade

The value of Liquid limits (LL) ranges from 24-40% in subgrade category (Table 11). Results showed that, LL were bellow 50% hence meet the standard specification (FMW&H, 1997). Suggesting that, all sampled locations are of good quality materials in the subgrade category. This implies that, all thections of LL in subgrade along Ilorin-Omuaran-Iloofa road are good and adequate for road construction.

Plastic Limit (PL) Subbase

PL in the subbase category in Table 11 ranges from 15-26%. This suggests that, PL in along the 54 locations were above 12%. This shows the materials did not passed the plastic limit test for the construction of road and bridges in Nigeria (FMW&H, 1997). This implies that, results obtained for subbase materials along the road sections is not completely suitable for road construction. Plastic limit is an indication of the amount of water in the materials and a measure

of how such materials respond to water. Suggesting that, due to heavy clayey materials along the road there is a tendency that the subbase retaned much water which is not good for subbase of the road.

Plastic Limit (PL) Subgrade

The plastic limit is an indication of the quantitiy of water and how plastic the soil can be. PL ranges from 10-27% as presented in Table 11 in the subgrade. PL values benchmark is >30%. This suggests that all values along the road section were lower than 30%. This suggests that, they confirm with the acceptable standard. This imlies that, all the 54 sampled locations (Table11) passed the benchmark of less than 30% for a relatively durability of road along the section.

Maximum Dry Density (MDD) Subbase

. MDD for subbase (Table 8) ranges from 1.70-1.88g/cc in the 54 locations. In all 54 locations sampled 16(29.6%) locations ranges < 1.80g/cc this implies that the materials are made of low clay materials, 21(38.9%) locations ranges from 1.80-1.85g/cc shows materials also consist of medium clay types and 17(31.5%) locations ranges from 1.85-1.90g/cc suggesting that materials composed of high clay contents This shows that the magnitude of road failure vary according to the clay types along the road. The mean of MDD for subbase is 1.86g/cc(Table 11).The subbase can also easily be compacted in view of the results displayed above.

Maximum Dry Density (MDD) Subgrade

The MDD is the measure of the level of compaction that a material required this is because there are materials that cannot be compacted. MDD for subgrade (Table 11) ranges from 1.60-1.88g/cc in all the 54 sample locations along the road. Results showd that, out of 54 locations 16(29.9%) location ranges into < 1.80g/cc which indicated low clay contents, 23(42.6%)

locations ranges from 1.80-1.85 suggesting thes locations composed of medium clay contents and 14 (25.9%) locations ranges from 1.85-1.90g/cc also indicates high clay contents. Results suggest that, at each sample locations they are various types of clay materials responsible to road failure along the road sections in the study area. Results indicated above showed this materials can easily be compacted.

California Bearing Ratio (CBR) Subbase

CBR in subase category presented in (Table 11) ranges from 5.45-43% for soaked sample along 54 sampled points. The benchmark for CBR for the construction of road and bridges in Nigeria is > 30%. Hence the value were reached in only in 28(51.9%) got the pass mark of 30% of the sample location suggesting that, the pass the test for standard specification for road and bridges(FMW&H,1997). The situation was equally bad in 26 (48.1%) locations were higher than the benchmark hence they failed the specification for the road and bridges in Nigeria. Hence the road section failed.The mean of CBR for subase is 16.1.

California Bearing Ratio (CBR) Subgrade

The CBR is a measure of soil stability. CBR soaked in the subgrade category ranges from 5.45-34.10% in 54 sampled locations. The benchmark for CBR for the construction of road and bridges in Nigeria is > 30%. Hence the value were reached in only in 32 (59.2%) sample location suggesting that, the pass the test for standard specification for road and bridges(FMW&H,1997). This situation is worst in 22(40.7%) locations were higher than the benchmark hence they failed the specification for the road and bridges in Nigeria. The mean of CBR for subbase is 25.6%.

Table 11: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Ilorin-Ajase-Ipo-Umuaran-Illoffa Road 45(A.125)

Soil Properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8 – 10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM22-24+000KM			FMW&H, 1997
Sampled locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	30	35	45	43	66	58	64	20	58	34	20	32	15	64	66	58	52	16	>35%
(%)	SG	50	65	56	57	34	42	36	68	42	66	68	68	56	36	34	42	48	56	>35%
*LL	SB	62	65	55	60	70	65	64	65	65	68	58	62	63	59	70	68	66	65	>35%
(%)	SG	28	35	29	35	40	30	30	25	35	38	36	26	25	25	30	36	39	37	>50%
*PL	SB	14	25	15	18	26	22	20	21	21	23	18	15	20	17	25	18	16	21	>12%
(%)	SG	14	20	10	14	27	15	10	25	12	20	10	14	15	16	18	19	20	22	>30%
*PI	SB	48	40	40	42	44	43	44	28	44	42	40	47	43	42	45	50	50	44	----
(%)	SG	14	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.80	1.88	1.83	1.88	1.83	1.88	1.83	1.78	1.80	1.82	1.88	1.88	1.80	1.81	1.88	1.78	1.78	1.79	----
g/cc	SG	1.78	1.80	1.80	1.60	1.76	1.79	1.80	1.70	1.80	1.82	1.88	1.84	1.80	1.81	1.88	1.78	1.88	1.88	
**OMC	SB	35	25	32	25	35	40	35	30	25	35	50	30	25	45	35	40	42	37	-----
(%)	SG	40	30	35	29	32	30	30	35	30	30	25	35	32	37	25	35	32	35	
**CBR	SB	30.45	34.58	13.4	30.45	13.4	31.17	34.54	5.45	34.57	13.4	13.0	5.45	30.05	13.0	35.48	5.45	55.30	34.70	>30%
(%)	SG	31.10	22.30	30.1	31.45	34.1	20.10	13.50	31.50	30.16	20.1	5.45	31.10	34.10	30.1	20.19	31.3	13.45	31.45	>30%
*ASHTO Soil Class				A-2-6						A-7-5								A-7-6		

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table11: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Ilorin-Ajase-Ipo-Umuaran-Illoffa Road 45(A.125)

Soil Properties		KM 26 – 28+000KM			KM 30-32+000KM			KM 34 – 36+000KM			KM38-40+000KM			KM 42 – 44+000KM			KM46-48+000KM			FMW&H 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	58	35	5	43	66	58	64	20	58	34	20	32	05	64	66	58	52	5	>35%
(%)	SG	42	56	40	56	34	42	36	56	42	56	50	50	56	36	34	54	48	45	>35%
*LL	SB	65	65	55	60	70	65	64	65	65	68	58	62	63	59	70	68	66	65	>35%
(%)	SG	35	35	24	35	40	30	30	20	35	38	36	24	25	25	30	36	39	37	>50%
*PL	SB	21	25	15	18	26	22	25	15	18	26	22	20	20	17	25	18	16	21	>12%
(%)	SG	12	20	10	14	27	15	20	10	14	27	15	10	15	16	18	19	20	22	>30%
*PI	SB	44	40	40	42	44	43	44	28	44	42	40	47	43	42	45	50	50	44	----
(%)	SG	26	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.80	1.80	1.80	1.78	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.88	1.80	1.81	1.88	1.78	1.88	1.79	----
g/cc	SG	1.80	1.80	1.80	1.78	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.80	1.80	1.81	1.88	1.76	1.88	1.79	
**OMC	SB	25	25	32	25	35	40	35	30	25	35	50	30	25	45	35	40	42	37	-----
(%)	SG	30	30	35	29	32	30	30	35	30	30	25	35	32	37	25	35	32	35	
**CBR	SB	34.57	34.52	13.4	30.45	13.4	5.10	34.56	5.45	34.56	13.4	13.0	5.45	13.0	13.0	38.46	5.45	32.05	34.56	>30%
(%)	SG	30.16	22.30	30.1	31.57	34.1	20.10	13.50	31.5	30.18	20.1	5.45	31.10	34.1	30.1	20.15	31.30	13.45	31.45	>30%
*ASHTO Soil Class				A-2-6						A-7-5								A-7-6		

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table11: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Ilorin-Ajase-Ipo-Umuaran-Illoffa Road 45(A.125)

Soil Properties		KM 26 – 28+000KM			KM 30-32+000KM			KM 34 – 36+000KM			KM38-40+000KM			KM 42 – 44+000KM			KM46-48+000KM			FMW&H 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	58	35	5	43	66	58	64	20	58	34	20	32	05	64	66	58	52	5	>35%
(%)	SG	42	56	40	56	34	42	36	56	42	56	50	50	56	36	34	54	48	45	>35%
*LL	SB	65	65	55	60	70	65	64	65	65	68	58	62	63	59	70	68	66	65	>35%
(%)	SG	35	35	24	35	40	30	30	20	35	38	36	24	25	25	30	36	39	37	>50%
*PL	SB	21	25	15	18	26	22	25	15	18	26	22	20	20	17	25	18	16	21	>12%
(%)	SG	12	20	10	14	27	15	20	10	14	27	15	10	15	16	18	19	20	22	>30%
*PI	SB	44	40	40	42	44	43	44	28	44	42	40	47	43	42	45	50	50	44	----
(%)	SG	26	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.80	1.80	1.80	1.78	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.88	1.80	1.81	1.88	1.78	1.88	1.79	----
g/cc	SG	1.80	1.80	1.80	1.78	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.80	1.80	1.81	1.88	1.76	1.88	1.79	
**OMC	SB	25	25	32	25	35	40	35	30	25	35	50	30	25	45	35	40	42	37	-----
(%)	SG	30	30	35	29	32	30	30	35	30	30	25	35	32	37	25	35	32	35	
**CBR	SB	34.57	34.52	13.4	30.45	13.4	5.10	34.56	5.45	34.56	13.4	13.0	5.45	13.0	13.0	38.46	5.45	32.05	34.56	>30%
(%)	SG	30.16	22.30	30.1	31.57	34.1	20.10	13.50	31.5	30.18	20.1	5.45	31.10	34.1	30.1	20.15	31.30	13.45	31.45	>30%
*ASHTO Soil Class				A-2-6						A-7-5								A-7-6		

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 11: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Ilorin-Ajase-Ipo-Umuaran-Illoffa Road 45(A.125)

Mophoclimatic Zones	State	Road section KM	Geotechnical properties	Sub base		Sub grade		Sample location	Road KM
				Passed	Failed	passed	Failed		
Hot Humid (zone 3)	Kwara	Ilorin-Umuaran-Illoffa Rd. 45(A.125)	PSD	25	29	06	48	54	89
			LL	--	54	54	---	54	89
			PL	---	54	54	---	54	89
			MDD	----	---	---	---	54	89
			CBR	28	26	32	22	54	89
	Kogi	Ayingba-Ankpa-Ofa Rd.45(A.233)	PSD	8	46	25	29	54	94
			LL	08	46	25	37	54	94
			PL	--	54	18	36	54	94
			MDD	---	---	----	---	54	94
			CBR	31	23	39	15	54	94
Warm Humid (zone 4)	Delta	Asaba-Agbor-Edo(SB) Rd. 25(A.232)	PSD	22	32	14	40	54	85
			LL	----	54	54	---	54	85
			PL		54	12	42	54	85
			MDD	---	---	----	---	54	85
			CBR	31	23	39	15	54	85
	Rivers	Porthacourt-Elele-Umanelu Rd. 414(F.229)	PSD	20	25	5	40	45	72
			LL	---	45	45	---	45	72
			PL	45	--	23	12	45	72
			MDD	---	---	----	----	45	72
			CBR	39	6	34	11	45	72

Source: Author's compilation, (2018). * Highway Manuals, (2013)

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^3/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005).

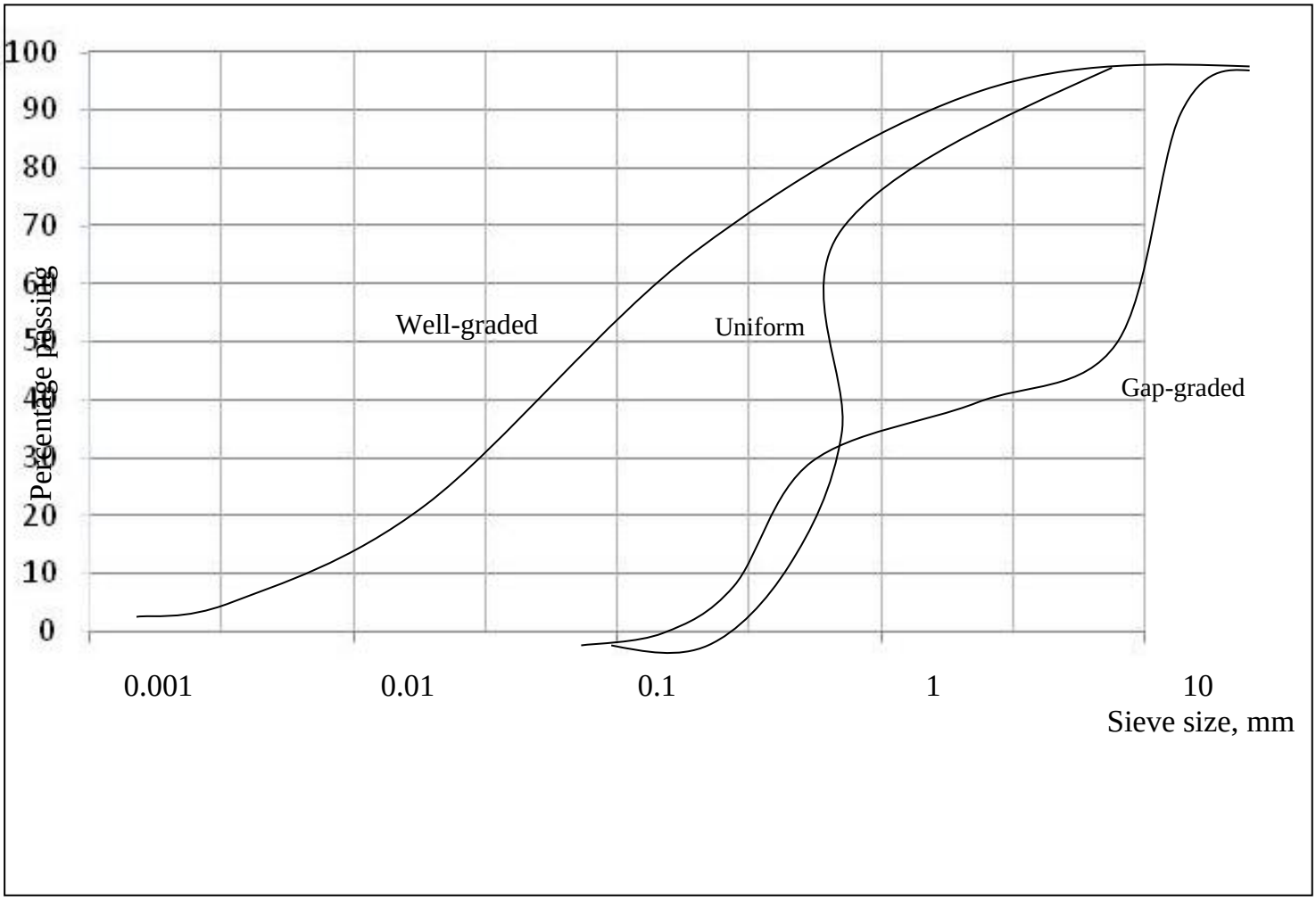


Figure 13 Particle Size Distribution for Ilorin-Ajase-Ipo-Omuaran-Illoffa Road
Source: Garber & Hoel, (2009).

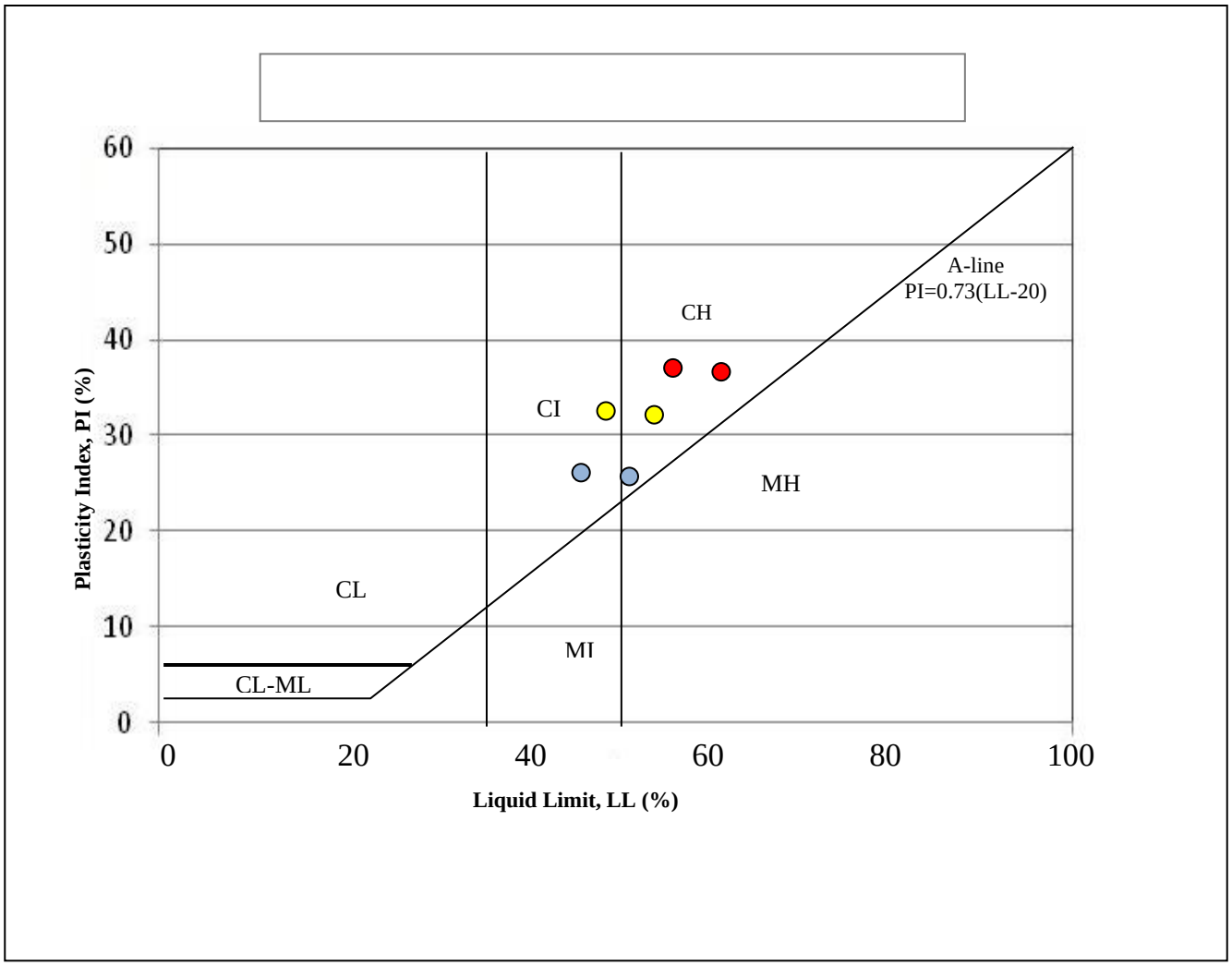


Figure 14 Plasticity chart for Ilorin-Iloffa Road
Source: Garber & Hoel, (2009).

4.7 Geotechnical properties of subgrade and sub base of zone 3,(Hot Humid) Ayingba-Ankpa-Ofa Road 45(A.233.) 94 KM

Particle Size Distribution (PSD) Subbase

PSD subbase category presented in Table 12 ranges from 6-70% in the 54 locations of the study areas. In the results 46(58.3%) sample locations were greater than 35% benchmark value of FMW&H, (1997) suggesting 58.3% of the road under study did not complied with the standard specification. Only 8(14.8%) sample locations passed the acceptable value of ≤ 35% for Nigerian road FMW&H,(1997). The PSD has a mean of 18.1% this showed that, 58.3% of the road is stable. The soil materials are classified in to AASHTO classification of A-2-6, A-2-4, A-2-6, A-2-7, A-27, A-2-6 and A-2-7.

Particle Size Distribution (PSD) Subgrade

The particle size distribution explains the percentage clay retained in the soil in road foundation. PSD in subgrade category presented in Tables 12 ranges from 6- 64% in 54 locations. The results showed that, in 25(46.3%) locations out of the 54 sample location have PSD values lower than 35%. This suggests that, only 46.3% of the section of road studied complied with the Nigerian standard for road construction and bridges FMW&H, (1997). Only 29(53.7%) locations failed the PSD value for the standard specification. This implication therefore, is that 53.7% of Ayingba-Ankpa-Ofa highway is clayey in nature and as a problem soil road failure is expected. The mean PSD is 57.7%. The distribution of soil samples in the foundation of the road according to American Association of State Highway and Transport Official (AASHTO) falls into A-2-4, A-2-6,A-2-7,A-2-6 and A-2-7, A-7-6 for subgrade.

Liquid Limit (LL) Subbase

In the subbase category liquid limit (LL) ranges from 25-40% Table 12 in all the 54 location sampled. The subbase materials were higher than 35% in 46 (85.2%) sampled points along the road suggesting that, they did not confirmed with the standard specification of >35% for the construction of road and bridges as stipulated by (FMW&H,1997) except in 8(14.8%) sampled locations were less than 35% benchmark as prescribed by FMW&H,(1997). This showed that, 85.2% LL for subbase materials can be said they largely unconsolidated along Ayingba-Ankpa-Ofa Road and were very poor. The mean value for LL is 55.7% in the study.

Liquid Limit (LL) Subgrade

The soil liquid limit is an indication of how cohesive, consistent and consolidated the soil is. The pattern of liquid limit (LL) recorded 22-40% in Table 12 in 54 different locations. When compared with the benchmark of ≤ 355% for subgrade results showed that, liquid limit was less than 50% in all the 54 locations of the road studied. This implies that, all the locations passed the LL benchmark value for construction of road and bridges (FMW&H, 1997). This implies that all location meet the acceptable standard for road construction.

Plastic Limit (PL) Subbase

PL in subbase in (Table 12) ranges from 15-26% in all locations were above 12% benchmark as stipulated by (FMW&H, 1997). This suggests that, results obtained in all the 54 location sampled in Table 12 did not meet the bench mark of theacceptable value of >12% for the construction of road and bridges of the FMW&H, (1997) suggesting that these locations failed the PL test. The mean of PL is 19.5%.

Plastic Limit (PL) Subgrade

The value of PL for subgrade ranges from 10-27% presented in Table 12. The value for PL value bench mark is ≤ 30. Results obtained obtained in 18(33.3%) locations out of the 54 locations studied showed that, there is 33.3% rate of compliance with standard specification as prescribed by FMW&H,(1997)in the study area.. Out of 54 locations sampled 36(66.7%) locations failed the test of PL value of the bench mark of ≤ 30% for the construction of road and bridges of FMW&H, (1997) This is as aresults of high clay contents of the soil in these locations .Hence, the subgrade materials are substandard in these locations. The plastic limit is an indication of the quantity of water in the soil and measure of how soil can flow or becomes plastic. The results obtained in these 36 locations showed that, there is a presence of water in the subgrade in these locations becomes plastic and therefore failed.

Maximum Dry Density (MDD) Subgrade

The MDD is a measure of the level of compaction that a material required, this measure is important because there are materials that cannot be compacted. MDD for subgrade in Table 12 ranges from 1.70-1.94g/cc in all the 54 locations. Results showed that out of 54 locations 21(38.8%) location ranges into < 1.80g/cc which suggest that, the soil is composed of low clay contents, 22(40.7%) locations ranges from 1.80-1.85g/cc which indicated medium clay contents, 6(11.1%) locations ranges from 1.85-1.90g/cc indicating high clay contents and 5(9.3%) locations ranges >1.90g/cc which shows that there is a very high clay content. The mean of MDD in the study is 1.79g/cc (Table 12). The results showed that materials can easily be compacted.

Maximum Dry Density (MDD) Subbase

The values MDD for subbase category as presented im Table 12 ranges from 1.70-1.94g/cc in all 54 sample locations in the study area. Out of 54 locations 16(29.6%) range < 1.80g/cc suggesting that, these locations are categorized under low clay contents, 21(38.8%) locations ranges from 1.80-1.85g/cc which is confirms the sections of road comprises medium clay types, 9(16.7%) locations ranges from 1.85-1.90g/cc which is also an indication of a high clay type and 8(14.8%) locations comprises of very high clay contents. This shows that the magnitude of road failure vary according to the clay types along the road. The subbase can also easily be compacted in view of the results displayed above.

California Bearing Ratio (CBR) Subbase

CBR in the subase category presented in Table 12 ranges from 5.45-45.44% for soaked samples along the 54 sample points. Results of CBR in subbase showed that, 44(81.5%) passed the CBR test suggesting that 82% of road passed and these location were stable and only 10(18.5%) failed the test therefore, the benchmark value of ≤30% of FMW&H,(1997) were not met. The mean CBR for subase is 13.3%.

California Bearing Ratio (CBR) Subgrade

The soaked CBR test is a measure of how stable an earth materials will be when such materials are wet. CBR soaked in subgrade presented in Table 12 ranges from 5.45-34.50% in the 54 locations of the study area. The bench mark for CBR soaked for the construction of road and bridges in Nigeria is ≤ 30%. Henc, the bench mark values were reached in 31(57.4%) the sampled locations. Suggesting that, 57% the section of the road passed the test. Only 23(42.6%) locations failed the standard specification

suggesting 42.6% of the road did not complied with stanadard that explains why these sections failed and ths implies that materials for subgrade are substandard. The mean CBR for subgrade is 25.9%.

Table 12: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Ayingba-Akpa-Ofa Road 45(A.233)

Soil Properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8 – 10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM22-24+000KM			FMW&H 1997
Sampled locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	30	35	10	43	40	44	64*	20	44	34	20	32	05	64*	66*	58	52	15	>35%
(%)	SG	70*	65*	95*	10	34	42	36	80*	42	66*	80*	68*	95*	36	34	42	48	95*	>35%
*LL	SB	62	65	22*	41	70	65	64	65	65	68	26*	62	41	59	70	68	25*	65	>35%
(%)	SG	28*	35	29*	35	40	30	30	25*	35	38	36	26*	25*	25*	30	36	39	37	>50%
*PL	SB	22	25	15	18	26	22	20	26	22	25	15	18	26	22	20	18	16	21	>12%
(%)	SG	15	20	10	14	27	15	10	27	15	20	10	14	27	15	10	19	20	22	>30%
*PI	SB	10	20	08	25	11	05	26	25	26	25	26	10	22	21	20	22	26	20	----
(%)	SG	14	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.70	1.80	1.80	1.87	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.78	----
g/cc	SG	1.70	1.80	1.80	1.78	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.78	1.83	
**OMC	SB	12	14	12	15	15	13	13	14	13	18	15	12	14	14	14	13	11	12	-----
(%)	SG	20	25	35	29	32	30	30	35	30	30	25	35	32	25	25	35	32	35	
**CBR	SB	13.40	13.0	5.45	34.5	13.4	5.45	13.41	5.10	13.4	5.45	13.41	5.10	13.00	13.0	13.40	13.0	5.45	13.0	>30%
(%)	SG	20.10	5.45	31.10	22.30	30.1	31.5	34.10	20.10	30.1	31.5	34.10	20.10	34.10	30.1	20.10	5.45	31.10	34.0	>30%
*ASHTO		A-2-4. A-2-6.A-2-7						A-2-4.A-2-6 A-2-7						A-7-6			A-6			
Soil Class		A-2-4. A-2-6						A-2-7						A-7-6			A-4			

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.
Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 12: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Ayigba-Akpa-Ofa Road 45(A.233)

Soil Properties		KM 26 – 28+000KM			KM 30-32+000KM			KM 34 – 36+000KM			KM 38-40+000KM			KM 42 – 44+000KM			KM46 - 48+000KM			FMW&H, 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	64	20	44	34	20	32	32	05	64	66	58	52	30	35	10	43	40	44	>35%
(%)	SG	36	80	42	66	80	68	68	95	36	34	42	48	70	65	95	10	34	42	>35%
*LL	SB	64	65	65	68	26	62	62	41	59	70	68	25	62	65	22	41	70	65	>35%
(%)	SG	30	25	35	38	36	26	28	25	25	30	36	39	28	35	29	35	40	30	>50%
*PL	SB	20	26	22	25	15	18	26	15	18	26	22	20	18	22	25	15	18	26	>12%
(%)	SG	10	27	15	20	10	14	27	10	14	27	15	10	19	15	20	10	14	27	>30%
*PI	SB	26	25	26	25	26	26	09	22	21	20	22	26	20	20	22	25	24	24	----
(%)	SG	15	10	26	16	16	12	12	10	15	16	17	19	14	15	19	21	13	15	
**MDD	SB	1.80	1.70	1.80	1.82	1.88	1.94	1.94	1.80	1.81	1.88	1.70	1.90	1.70	1.80	1.80	1.87	1.70	1.70	----
g/cc	SG	1.80	1.70	1.80	1.82	1.88	1.94	1.94	1.80	1.81	1.88	1.70	1.78	1.70	1.80	1.80	1.78	1.70	1.70	
**OMC	SB	13	14	13	18	15	12	12	14	14	14	13	11	12	14	12	15	15	13	-----
(%)	SG	30	35	30	30	25	35	35	32	25	25	35	32	20	25	35	29	32	30	
CBR	SB	30.45	5.10	13.4	45.44	13.4	5.10	5.10	33.15	13.0	13.40	37.0	5.45	13.4	13.0	30.45	34.5	13.4	5.45	>30%
(%)	SG	34.10	20.10	30.1	31.54	34.1	20.10	20.10	34.10	30.1	20.10	5.45	31.10	20.1	5.45	31.10	22.3	30.1	31.5	>30%
*ASHTO		A-2-4. A-2-6.A-2-7						A-2-4.A-2-6		A-2-7				A-7-6			A-6			
Soil Class		A-2-4. A-2-6						A-2-7						A-7-6			A-4			

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.
Transport
Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index

MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway

Officials
SB: Sub base
SG: Sub grade

Table 12: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Ayigba-Akpa-Ofa Road 45(A.23)

Soil Properties		KM 50 – 52+000KM			KM 54-56+000KM			KM 58 – 60+000KM			KM 62-64+000KM			KM 66 – 68+000KM			KM72-74+000KM			Mean
Sampled locations		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
*PSD	SB	10	35	10	43	40	44	64*	20	44	34	20	32	32	05	64*	66*	58*	52	35.6
(%)	SG	95	65*	95*	10	34	42	36	80*	42	66*	80*	68*	68*	95*	36	34	42	48	50.8
*LL	SB	22	65	21*	41	70	65	64	65	65	68	26*	62	62	41	59	70	68	25*	52.5
(%)	SG	29	35	29*	35	40	30	30	25*	35	38	36	26*	26*	25*	25*	30	36	39	29.8
*PL	SB	25	26	15	18	26	22	20	18	22	20	18	22	25	15	20	26	22	25	
(%)	SG	20	27	10	14	27	15	10	19	15	10	19	15	20	10	10	27	15	20	
*PI	SB	22	20	10	25	20	10*	26	10*	26	25	08*	25	12*	22	12*	20	12*	10*	15.9
(%)	SG	19	15	19	21	13	15	15	10	26	16	16	12	12	10	15	16	17	19	18.5
**MDD	SB	1.80	1.80	1.80	1.87	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.94	1.80	1.81	1.88	1.70	1.90	1.89
g/cc	SG	1.80	1.80	1.80	1.78	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.94	1.80	1.81	1.88	1.70	1.78	1.97
**OMC	SB	12	14	12	15	15	13	13	14	13	18	15	12	12	14	14	14	13	11	13.7
(%)	SG	35	25	35	29	32	30	30	35	30	30	25	35	35	32	25	25	35	32	22.7
**CBR	SB	30.45	13.0	5.45	34.5*	13.4	5.45	13.41	5.10	45.4*	5.45	13.41	5.10	5.10	34.0*	13.0	35.4*	13.0	5.45	13.3
(%)	SG	31.10	5.45*	31.1	22.30	30.1	31.5	34.10	20.1	30.1	31.5	34.10	20.10	20.10	34.10	30.1	20.10	5.45*	31.0	24.7
*ASHTO		A-2-4. A-2-6.A-2-7						A-2-4.A-2-6 A-2-7							A-7-6			A-6		
Soil Class		A-2-4. A-2-6						A-2-7							A-7-6			A-4		

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index

MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 12: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Hot humid (Zone 3) and warm Humid (Zone 4)

Mophoclimatic Zones	State	Road section KM	Geotechnical properties	Sub base		Sub grade		Sample location	Road KM
				Passed	Failed	passed	Failed		
Hot Humid (zone 3)	Kwara	Ilorin-Umuaran-Illoffa Rd. 45(A.125)	PSD	25	29	06	48	54	89
			LL	--	54	54	---	54	89
			PL	---	54	54	---	54	89
			MDD	----	---	---	---	54	89
			CBR	28	26	32	22	54	89
	Kogi	Ayingba-Ankpa-Ofa Rd.45(A.233)	PSD	8	46	25	29	54	94
			LL	08	46	25	37	54	94
			PL	--	54	18	36	54	94
			MDD	---	---	----	---	54	94
			CBR	31	23	39	15	54	94
Warm Humid (zone 4)	Delta	Asaba-Agbor-Edo(SB) Rd. 25(A.232)	PSD	22	32	14	40	54	85
			LL	----	54	54	---	54	85
			PL		54	12	42	54	85
			MDD	---	---	----	---	54	85
			CBR	31	23	39	15	54	85
	Rivers	Porthacourt-Elele-Umanelu Rd. 414(F.229)	PSD	20	25	5	40	45	72
			LL	---	45	45	---	45	72
			PL	45	--	23	12	45	72
			MDD	---	---	----	----	45	72
			CBR	39	6	34	11	45	72

Source: Author's compilation, (2018). * Highway Manuals, (2013)

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^3/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005).

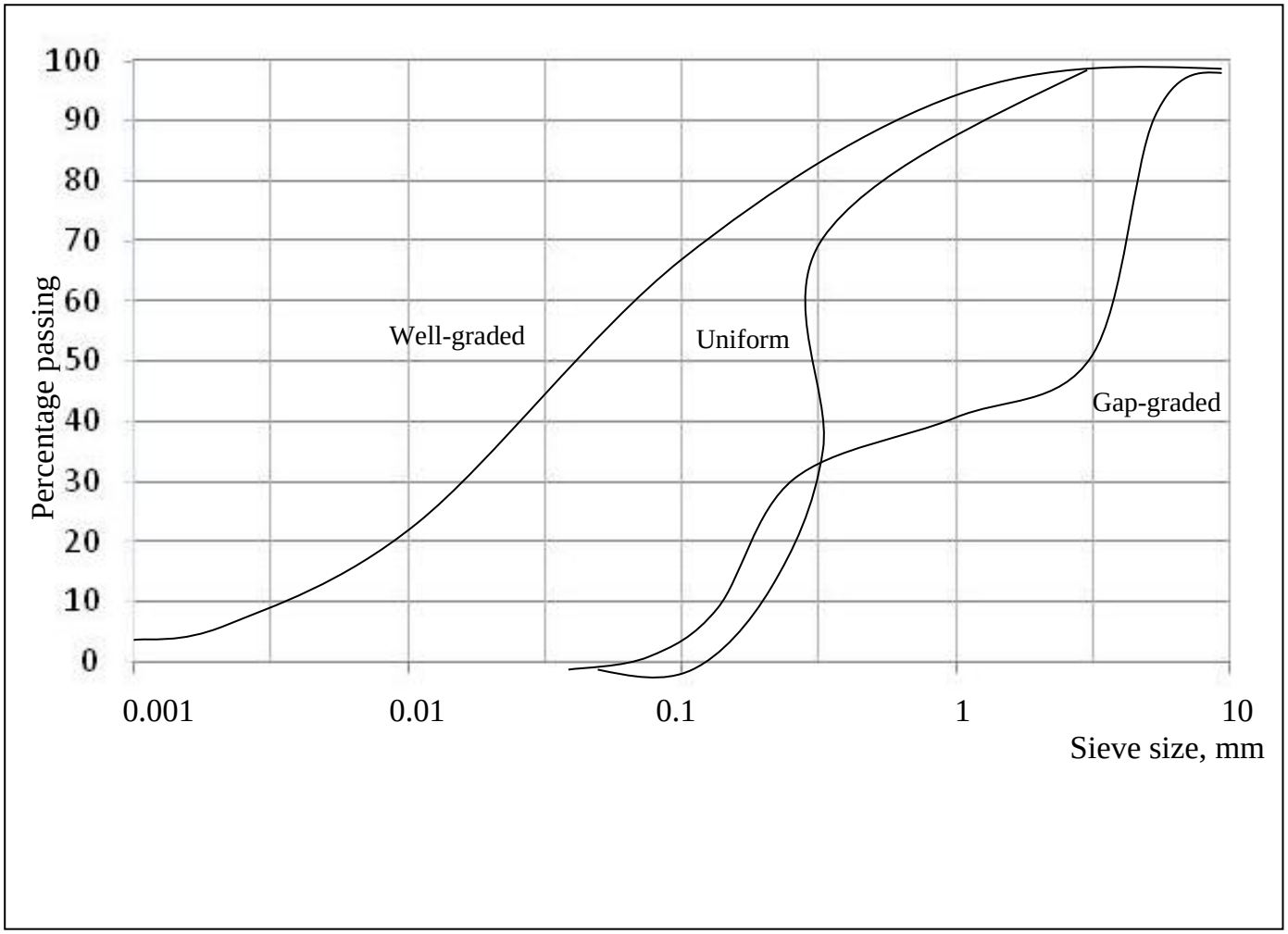


Figure 15: Particle Size Distributions for Ayangba-Ofa-Ankpa Road

Source: Garber & Hoel, (2009)

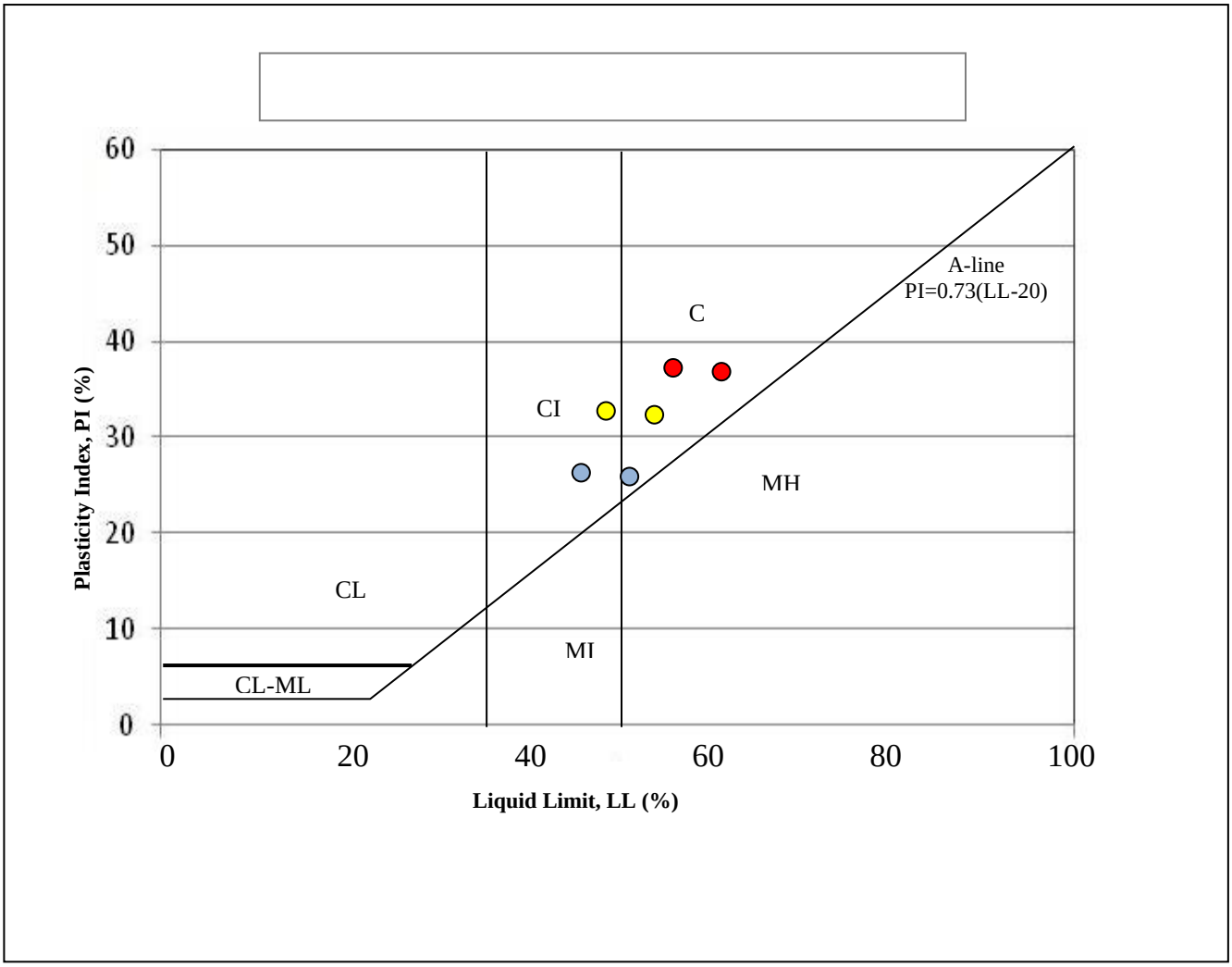


Figure 16: Plasticity Chart for Ayingba-Ankpa Road
Source: Garber & Hoel, (2009)

4.8 Geotechnical properties of Zone 4 (Warm Humid) Edo-Agbor-Asaba Road 25(A.252) 85KM Width 7.3.

Particle Size Distribution (PSD) Subbase

The PSD values in the subbase category presented in Table 13 ranges from 32-96% in all the 54 location sampled. In all the sample collected 22(40.7%) locations were less than 35% of the benchmark for road and construction as prescribed by the FMW&H,(1997) standard therefore they passed the test for PSD in subbase alonfg the road and only 32(59.3%) failed the acceptable limit of the benchmark value ≤ 35% . This is expected in view of high clayey content in the study area. The foundation materials are is classified in to AASHTO classification of A-2-7, A-7, A-2-4, A-2-5, A-2-7, A-7-5, and A-7-6. The mean PSD is 52.6%.

Particle Size Distribution (PSD) Subgrade

The values for PSD for subgrade category as presented in Tables 13 ranges from 19- 96% in the 54sample points. The results showed that, 14(25.9%) sampled locations passed the FMW&H, (1997) satandard ≤ 35% for road in Nigeria and 40(74.1%) failed the test suggesting that, in all these locations almost 74.1% were not retained because they have high percentage of clayey materials retained were more than the stipulated value of ≤35% of clay materials. The mean PSD is 34.1 %. Road failure is recorded in these road in view of the high clay contents in many part of the study area. The distribution of soil samples in the foundation of the road as stipulated by the American Association of State Highway and Transport Official (AASHTO) falls into of A-2-4,A-2-4,A-2-6,A-2-7, A-2-7-4, A-7-6.

Liquid Limit (LL) Subbase

The value of Liquid limit (LL) in subbase category ranges from 58-70% (Table 13) in 54 locations. This suggest that, in all these locations are higher than 35% of the standard benchmark for road construction (FMW&H, 1997) suggesting that, all the sampled location of the road under study failed the LL test hence, subbase materials are poor not fit for road.

Liquid Limit (LL) Subgrade

The soil liquid limit is an indication of how cohessive, consistent and consolidated the soil is. The value of Liquid limits (LL) in subgrade ranges from 29-40% as presented in Tables 13 in all the 54 locations sampled in the study area. All the 54 section of the road were bellow 50% benchmark for standard specification for road and bridges in Nigeria and this suggesting that all the locations passed the LL test for subgrade in accordance with the FMW&H, (1997).

Plastic Limit (PL) Subbase

The value of PL in subbase category presented in Table 13 ranges from 16-30%. The values obtained for subbase in all the 54 sampled locations were above the benchmark value of >12% hence all locations failed the test for the construction of road and bridges of the FMW&H, (1997) .This suggest that all the section of the road did not passed the PL test in Edo-Agbor-Asaba road.The mean PL for subbase is 34.5%.

Plastic Limit (PL) Subgrade

The PL in subgrade category along Edo-Agbor-Asaba road ranges from 15-35% presented in Table 13 in 54 locations in the study area. The PL values obtained showed that, in 42(77.8%) passed the standard specification for the construction of road and bridges in Nigeria (FMW&H, 1997). This implies that, 77.8% of the road section complied with the benchmark value of ≤ 30%

and 12(22.2%) section of the road failed the bench mark of >30% as stipulated by FMW&H, 1997 for road and bridges in Nigeria.

Maximum Dry Density (MDD) Subbase

MDD for subbase category (Table 13) ranges from 1.60-1.94g/cc in the 54 locations in the study area. Results show that, 33(61.1%) out of the 54 locations range < 1.86g/cc this implies that materials consist of low clay contents, 5(9.3%) locations also have MDD ranging between 1.80-1.85g/cc indicating a medium clay types, and 16 (29.6%) locations range > 1.90g/cc which also indicated the presence of very high clay contents. The results shows the magnitude of road failure determine by the levl of cclayey materials of various magnitude as shown in figue 4.The subbase materials can also be easily compacted along the road.

Maximum Dry Density (MDD) Subgrade

MDD is a measure of the level of compaction that materials required in a typical road construction this is because not all materials are compacted. MDD for subgrade category presented in Table 13 ranges from 1.32-1.94g/cc along various sample points in the 54 location. MDD does not have acceptable value because of the complexity and variation of clay soil types in Nigeria as presented in figure 4. This variation in clayey materials in Nigeria makes it difficult to have a clear cut range or bench mark for construction of road and bridges in Nigeria. However, Affonime and Anniekan (2005) categorize MDD into low (< 1.80g/cc), medium (1.80-1.85g/cc), high (1.85-1.90g/cc) and very high (>1.90g/cc). It is on this basis that results in this study were analyesed. Results show that out of the 54 locations MDD in 46(85.2%) locations ranges < 1.80g/cc suggesting materials composed of low clay contents, 3(5.6%) locations also ranges from 1.80-1.85 suggesting that materials are made of medium clay contents, and 5(9.3%)

locations ranges >1.90g/cc which also indicate a very high clay content. This is an indication that at each location constitutes a particular clay content which could also causes the road section to fail failure experience at the road under study. The mean MDD is 1.67g/cc.The results above indicated that materials are easily compacted.

California Bearing Ratio (CBR) Subgrade

The CBR considered in the study is soaked in the subgrade category in Table 13 ranges from 5.46-89.40% in 54 sampled locations. The prescribed values for CBR in subgrade for Nigerian road is >30%. A comparison of the value obtained in the study and FMW&H (1997) standard showed that, the value is lower than the specified 30% standard in 39(72.29%) locations indicating that they failed the test while 15(27.8%) locations failed the prescribed standard of FMW&H,(1997).This suggest in almost 72.29% of the road were good materials for road construction. The mean of CBR in subgrade is 24.1%..

California Bearing Ratio (CBR) Subbase

The CBR in subase category presented in (Table 13) ranges from 5.45-34.89% for soaked sample in 54 locations. Results showed that, 23(42.6%) locations are higher than the prescribed standard specification for the construction of road and bridges in Nigeria (FMW&H, 1997). Results obtained in the study also suggest that, out of 54 location 31(57.4%) passed the prescribed standard specification of value for > 30% for the construction of road and bridges in Nigeria FMW&H,(1997). The mean of CBR for subbase is 24.1% (see Table 13).

Table 13: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Asaba-Agbor-Edo (SB) Road 25(A232)

Soil Properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8 – 10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM22-24+000KM			FMW&H ,1997
Sampled locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	87	70	96	43	60	58	64	22	58	34	20*	32	19	64	66	58	78	24	>35%
(%)	SG	30	32	29	57	34	42	70	80	42	66	50	60	58	36	34	42	48	80	>35%
*LL	SB	62	65	55	60	70	65	64	65	65	68	58	62	63	59	70	68	66	65	>35%
(%)	SG	28	35	29	35	40	30	30	25	35	38	36	26	25	28*	30	36	39	37	>50%
*PL	SB	22	30	24	17	20	30	24	18	22	16	17	20	23	22	19	19	22	21	>12%
(%)	SG	23	33	22	28	15	25	27	22	27	35	20	22	23	33	30	28	16	15	>30%
*PI	SB	12	40	10	42	44	11	44	12	44	10	40	12	43	10*	45	11	50	12	----
(%)	SG	14	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	37	
**MDD	SB	1.32	1.80	1.94	1.60	1.45	1.62	1.80	1.32	1.94	1.94	1.32	1.94	1.67	1.94	1.35	1.45	1.78	1.67	----
g/cc	SG	1.40	1.65	1.94	1.60	1.54	1.70	1.32	1.70	1.32	1.34	1.45	1.64	1.32	1.38	1.80	1.65	1.94	1.70	
**OMC	SB	10	25	24	24	6.6	10	25	15	18	20	24	19	23	24	20	18	17	24	-----
(%)	SG	23	24	17	23	15	23	20	18	24	23	25	30	32	25	30	35	32	35	
**CBR	SB	32.4	34.5	89.4	30.5	13.4*	40.0	34.45	50.4	34.5	13.67	15.4	5.46	34.0	12.56	10.5	12.1	14.0	13.2	>30%
(%)	SG	13.00	26.45	31.45	25.45	10.45	30.45	29.45	5.45*	20.5	25.4	31.4	25.5	32.2	15.38	21.4	32.4	24.2	23.4	>30%
***ASHTO Soil Class**		**A-2-4**	**A-2-6**	**A-2-7**	**A-2-4**	**A-2-6**	**A-2-7**	**A-4**	**A-7-5**	**A-7-6**	**A-7-5**	**A-6**			**A-7-6**						

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 13: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Asaba-Agbor-Edo (SB) Road 25(A232)

Soil Properties		KM 26 – 28+000KM			KM 30-32+000KM			KM 34 – 36+000KM			KM 38-40+000KM			KM 42 – 44+000KM			KM46-48+000KM			FMW&H 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	64	20	58	34	25	32	19	64	66	58	78	20	87	70	96	43	60	58	>35%
(%)	SG	70	80	42	66	50	60	58	36	34	42	48	80	30	32	29	57	34	42	>35%
*LL	SB	64	65	65	68	58	62	63	59	70	68	66	65	62	65	55	60	70	65	>35%
(%)	SG	30	25	35	38	36	28	25	29	30	36	39	37	28	35	29	35	40	30	>50%
*PL	SB	17	20	30	24	18	22	16	17	20	18	22	16	17	20	23	22	19	21	>12%
(%)	SG	28	15	25	27	22	27	35	20	22	22	27	35	20	22	23	33	30	15	>30%
*PI	SB	40	28	44	12	40	47	43	42	45	10*	50	44	48	12	40	42	09	43	----
(%)	SG	15	10	26	16	16	12	10	15	16	17	19	37	14	15	19	21	13	15	
**MDD	SB	1.80	1.32	1.94	1.94	1.32	1.94	1.67	1.94	1.35	1.45	1.78	1.67	1.32	1.80	1.94	1.60	1.45	1.62	----
g/cc	SG	1.32	1.70	1.32	1.34	1.45	1.64	1.32	1.38	1.80	1.65	1.94	1.70	1.40	1.65	1.94	1.60	1.54	1.70	
**OMC	SB	25	15	18	20	24	19	23	24	20	18	17	24	10	25	24	24	6.6	10	-----
(%)	SG	20	18	24	23	25	30	32	25	30	35	32	35	23	24	17	23	15	23	
**CBR	SB	34.45	50.4	34.5	13.47	15.07	5.4	34.0	12.08	10.08	12.8	14.09	13.1	32.45	34.45	89.40	30.56	13.40	89.34	>30%
(%)	SG	29.45	5.47	20.4	25.46	31.4	25.5	32.2	15.32	21.43	32.4	24.2	23.4	13.00	26.45	31.45	25.45	10.45	30.45	>30%
*ASHTO								A-2-4	A-2-6	A-2-7				A-7-5	A-7-6					
Soil Class						A-2-4	A-2-6	A-2-7	A-4					A-7-5	A-6			A-7-6		

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 13: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Asaba-Agbor-Edo (SB) Road 25(A232)

Soil Properties		KM 50-52+000KM			KM 54-56+000KM			KM 58 – 60+000KM			KM 62-64+000KM			KM 66 – 68+000KM			KM70-72+000KM			Mean
Sampled locations		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
*PSD	SB	78	26*	87	70	34	20*	32	19*	26*	64	66	58	34	20*	32	19	64	60	44.2
(%)	SG	48	80	30*	32*	66	50	60	58	58	36	34*	42	66	50	60	58	36	34*	49.9
*LL	SB	66	65	62	65	68	58	62	63	63	59	70	68	68	58	62	63	59	70	63.8
(%)	SG	39	37	28*	35	38	36	26*	28	24*	20*	30*	36	38	36	26*	30*	25*	40	31.7
*PL	SB	22	16	17	20	18	22	16	17	17	20	30	24	18	22	23	22	19	21	21.4
(%)	SG	27	35	20	22	22	27	35	20	28	15	25	27	22	27	23	33	30	15	24.7
*PI	SB	50	44	48	40	42	40	47	43	43	42	45	50	42	40	47	43	42	44	44.1
(%)	SG	19	37	14	15	16	16	12	10	10	15	16	17	16	16	12	10	15	13	15.6
**MDD	SB	1.78	1.67	1.32	1.80	1.94	1.32	1.94	1.67	1.67	1.94	1.35	1.45	1.94	1.32	1.94	1.67	1.94	1.45	1.77
g/cc	SG	1.94	1.70	1.40	1.65	1.34	1.45	1.64	1.32	1.32	1.38	1.80	1.65	1.34	1.45	1.64	1.32	1.38	1.54	1.56
**OMC	SB	17	24	10	25	20	24	19	23	23	24	20	18	20	24	19	23	24	6.6	20.2
(%)	SG	32	35	23	24	23	25	30	32	32	25	30	35	23	25	30	32	25	15	27.6
**CBR	SB	14.0*	13.0*	32.5	34.5	13.4*	15*	5.45*	34.0	34.0	12*	10*	12*	13*	15.0	5.45*	34.0	12.00	13.41	17.9
(%)	SG	24.2	23.4	13.00	26.45	25.40	31.4	25.5	32.2	32.2	15.3	21.4	32.4	25.4	31.4	25.5	32.2	15.32	10.45	24.1
*ASHTO Soil Class					A-2-4	A-2-6	A-2-4 A-2-7	A-2-6 A-4	A-2-7				A-7-5 A-7-6 A-7-5	A-6		A-7-6				

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 13: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for hot humid (Zone 3) and warm Humid (Zone 4)

Mophoclimatic Zones	State	Road section KM	Geotechnical properties	Sub base		Sub grade		Sample location	Road KM
				Passed	Failed	passed	Failed		
Hot Humid (zone 3)	Kwara	Ilorin-Umuaran-Illoffa Rd. 45(A.125)	PSD	25	29	06	48	54	89
			LL	--	54	54	---	54	89
			PL	---	54	54	---	54	89
			MDD	----	---	---	---	54	89
			CBR	28	26	32	22	54	89
	Kogi	Ayingba-Ankpa-Ofa Rd.45(A.233)	PSD	8	46	25	29	54	94
			LL	08	46	25	37	54	94
			PL	--	54	18	36	54	94
			MDD	---	---	----	---	54	94
			CBR	31	23	39	15	54	94
Warm Humid (zone 4)	Delta	Asaba-Agbor-Edo(SB) Rd. 25(A.232)	PSD	22	32	14	40	54	85
			LL	----	54	54	---	54	85
			PL		54	12	42	54	85
			MDD	---	---	----	---	54	85
			CBR	31	23	39	15	54	85
	Rivers	Porthacourt-Elele-Umanelu Rd. 414(F.229)	PSD	20	25	5	40	45	72
			LL	---	45	45	---	45	72
			PL	45	--	23	12	45	72
			MDD	---	---	----	----	45	72
			CBR	39	6	34	11	45	72

Source: Author's compilation, (2018). * Highway Manuals, (2013)

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^3/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005)..

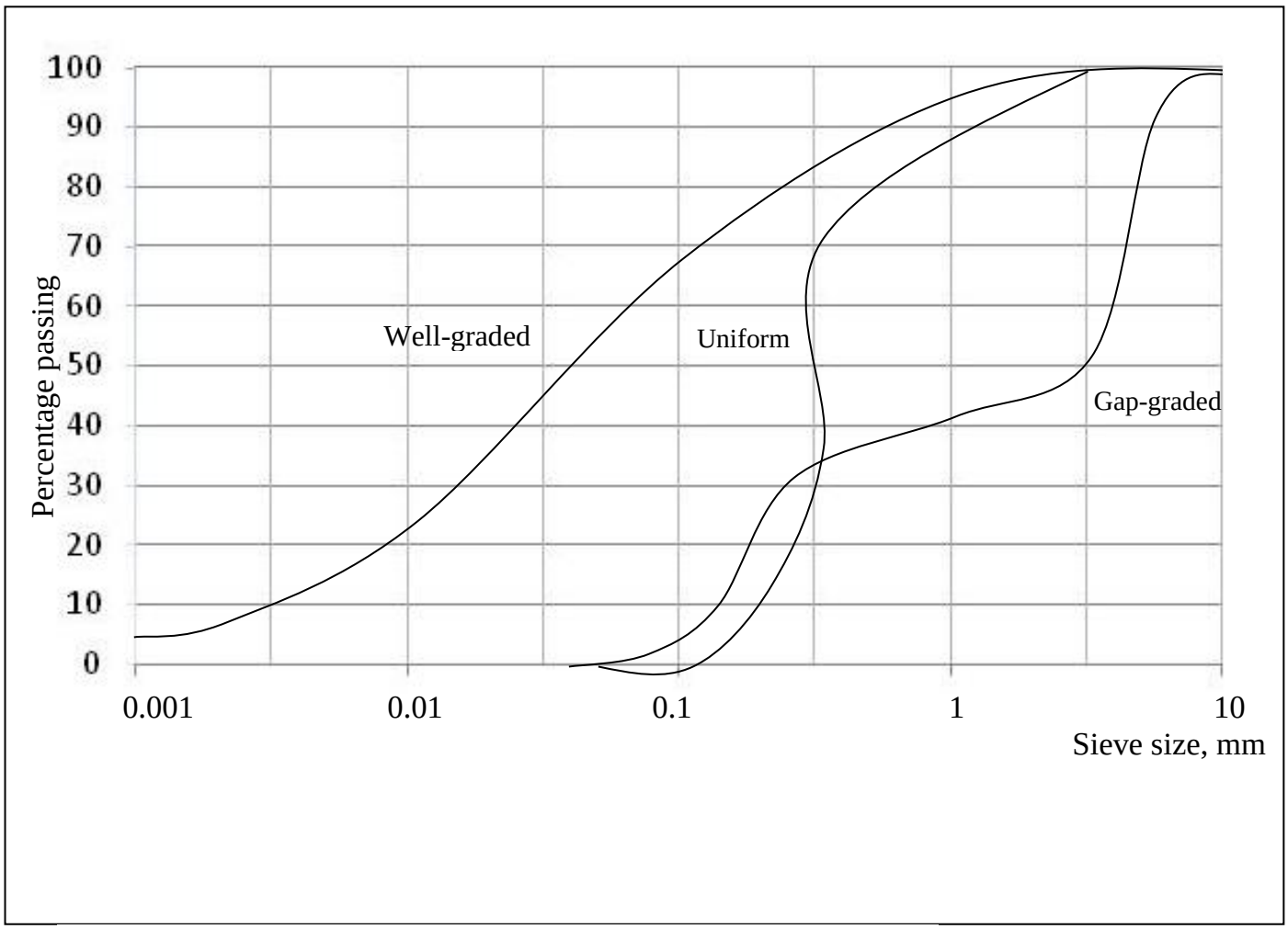


Figure 17: Particle Size Distributions for Edo-Agbor-Asaba Road
Source: Garber & Hoel, (2009)

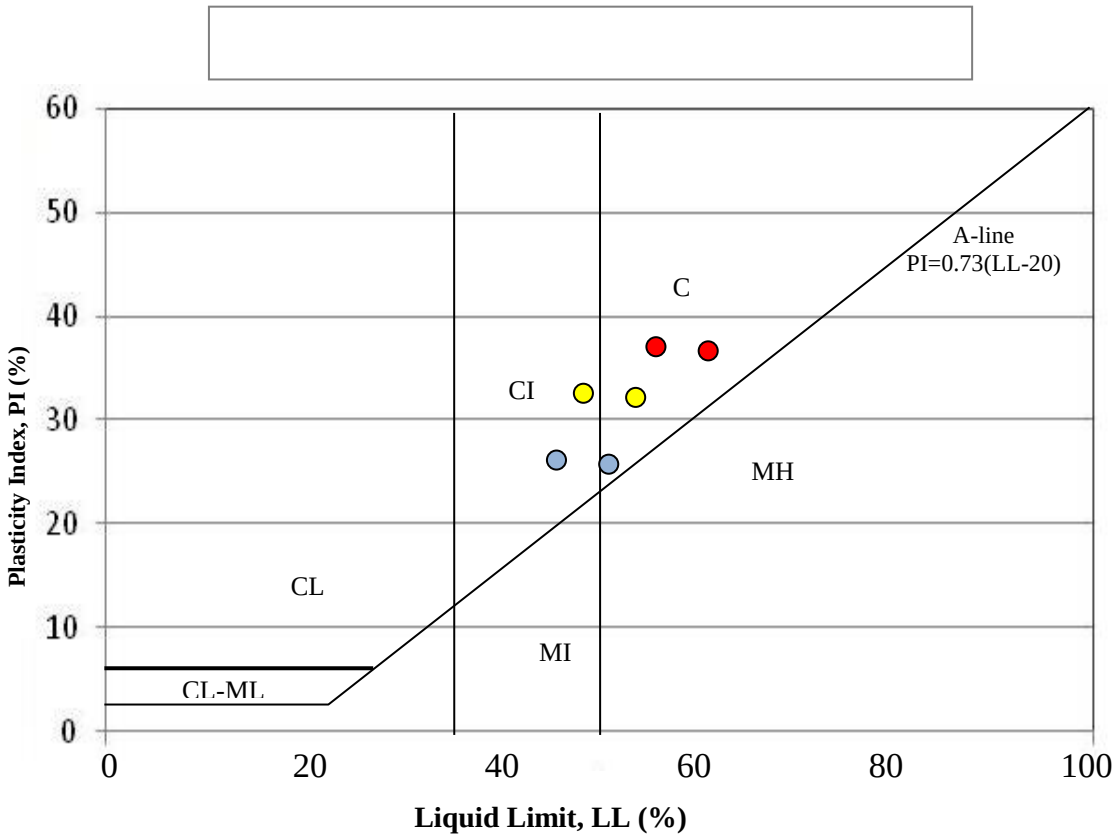


Figure 18 Plasticity Index for Edo-Asaba Road

Figure 18 Plasticity Index for Edo-Asaba Road
Source: Garber & Hoel, (2009)

4.9 Geotechnical properties of Zone 4 (Warm Humid) Porthacourt-Elele-Umanelu Road 414(F.229) 72 KM.

Particle Size Distribution (PSD) Subbase

Results presented in Table 14 showed that PSD value in the subbase category ranges from 5-66% Out of the 45 locations in the study area. 20(44.4%) locations were less than 35% henced they passed the benchmark for road and construction of FMW&H,(1997) standard while 25(55.6%) failed the test in the study area. This is expected because of the high clay contents in these failed section along the road in the study area. The mean PSD of the subbase is 45.6%. The foundation materials are is classified in to AASHTO classification of A-2-4, A-2-6 , A-5-7 -A-5-7 and A-7-6.

Particle Size Distribution (PSD) Subgrade

PSD measures the percentage contained in soil materials especially road foundation, this test is carried out to determine the level of clayey materials. The FMW&H, (1997) stipulated that, PSD must not be more than 35%. The PSD for subgrade presented in Tables 14 and it ranges from 34- 95% in 45 locations in the study area. The results showed that, only 5(11.1%) sampled locations were less than 35% hence they were retained and passed the FMW&H, (1997) satandard for road in Nigeria and 40(88.9%) failed the test. This suggests that, in all these locations almost 88.9% were not retained. The mean PSD is 33.3 %.This is in view of the large clay contents in many part of the study area. The distribution of soil samples in the foundation of the road as stipulated by the American Association of State Highway and Transport Official (AASHTO) fall into the category of A-2-4, A-2-6, A-2-7, A-4, A-7-5, A—6,A-7-6.

Liquid Limit (LL) Subbase

The value of Liquid limit (LL) in subbase category ranges from 55-70% presented in Table 14 in 45 locations sampled. Results shoed that, 45 locations sampled in the study area are higher than 35% of the specified standard for road and construction in Nigeria. This suggests that, in all the locations sampled failed the test for LL in subbase standard benchmark for road construction (FMW&H, 1997).

Liquid Limit (LL) Subgrade

The value of Liquid limits (LL) in subgrade ranges from 25-40% as presented in Tables 14 in all the 45 sampled locations in the study area. All the 45 locations sampled passed the specified standard of less than 50% for road construction according to FMW&H,(1997) suggesting that, LL in subgrade along Portharcourt-Elele-Umanelu road passed the prescribed standard for road in Niegria.

Plastic Limit (PL) Subbase

The value of PL in subbase category as presented in Table 14 ranges from 17-30%. The values obtained for subbase in all the 45 locations sampled were above the benchmark value of >12% hence all locations failed the test for the construction of road and bridges of the FMW&H, (1997) .This suggest that all the section of the road did not passed the PL test in Porthacourt-Elele-Umanelu road. The mean PL is 34.5%.

Plastic Limit (PL) Subgrade

PL is an indication of the quantity of water and how plastic the soil can be. The PL ranges from 15-35% as presented in Table 14 in 45 locations in the study area. Results obtained showed that, only 23(51.1%) were less than 30% of the prescribed specification for the construction of road and bridges in Nigeria (FMW&H, 1997) and 12(48.9%) locations failed the bench mark of >30%

for road and bridges in Nigeria. Suggesting that, only 51.1% of the roads have very good foundation materials.

Maximum Dry Density (MDD) Subbase

MDD for subbase category (Table 14) ranges from 1.60-1.94g/cc in the 45 locations in the study area. Of all the sampled locations 18(40%) out of the 45 locations ranges < 1.80g/cc this implies materials are made up of low clay contents, 17(37.8%) locations also have MDD ranging between from 1.80-1.85g/cc which is medium clay types, 4(8.9%) locations ranges from 1.85-1.90g/cc suggesting high clay contents and 76(13.3%) locations range > 1.90g/cc implies that, materials are composed of a very high clay contents. This showed that the magnitude of road failure caused by MDD was determined by the levl of cclayey materials various magnitude in Nigerian road. The subbase category also has a very good composition of campactable soil along the road.

Maximum Dry Density (MDD) Subgrade

MDD for subgrade (Table 14) ranges from 1.60-2.20g/cc along various sample points in the 45 location. MDD does not have acceptable value because of the complexity and variation of clay soil types in Nigeria as presented in figure 4. This variation in clayey materials in Nigeria makes it difficult to have a bench mark for construction of road and bridges in Nigeria however, Affonime and Anniekan (2005) categorize MDD into low (< 1.80g/cc), medium (1.80-1.85g/cc), hgh (1.85-1.90g/cc) and very high (>1.90g/cc). Results of this study showed that, out of the 45 locations MDD in 19(42.2%) locations ranges < 1.80g/cc suggesting materials composed of low clay contents, 18(40%) locations also ranges from 1.80-1.85 suggesting that, materials are medium clay contents, 4(8.9%) locations ranges from 1.85-1.90g/cc indicating high clay contents and 4(8.9%) locations ranges from >1.90g/cc (Table 14), which also indicate a very

high clay content. The amounts of clay contents determine the failure of the road in the study area. Results presented showed that materials are compactable for the road under study.

California Bearing Ratio (CBR) Subgrade

The CBR considered in the study for soaked in the subgrade category presented in Table 14 ranges from 11.40-36% in 45 locations sampled for the study. The prescribed values for CBR in subgrade for Nigerian road is >30%. A comparison of the value obtained in the study and FMW&H (1997) standard showed that, the value is higher than the specified 30% standard only in 11(24.4%) locations indicating that they failed the test and 34(75.6%) location passed the prescribed standard of FMW&H, (1997) of all 45 sampled points.This suggest in almost 75.64% of the samples were good materials for road construction and 24.4% of the road section were not stable especially when they become wet during rainy season in Edo-Agbor-Asaba area. This condition explains the reasons why road fail in the study area.

California Bearing Ratio (CBR) Subbase

The CBR in subase category presented in (Table 14) ranges from 5.50-36.0% for soaked sample in 45 locations. Results showed that, only 6(13.3%) locations are higher than the prescribed standard specification for the construction of road and bridges in Nigeria (FMW&H, 1997) hence they failed the standard test This condition explain why road failure is experienced in this section of the road in the study area. Results obtained in the study also suggest that, out of 45 location 39(86.7%) passed the prescribed standard specification of value for > 30% for soaked CBR for the construction of road and bridges in Nigeria FMW&H,(1997). The mean of CBR for subbase is 16.1% (see Table 14).

Table 14: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Porthacourt-Elele-Umanelu Road 414(F.229)

Soil Properties		KM 0 – 2+000KM			KM 4-6+000KM			KM 8 – 10+000KM			KM 12-14+000KM			KM 16 – 18+000KM			KM22-24+000KM			FMW&H 1997
Sampled locations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
*PSD	SB	30	35	05*	43	66	58	64	12*	58	34	20*	32	05*	64	66	58	52	05*	>35%
(%)	SG	70	65	95	57	34	42	36	80	42	66	80	68	95	36	34*	42	48	95	>35%
*LL	SB	62	65	55	60	70	65	64	65	65	68	58	62	63	59	70	68	66	65	>35%
(%)	SG	28*	35	29*	35	40	30*	30	25*	35	38	36	26*	25*	28*	30*	36	39	37	>50%
*PL	SB	22	30	24	17	20	30	24	18	22	16	17	20	23	22	19	19	22	21	>12%
(%)	SG	23	33	22	28	15	25	27	22	27	35	20	22	23	33	30	28	16	15	>30%
*PI	SB	48	40	40	42	44	43	44	28	44	42	40	47	43	42	45	50	50	44	----
(%)	SG	14	15	19	21	13	15	15	10	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.70	1.80	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	----
g/cc	SG	1.70	1.80	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	
**OMC	SB	35	25	32	25	35	40	35	30	25	35	50	30	25	45	35	40	42	37	-----
(%)	SG	40	30	35	29	32	30	30	35	30	30	25	35	32	37	25	35	32	35	
**CBR	SB	11.4	34.5	13.4*	5.5*	13.4*	13.*	5.45*	10.4*	34.5	13.4	13.0*	5.45	13.0	13.0	10.0	12.0	14.0	13.0	>30%
(%)	SG	13.5	12.4	26.4	20.4	11.40	36.0	12.5	15.4	24.4	35.0	20.5	16.0	25.0	24.7	16.7	34.9	34.8	12.6	>30%
*ASHTO Soil Class		A-2-6						A-2-6. A-2-7 A-2-4 A-7-5										A-7-6		

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 14: Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Porthacourt-Elele-Umanelu Road 414(F.229)

Soil Properties		KM 26 – 28+000KM			KM 30-32+000KM			KM 34 – 36+000KM			KM 38-40+000KM			KM 42 – 44+000KM			KM46-48+000KM			FMW&H 1997
Sampled locations		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
*PSD	SB	64	12*	58	34	20*	32	05*	64	58	34	20*	32	05*	64	66	58	52	05*	>35%
(%)	SG	36	80	42	66	80	68	95	36	42	66	80	68	95	36	34*	42	48	95	>35%
*LL	SB	64	65	65	68	58	62	63	59	65	68	58	62	63	59	70	68	66	65	>35%
(%)	SG	30	25*	35	38	36	26*	25*	28*	35	38	36	26*	25*	27*	30	36	39	37	>50%
*PL	SB	24	18	22	16	17	20	23	22	22	19	19	22	21	22	19	19	22	21	>12%
(%)	SG	27	22	27	35	20	22	23	33	33	30	28	16	15	33	30	28	16	15	>30%
*PI	SB	44	28	44	42	40	47	43	42	44	42	40	47	43	25	45	50	50	44	----
(%)	SG	15	10	26	16	16	12	10	15	26	16	16	12	10	15	16	17	19	08	
**MDD	SB	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	----
g/cc	SG	1.80	1.70	1.80	1.82	1.88	1.94	1.80	1.81	1.80	1.82	1.88	1.94	1.80	1.81	1.88	1.70	1.90	1.70	
**OMC	SB	35	30	25	35	50	30	25	45	25	35	50	30	25	45	35	40	42	37	-----
(%)	SG	30	35	30	30	25	35	32	37	30	30	25	35	32	37	25	35	32	35	
**CBR	SB	5.45*	10.4	34.5	13.4	13.0*	5.45	13.0	13.0	12.00	14.0	13.0	34.5	13.4	5.45	13.4	13.0	13.41	13.0	>30%
(%)	SG	12.5	15.4	24.4	35.0	20.5	16.0	25.0	24.7	34.9	34.8	12.6	12.4	26.4	20.4	11.4	36.0	11.40	36.0	>30%
*ASHTO Soil Class		A-2-6 A-2-6. A-2-7									A-2-4 A-7-5								A-7-6	

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated)
Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 14: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Porthacourt-Elele-Umanelu Road 414(F.229)

Soil properties		KM50 – 52+000KM			KM54-56+000KM			KM58 – 60+000KM			Mean
Sampled locations		37	38	39	40	41	42	43	44	45	
*PSD	SB	34	12*	05*	43	66	58	64	20*	58	42.1
(%)	SG	66	80	95	57	34*	42	36	80	42	57.9
*LL	SB	68	65	55	60	70	65	64	65	65	31.9
(%)	SG	38	25*	29*	35	40	34*	30*	25*	35	41.4
*PL	SB	16	18	22	21	22	19	19	22	21	21.4
(%)	SG	35	22	16	15	33	30	28	16	15	24.7
*PI	SB	42	28	40	42	44	43	44	28*	44	16.4
(%)	SG	16	10	19	21	13	15	15	10	26	20.5
**MDD	SB	1.82	1.70	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.73
g/cc	SG	1.82	1.70	1.80	1.60	1.70	1.70	1.80	1.70	1.80	1.87
**OMC	SB	35	30	32	25	35	40	35	30	25	31.4
(%)	SG	30	35	35	29	32	30	30	35	30	32.3
**CBR	SB	13.4	10.4*	5.45	13.4	13.0	13.4	34.5	13.4	13.0	5.45
(%)	SG	35.0	15.4	20.4	11.4	36.0	11.4	24.4	35.0	20.5	16.0
*ASHTO Soil Class				A-2-6. A-2-7 A-2-4 A-7-5			A-2-6		A-7-6		

Sources: *Pavement Evaluation Unit (FMW&H, 2001-2003)
**Inventory of geotechnical properties in Nigeria (undated) Technical dept TREVI Foundation Nigeria, Ltd.

Note: PSD: Particle size distribution
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index
MDD: Maximum dry density
CBR: California bearing ratio
ASHTO: American Association of State Highway Transport Officials
SB: Sub base
SG: Sub grade

Table 14: Summary of Geotechnical Properties of Sub Base (SB) and Sub Grade (SG) for Hot humid (Zone 3) and warm Humid (Zone 4)

Mophoclimatic Zones	State	Road section KM	Geotechnical properties	Sub base		Sub grade		Sample location	Road KM
				Passed	Failed	passed	Failed		
Hot Humid (zone 3)	Kwara	Ilorin-Umuaran-Illoffa Rd. 45(A.125)	PSD	25	29	06	48	54	89
			LL	--	54	54	---	54	89
			PL	---	54	54	---	54	89
			MDD	----	---	---	---	54	89
			CBR	28	26	32	22	54	89
	Kogi	Ayingba-Ankpa-Ofa Rd.45(A.233)	PSD	8	46	25	29	54	94
			LL	08	46	25	37	54	94
			PL	--	54	18	36	54	94
			MDD	---	---	----	---	54	94
			CBR	31	23	39	15	54	94
Warm Humid (zone 4)	Delta	Asaba-Agbor-Edo(SB) Rd. 25(A.232)	PSD	22	32	14	40	54	85
			LL	----	54	54	---	54	85
			PL		54	12	42	54	85
			MDD	---	---	----	---	54	85
			CBR	31	23	39	15	54	85
	Rivers	Porthacourt-Elele-Umanelu Rd. 414(F.229)	PSD	20	25	5	40	45	72
			LL	---	45	45	---	45	72
			PL	45	--	23	12	45	72
			MDD	---	---	----	----	45	72
			CBR	39	6	34	11	45	72

Source: Author's compilation, (2018). * Highway Manuals, (2013)

Note: *

	Low	Medium	High	Very High
CBR (%):	<10.0	10.15	15-30	>30
MDDkgm^3/:	<1800	1800-1850	1850-1900	>1900

After offonime and Aniekan,(2005).

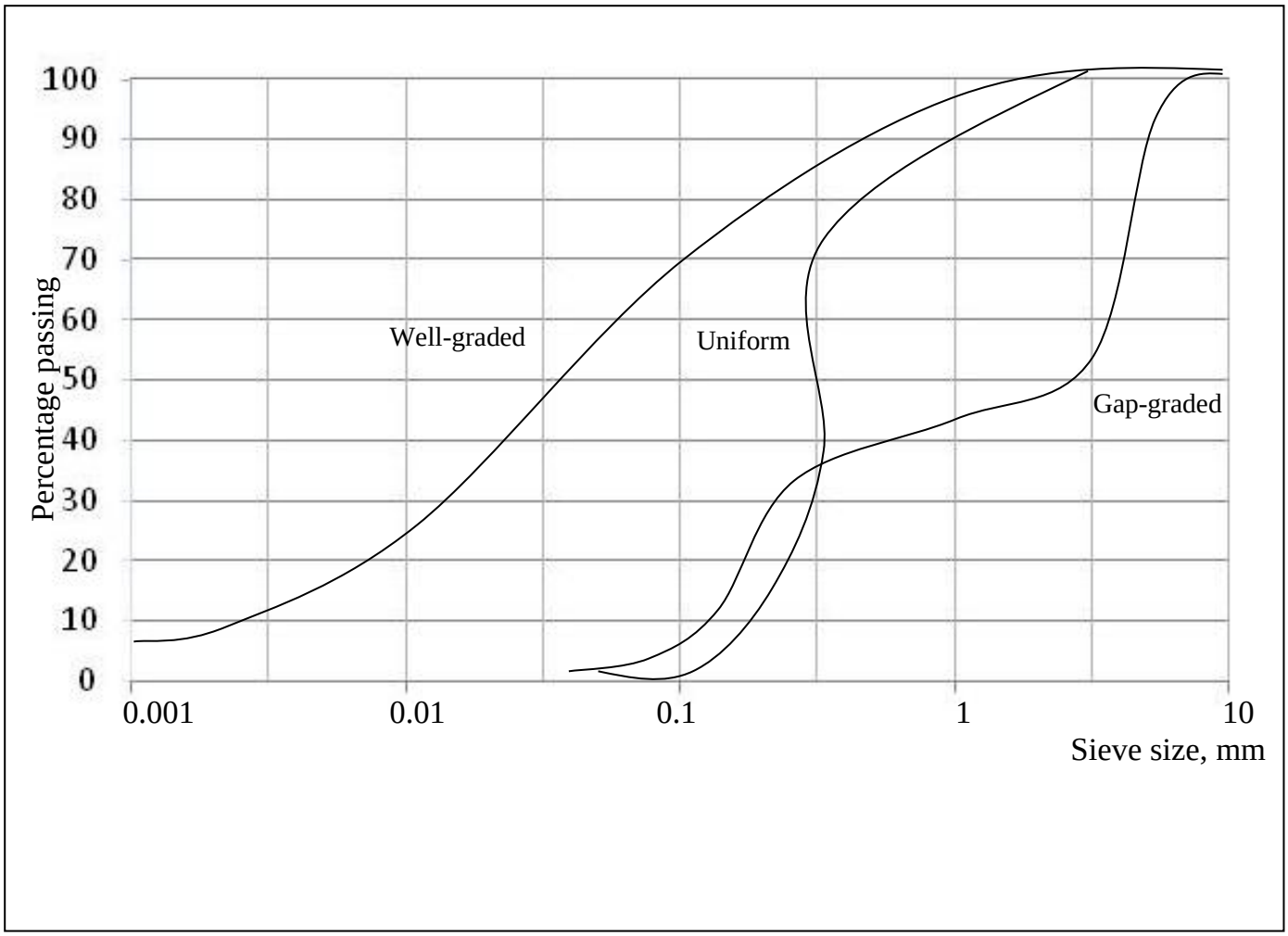
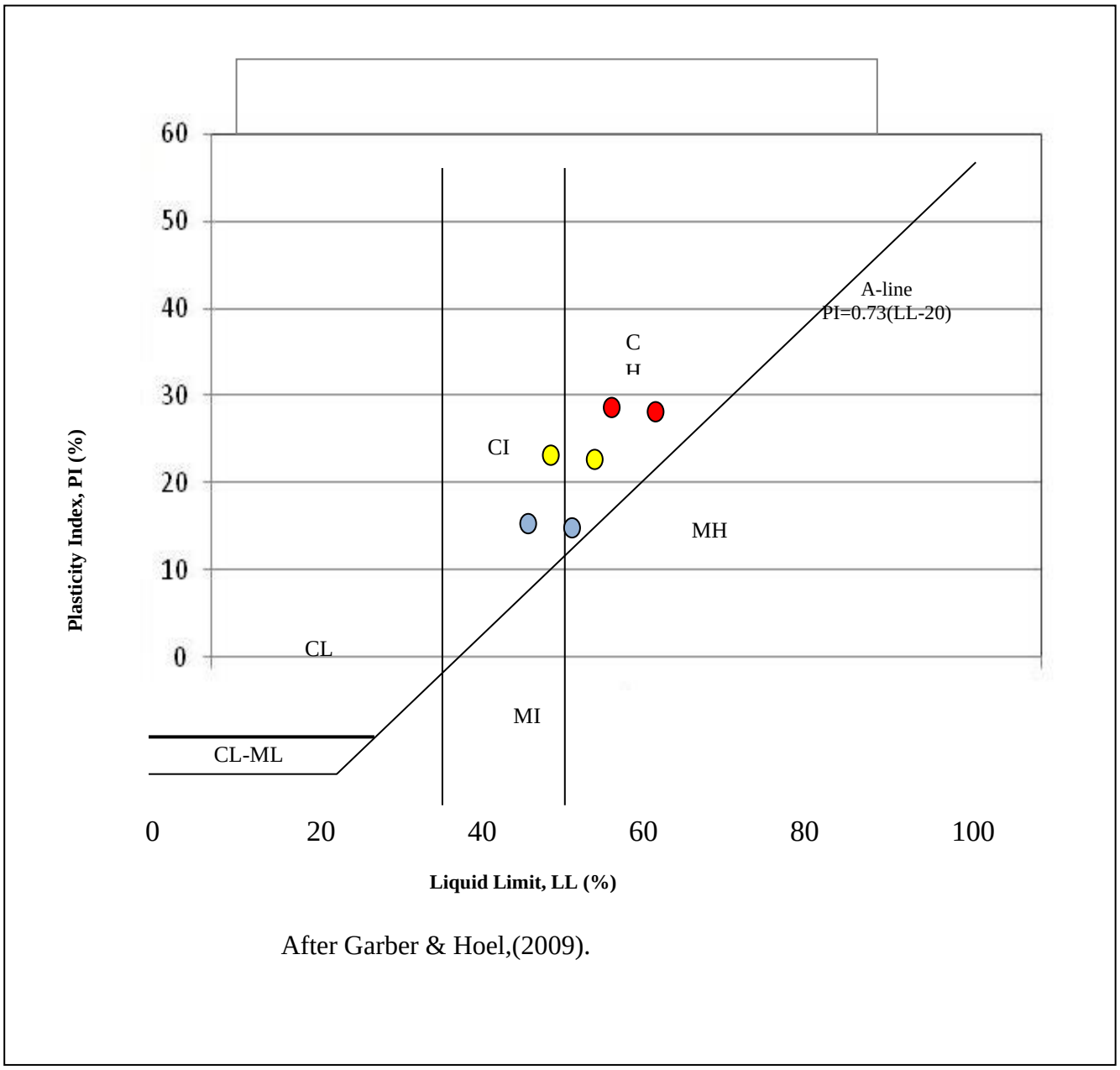


Figure 19: Particle Size Distributions for Portharcourt-Elele-Umunelu Road

Source: Garber & Hoel,(2009).



After Garber & Hoel,(2009).

Figure 20: Plasticity Chart for Portharcourt-Elele-Umunelu Road
Source: Garber & Hoel,(2009).

CHAPTER FIVE

INTERELATIONSHIP BETWEEN CLIMATIC VARIABLES AND GEOTECHNICAL PROPERTIES

5.0 Introduction

This chapter explains the degree of interrelationship between climatic variables and geotechnical properties of road foundation in the four morphoclimatic zones in Nigeria.

5.1 Relationship between Climate and Road SubBase (SB) along Birnin-Yauri-Malando-Wara Road

Table 15 presents the interrelation between climate and geotechnical properties along Birnin-Yauri –Malando-Wara road. There is a strong relationship between maximum temperature (0.577), Optimum moisture content (0.543), plastic limit (0.833) and particle size distribution in road sub base (SB) This implies that, excessive temperature and rainfall are capable of causing excessive dryness on subbase which resulting from frequent emergence of crack and other forms of deformation such as potholes and various kind of cracks found on the road subbase which are very common road failure types along Birnin-Yauri –wara –malando road, this results agrees with the findings of Yang (2004).

5.2 Relationship between Climate and Road Subgrade (SG) along Birnin-Yauri-Malando-Wara Road

Table 16 shows the interrelationship between climate and road subgrade along Birnin-Yauri-Malando-Wara road. There is a strong relationship between liquid limit (0.956), rainfall (0.715), Minimum Temperature (0.740) and plastic limit (0.645) with PSD in the subgrade respectively bu inversely related with plasticity index(-.350), optimum moisture content(-.160) and maximum temperature(-.366). Climatic variables such rainfall recorded over 70% this implies that more rainfall and temperature have the tendency to causing instability in subgrade and cracks in of the

road foundation. This work agrees with that of Oluyemi and Ola (2015) on the stabilization of Black cotton soils in North Eastern Nigeria.

Table 15: Correlation Matrix for assessing interrelationship between climate and road sub base

Variables	PSDsg	MCsg	SPGsg	LLsg	PLsg	PIsg	MDDsg	OMCsg	CBRsg	RF	MaxT	MinT
PSD	1.00	-.357	.401	-.426	-.047	-.350	-.107	-.160	-.279	.535*	-.115	.141
MC		1.00	.408	.308	.523*	-.033	.460	.154	.013	-.075	.136	-.178
SPG			1.00	-.053	.467	-.271	-.049	.014	.000	-.033	-.056	-.101
LL				1.00	.144	.705**	.536*	.169	.098	-.609**	-.053	-.017
PL					1.00	-.549*	.459	.223	.083	-.202	-.358	-.611**
PI						1.00	.068	-.058	.082	-.366	.234	.430
MDD							1.00	.096	.094	-.133	-.067	-.111
OMC								1.00	.473*	-.224	-.441	-.468
CBR									1.00	-.402	-.366	-.201
ARF										1.00	.158	.123
Tmax											1.00	.730**
Tmin												1.00

** Significant at 0.01* Significant at 0.05 levels
Source: Author's Computation (2018)

Table 16: Correlation Matrix for assessing interrelationship climate and road sub grade

Variables	PSDsg	MCsg	SPGsg	LLsg	PLsg	PIsg	MDDsg	OMCsg	CBRsg	RF	MaxT	MinT
PSD	1.00	-.432	.333	-.426	-.047	-.350	-.107	-.160	-.279	.386*	-.115	.331
MC		1.00	.153	.098	.523*	-.141	.660	.154	.013	-.075	.136	-.178
SPG			1.00	-.053	.467	-.271	-.049	.014	.000	-.033	-.056	-.560
LL				1.00	.144	.956**	.536*	.169	.098	-.715**	-.053	-.645
PL					1.00	-.956*	.459	.223	.083	-.202	-.658	-.611**
PI						1.00	.068	-.058	.082	-.366	.234	.430
MDD							1.00	.096	.094	-.133	-.067	-.111
OMC								1.00	.473*	-.224	-.441	-.468
CBR									1.00	-.944	-.366	-.201
ARF										1.00	.158	.123
Tmax											1.00	.740**
Tmin												1.00

** Significant at 0.01* Significant at 0.05 levels
Source: Author's Computation (2018)

5.3 Interelationship between Climate and Road SubBase (SB) along Kano-Gwarzo-Katsina Road

The interrelationship between climate and subbase along kano-Gwarzo-Katsina road is presented in Table 17.There is a strong relationship between moisture content (0.603), liquid limit (0.705), rainfall (0.609), and maximum temperature (0.611) with PSD in the subbase respectively but inversely related with maximum dry density (-.133), and carlifornia bearing ratio (-.070). This implies that, with an increase in rainfall (60%), maximum temperature (61%) climatic variables contribute more to subbase failure and this results to various forms of deformation this results agree with several works (Hijab et al, 2013, Olauyemi and Ola, 2015).

5.4 Interelationship between Climate and Road Subgrade (SG) along Kano-Gwarzo-Katsina Road

Table 18 showed the interrelationship between climate and road sub grade along Kano-Gwarzo-Katsina road. There is a strong relationship between carlifornia bearing ratio (0.700), plastic limit (0.532), liquid limit (0.505) and maximum dry density (0.536) with particle size distribution in the sub grade respectively but inversely related with moisture content (-.432), plasticity index(-271) and CBR(-.279).This suggests that, maximum dry density which shows the low to medium clayey materials tend to expand and contract with the increasing moisture content have adverse effect on road subgrade thereby causing swelling and crack within the foundation of subgrade and this will also have adverse effect on road pavement the results agrees with the findings of Hijab et.al (2012) in a work carried out on pavement failure along Gombe-Biu highway.

Table 17: Correlation Matrix for assessing interrelationship between morphoclimate and road subbase

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	-.357	.401	-.426	-.047	-.350	-.107	-.160	-.279	.535*	-.115	.141
MC		1.00	.408	.308	.623*	-.033	.460	.154	.013	-.075	.136	-.178
SPG			1.00	-.053	.467	-.271	-.049	.014	.000	-.033	-.056	-.101
LL				1.00	.144	.705**	.536*	.169	.098	-.609**	-.053	-.017
PL					1.00	-.549*	.459	.223	.083	-.202	-.358	-.611**
PI						1.00	.068	-.058	.082	-.366	.234	.430
MDD							1.00	.096	.094	-.133	-.067	-.111
OMC								1.00	.473*	-.224	-.441	-.468
CBR									1.00	-.402	-.366	-.201
ARF										1.00	.158	.123
Tmax											1.00	.730**
Tmin												1.00

** Significant at 0.01* Significant at 0.05 levels
Source: Author's Computation (2018)

Table 18: Correlation Matrix for assessing interrelationship between morphoclimate and road subgrade

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	-.157	.201	-.326	-.147	-.250	-.147	-.260	-.269	.435*	-.105	.241
MC		1.00	.408	.308	.523*	-.033	.460	.154	.013	-.075	.136	-.178
SPG			1.00	-.053	.467	-.271	-.049	.014	.700	-.033	-.056	-.101
LL				1.00	.144	.505**	.536*	.169	.098	-.109	-.053	-.017
PL					1.00	-.549*	.459	.223	.083	-.202	-.358	-.211**
PI						1.00	.068	-.058	.082	-.366	.234	.430
MDD							1.00	.096	.094	-.133	-.067	-.111
OMC								1.00	.473*	-.224	-.441	-.468
CBR									1.00	-.402	-.366	-.201
ARF										1.00	.158	.123
Tmax											1.00	.730**
Tmin												1.00

** Significant at 0.01* Significant at 0.05 levels
Source: Author's Computation (2018).

5.5 Relationship between Climate and Road Subbase (SB) along Katchia-Kwoi- Nassarawa road

The interrelationship between climate and road subbase along Katchia-Kwoi-Nassarawa road is presented in Table 19. There is a strong relationship between carlifornia bearing ratio (0.616), liquid limit (0.705), Maximum Temperature (0.521), plastic limit (0.722) and rainfall (0.535) but inversely related with maximum dry density (-.049), moisture content (-0.75) minimum temperature (-0.17) with particle size distribution in the subbase respectively. Suggesting That that, CBR maintain 61% of geotechnical properties on the road subbase by implication CBR was not established due to problem soils such as clayey materials which are not good for road subbase and this adversely affect the stability of subase of the road hence, deformation of occur, this position agrees with the findings of Oluyemi and Ola (2015) suggesting the need of the stabilization agent on subbase of Black cotton soils in North Eastern Nigeria.

5.6 Relationship between Climate and Road subgrade (SG) along Katchia-Kwoi-Nassarawa road

Table 20 presents interrelationship between climate and subgrade and sub base for temperate dry. A strong relationship exists between rainfall (0.543), carlifornia bearing ratio (0.415), and plastic limit (0.490) maximum temperature (0.442) with particle sze distribution but inversely and weak relation with maximum dry density (-282), liquid limit (-.033) and moisture content (-.2.04) in the sub grade respectively. This implies that, the high rate of CBR shows the presence of problem soils which are vulnerable to failure when in contant with moisture and temperature. These soils will become plastic, they crack when dry (Ola, 1987 and Hijab *et al*. 2012) have a similar findings in study carried out.

Table 19: Correlation Matrix for assessing interrelationship climate and road subbase along Katchia-Kwoi-Nassarawa road

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	-.386	.248	-.426	-.0197	-.350	-.122	-.160	-.229	.535*	-.115	.203
MC		1.00	.408	.308	.523*	-.033	.460	.154	.013	-.075	.136	-.178
SPG			1.00	-.053	.722	-.271	-.049	.014	.000	-.033	-.056	-.101
LL				1.00	.144	.705**	.536*	.169	.098	-.609**	-.053	-.017
PL					1.00	-.549*	.459	.223	.616	-.202	-.358	-.611**
PI						1.00	.068	-.058	.082	-.366	.234	.430
MDD							1.00	.096	.094	-.133	-.067	-.111
OMC								1.00	.473*	-.224	-.441	-.468
CBR									1.00	-.402	-.366	-.201
ARF										1.00	.158	.123
Tmax											1.00	.521**
Tmin												1.00

** Significant at 0.01* Significant at 0.05 levels
Source: Author's Computation (2018)

Table 20: Correlation Matrix for assessing interrelationship between climate on road subgrade along Katchia-Nassarawa road

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.453	.592	.033	-.229	.157	.021	.089	-.166	-.162	-.395	.142
MC		1.00	-.204	-.132	-.047	.117	-.282	.008	-.096	.231	-.386	.048
SPG			1.00	-.054	.182	.165	.364	.227	.131	-.017	.201	.332
LL				1.00	.211	.390	.067	-.044	.139	-.285	.145	.057
PL					1.00	.200	.409	-.197	.080	-.136	.442	-.107
PI						1.00	-.028	-.254	.415	.187	.017	-.309
MDD							1.00	.015	.125	-.548*	-.151	-.059
OMC								1.00	-.241	.142	-.104	-.032
CBR									1.00	-.241	-.302	-.432
ARF										1.00	.009	.153
Tmax											1.00	.353
Tmin												**1.00**

** Significant at 0.01* Significant at 0.05
Source: Author's Computation (2018)

5.7 Relationship between Climate Road Subbase (SB) along Akwanga-Toto-Abuja road

The interrelationship between climate and road subbase (SB) is presented in table 21. There is a strong relationship between minimum temperature (.384), rainfall (.637), maximum dry density (.412), and plastic limit(.480).There is a weak relationship between moisture content(-.132), Californian bearing ratio (.139), and liquid limit(.187).The implication of this result is that as rainfall increases, moisture content in sub base(SB) and this make the sub base lose strength and compaction characteristics of subbase of road thereby encountering unstable condition of the subbase of the road foundation.

5.8 Relationship between Climate and Road subgrade along Akwanga-Toto-Abuja road

Table 22 presents interelationship between climate and subgrade along Akwanga-Toto- Abuja road. A strong relationship exist between plastic limit (0.480), liquid limit (0.454), maximum dry density (0.582) optimum moisture content (0.582) and plastic limit (0.485) with particle size distribution in the sub grade respectively .This implies that influx of Moisture content due to rainfall Increase the moisture content which may result to failure in the sub grade. However, there is a weak strong relationship between minimum temperature (.057), optimum temperature (0.139) but an inverse relationship with liquid limit (-0.197).This implies that influx of moisture content in subgrade with high clay content. These soils will become plastic, they crack when dry (Ola, 1987 and Hijab *et al*. 2012).

Table 21: Correlation matrix for assessing interrelationship between climate and road sub base along Akwanga-Toto-Aabaji-Abuja road

Variable	MC	LL	PL	PI	FSW	MDD	OMC	CBR	RF	MaxT	MinT
MC	1.00	-.453	-.092	.033	-.229	-.157	.021	.089	-.079	-.493*	.142
LL		1.00	.480*	-.131	.320	.202	-.023	-.339	-.351	.313	.177
PL			1.00	-.584*	.081	.085	-.071	-.425	-.637**	.081	.384
PI				1.00	.114	-.025	.036	.282	.513*	-.168	-.458
FSW					1.00	.412	-.205	-.358	-.128	.134	.086
MDD						1.00	-.582*	-.086	-.206	.129	.023
OMC							1.00	.134	.270	-.159	-.110
CBR								1.00	.112	.209	-.033
ARF									1.00	-.177	-.242
Tmax										1.00	-.162
Tmin											1.00

** Significant at 0.01 * Significant at 0.05 levels

Source: Author's Computation (2018)

Table 22: Correlation matrix for assessing interrelationship between climate and road subgrade along Akwanga-Toto-Abaji road

Variable	MC	LL	PL	PI	FSW	MDD	OMC	CBR	RF	MaxT	MinT
MC	1.00	-.454	-.012	.133	-.429	-.357	.221	.181	-.379	-.193*	.242
LL		1.00	.480*	-.131	.520	.202	-.023	-.339	-.351	.313	.177
PL			1.00	-.584*	.081	.085	-.071	-.425	-.312	.081	.384
PI				1.00	.114	-.025	.036	.282	.513*	-.168	-.458
FSW					1.00	.412	-.205	-.358	-.128	.134	.086
MDD						1.00	-.582*	-.086	-.206	.129	.023
OMC							1.00	.134	.270	-.159	-.110
CBR								1.00	.112	.209	-.033
ARF									1.00	-.177	-.142
Tmax										1.00	-.150
Tmin											1.00

** Significant at 0.01* Significant at 0.05 levels

Source: Author's Computation (2018)

5.9 Relationship between Climate and Road Sub Base (SB) along Ilorin-Ajase-Ipo-Iloffa Road

Table 23 explains the degree of relationship between climate and road subbase along Ilorin-Iloffa road. There is an inverse relationship between liquid limit (-.132), natural moisture content (-204) and plasticity index (-.204). There is a strong relationship that was established in Carlifornia bearing ratio (0.412), rainfall (0.512), maximum dry density (0.548) and maximum dry density (0.442) with particle size distribution. The increase in maximum dry density and Carlifornia bearing ratio shows the low and medium clay present in subbase is an indication of the presence of clay materials which swell when in contact is capable of causing various deformations of sub base and pavement layer with potholes. This has been the reason why the road persistently failed each time maintenance was carried out. This result agrees with Ifabiyi and Kekere (2013).

5.10 Relationship between Climate and Road Subgrade (SG) along Ilorin-Ajase-Ipo-Iloffa Road

The relationship between climate and road subgrade along Ilorin-Ajase-Ipo road (SG) is presented in table 24. There is a strong interrelationship between maximum dry density (0.498), rainfall (0.270), and optimum moisture content (0.254), carlifornia bearing ratio (0.415) and minimum temperature (0.309) with particle size distribution in the sub grade respectively. This means that, the sub grade is equally well graded but increase in rainfall; maximum temperature and minimum temperature are likely going to have adverse effect on the subgrade compaction characteristics of foundation materials along the road thereby reducing the strength of subgrade .However, there is an inverse relationship between liquid limit (-132), plastic limit (-0.47) and maximum temperature (-.195).

Table 23: Correlation matrix for assessing interrelationship between climate on road subbase along Ilorin-Ajase ipo –Illofa road

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.326	.101	.281	-.198	.154	.191	.131	-.166	-.162	-.395	.118
MC		1.00	-.204	-.132	-.047	.117	-.282	.008	-.096	.231	-.386	.048
SPG			1.00	-.054	.182	.165	.364	.227	.131	.512	.201	.332
LL				1.00	.211	.390	.067	-.044	.139	-.285	.145	.057
PL					1.00	.200	.307	-.197	.080	-.136	.442	-.107
PI						1.00	-.028	-.254	.415	.187	.017	-.309
MDD							1.00	.015	.125	-.548*	-.151	-.059
OMC								1.00	-.241	.142	-.104	-.032
CBR									1.00	-.241	-.302	-.432
ARF										1.00	.009	.153
Tmax											1.00	.353
Tmin												1.00

** Significant at 0.01* Significant at 0.05
Source: Author's Computation (2018)

Table 24: Correlation matrix for assessing interrelationship between climates on road subgrade along Ilorin-Ajase Ipo-Illofa road

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.321	.201	.291	-.198	.051	.111	.102	-.166	-.062	-.195	.210
MC		1.00	-.104	-.132	-.047	.217	-.282	.008	-.096	.231	-.386	.191
SPG			1.00	-.054	.182	.165	.498	.227	.131	-.017	.201	.332
LL				1.00	.211	.390	.067	-.044	.139	-.285	.145	.057
PL					1.00	.200	.307	-.197	.080	-.136	.172	-.107
PI						1.00	-.028	-.254	.415	.187	.017	-.309
MDD							1.00	.015	.125	-.270*	-.151	-.059
OMC								1.00	-.241	.142	-.104	-.032
CBR									1.00	-.241	-.302	-.432
ARF										1.00	.009	.153
Tmax											1.00	.212
Tmin												1.00

** Significant at 0.01* Significant at 0.05
Source: Author's Computation (2018).

5.11 Relationship between Climate and Road Sub Base (SB) along Anyigba-Ankpa-Ofa Road

According to Table 25 results shows that a relationship exists between climatic variables and plasticity index (0.657), optimum moisture content (0.525), rainfall (0.309), maximum temperature (0.347), minimum temperature (0.351) with particle size distribution. There is a week relationship with maximum dry density (.049), carlifornia bearing ratio (.023) and minimum temperature (0.216) There is an inverse relationship with liquid limit (-.132), carlifornia bearing ratio (-.166), plastic limit (-.047).The failure of road subbase along the road is also attributed to poor materials imples that failure rate on subbase can be attributed to poor subbase materials which have been reported by several works.

5.12 Relationship between Climate and Road Subgrade (SG) along Anyigba-Ankpa-Ofa Road

Table 26 presents the interrelationship between climate and road subgrade along Anyigba-Ankpa-Ofa road. There is a strong relationship between minimum temperature (0.715), rainfall (0.619), maximum dry density (0.536), and plastic limit (0.605) with particle size distribution in the sub grade respectively. There is a weak relationship between liquid limit (0.144), moisture content (0.154), carlifornia bearing ratio (.013) and moisture (.013) and an inverse relationship with carlifornia bearing ratio(-.366) and particle size distribution(-.257).

Table 25: Correlation matrix for assessing interrelationship between Climate and road subbase along Anyigba-Ankpa-Ofa road

Variables	PSD	MC	SPG	LL	PL	PI	FSW	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.109	.009	-.043	.423	.052	-.293	-.045	-.055	-.069	.126	.098	.194
MC		1.00	-.014	-.306	-.066	-.349	-.469*	.090	-.070	.191	-.158	.021	-.173
SPG			1.00	-.112	.014	-.062	.062	-.433	.291	-.097	.273	-.162	.173
LL				1.00	.038	.651**	.036	-.233	-.296	-.314	.389	.102	-.321
PL					1.00	.037	-.109	-.199	.280	.230	.112	.347	-.004
PI						1.00	-.107	.049	-.525*	-.184	.170	-.079	-.406
FSW							1.00	.242	.182	.030	.086	.063	.351
MDD								1.00	-.209	.269	-.126	-.010	-.215
OMC									1.00	-.163	.222	.289	.222
CBR										1.00	-.223	-.024	-.032
ARF											1.00	.517*	-.216
Tmax												1.00	-.023
Tmin													1.00

** Significance at 0.01* Significance at 0.05 levels.
Source: Author's compilation (2018).

Table 26: Correlation matrix for assessing interrelationship between climate androad subgrade along Ayingba-Ankpa-Ofa road

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	-.357	.401	-.426	-.047	-.350	-.107	-.160	-.279	.535*	-.115	.141
MC		1.00	.408	.308	.523*	-.033	.460	.154	.013	-.075	.136	-.178
SPG			1.00	-.053	.467	-.271	-.049	.014	.000	-.033	-.056	-.101
LL				1.00	.144	.605**	.536*	.169	.098	-.619**	-.053	-.017
PL					1.00	-.549*	.459	.223	.083	-.202	-.358	-.715**
PI						1.00	.068	-.058	.082	-.366	.234	.430
MDD							1.00	.096	.094	-.133	-.067	-.111
OMC								1.00	.473*	-.224	-.441	-.468
CBR									1.00	-.402	-.366	-.201
ARF										1.00	.158	.123
Tmax											1.00	.530**
Tmin												1.00

** Significant at 0.01* Significant at 0.05 levels
Source: Author's Computation (2018).

5.13 Relationship between Climate and Road Subbase (SB) along Edo-Agbor-Asaba Road

According to table 27 there is an established relationship between climate and road sub base (SB) along Edo-Agbor-Asaba road. There is a strong relationship between maximum temperature (0.517), rainfall (0.573), minimum temperature (0.929), plastic limit (0.613) and moisture content (0.425) with particle size distribution. This implies that, some sections of the road is well graded while others are not in line with FMW &H standard specification for road and bridges an increase in rainfall has direct influence on sub base moisture content and the strong relationship with MDD exist this is an indication that, there is presence of clay materials (peat clay) which constituted foundation materials and is capable of causing failure due increasing moisture condition causing various deformations such as crack, rutting and shoven respectively.This results agrees with work of Ndefor(2012),

5.14 Relationship between Climate and Road Subgrade (SG) along Edo-Agbor-Asaba Road

According to 28, results show there is also a relationship exist between climatic variables and road failure on sub grade (SG) along Edo-Agbor-Asaba road. Plasticity index (0.525), rainfall (0.589), maximum temperature (0.517) and minimum temperature (0.406). weak relationship exist with particle size distribution (PSD) to indicate that PSD was not uniformly graded in some of the section on the road subgrade while others do not corfim with Carlifornia bearing ratio (0.191) and FSW (0.238). However, there is an inverse relationship with MinT (-0.173). By implication the relationship between MDD and OMC is an indication that with increasing moisture, the sub grade causes instability as a result of free swell that may occur on the clayey materials that constituted the sub grade a similar study by Ndefo (2012) also agrees to this finding.

Table 27: Correlation matrix for assessing interrelationship between climate and road subbase along Edo-Abgor-Asaba road

Variables	PSD	MC	SPG	LL	PL	PI	FSW	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.159	.009	-.053	.423	.026	-.293	-.045	-.055	-.022	.041	.071	.117
MC		1.00	-.014	-.306	-.066	-.349	-.469*	.090	-.070	.191	-.158	.021	-.173
SPG			1.00	-.112	.046	-.062	.062	-.433	.291	-.097	.573	-.162	.173
LL				1.00	.038	.613**	.036	-.233	-.296	-.314	.389	.102	-.321
PL					1.00	.037	-.109	-.199	.280	.230	.112	.347	-.004
PI						1.00	-.107	.049	-.425*	-.184	.170	-.079	-.406
FSW							1.00	.242	.182	.030	.086	.063	.351
MDD								1.00	-.209	.269	-.126	-.010	-.215
OMC									1.00	-.163	.222	.289	.222
CBR										1.00	-.223	-.024	-.032
ARF											1.00	.517*	-.216
Tmax												1.00	-.929
Tmin													1.00

** Significance at 0.01* Significance at 0.05 levels.
Source: Author's compilation (2018).

Table 28: Correlation matrix for assessing interrelationship between Climate and road subgrade Edo-Agbor-Asaba road

Variables	PSD	MC	SPG	LL	PL	PI	FSW	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.119	.029	-.443	.423	.052	-.393	-.045	-.055	-.069	.126	.098	.740
MC		1.00	-.014	-.306	-.066	-.349	-.469*	.090	-.070	.191	-.158	.021	-.173
SPG			1.00	-.112	.014	-.062	.062	-.433	.291	-.097	.273	-.162	.173
LL				1.00	.038	.751**	.036	-.233	-.296	-.314	.589	.102	-.321
PL					1.00	.037	-.109	-.199	.280	.230	.112	.347	-.004
PI						1.00	-.107	.049	-.525*	-.184	.170	-.079	-.406
FSW							1.00	.242	.182	.030	.086	.063	.151
MDD								1.00	-.209	.269	-.126	-.010	-.215
OMC									1.00	-.163	.222	.289	.222
CBR										1.00	-.223	-.024	-.032
ARF											1.00	.517*	-.216
Tmax												1.00	-.043
Tmin													1.00

** Significance at 0.01* Significance at 0.05 levels.
Source: Author's compilation (2018).

5.15 Relationship between Climate and Road Subbase (SB) along Port Harcourt–Elele-Umanelu Road

According to Table 29 results show that relationships exist between climatic variables and road subbase failure along Portharcourt-Elele-Umanelu road. Plasticity index (0.600), optimum moisture content (0.435), rainfall (0.389), maximum temperature (0.517) and minimum temperature (0.400) have a strong relationship with particle size distribution (PSD) this also indicates that PSD was uniformly graded on the subbas category and also has a weak relationship with plastic limit (0.46), carlifornia bearing ratio (0.22) and maximum dry density (0.090) but inversely related with freeswell (.-109). Failure of the road subbase in port Harcourt-Elele-Umenelu road could be attributed to poor soil materials of subbase due to geologic formation and problem soil. A similar study by Ndefo (2012) also agrees with the findings of this work.

5.16 Relationship between Climate and Road and Sub grade (SG) along Port Harcourt – Elele-Umanelu Road

The relationship between climate and road subgrade is presented in Table 30, there is a strong rrelationship between rainfall (0.548), maximum temperature (0.442), minimum temperature (0.353), carlifornian bearing ratio (0.415) and plasticity index (0.390) with particle size distribution (PSD) in the subgrade respectively. There is a weak relationship betweenmaximum dry density (0.191), liquid limit (0.211) and plastic limit (.047), and there is an inverse relationship with optimum moisture content (-.204), specific gravity (-.054) respectively. Rainfall recorded a high with 50% indicationg that an increasing in rainfall has influence in road subgrade failure along the road.

Table 29: Correlation Matrix for assessing interrelationship between Climate and road subbase Porthacourt-Elele-Umanelu road

Variables	PSD	MC	SPG	LL	PL	PI	FSW	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.109	.009	-.043	.423	.052	-.293	-.045	-.055	-.069	.126	.098	.194
MC		1.00	-.014	-.306	-.066	-.349	-.281*	.090	-.070	.191	-.158	.021	-.173
SPG			1.00	-.112	.014	-.062	.062	-.433	.291	-.097	.273	-.162	.173
LL				1.00	.038	.500**	.036	-.233	-.296	-.314	.389	.102	-.321
PL					1.00	.037	-.109	-.199	.280	.230	.112	.347	-.004
PI						1.00	-.107	.049	-.435*	-.184	.170	-.079	.406
FSW							1.00	.242	.182	.030	.086	.063	.351
MDD								1.00	-.209	.269	-.126	-.010	-.215
OMC									1.00	-.163	.222	.289	.222
CBR										1.00	-.223	-.024	-.032
ARF											1.00	.512*	-.216
Tmax												1.00	-.023
Tmin													1.00

** Significance at 0.01* Significance at 0.05 levels.
Source: Author's compilation (2018).

Table 30: Correlation matrix for assessing interrelationship between climate on road subgrade Porthacourt-Elele-Umanelu road

Variables	PSD	MC	SPG	LL	PL	PI	MDD	OMC	CBR	RF	MaxT	MinT
PSD	1.00	.326	.101	.281	-.198	.154	.191	.131	-.166	-.162	-.395	.118
MC		1.00	-.204	-.132	-.047	.117	-.282	.008	-.096	.231	-.386	.048
SPG			1.00	-.054	.182	.165	.364	.227	.131	-.017	.201	.332
LL				1.00	.211	.390	.067	-.044	.139	-.285	.145	.057
PL					1.00	.200	.307	-.197	.080	-.136	.442	-.107
PI						1.00	-.028	-.254	.415	.187	.017	-.309
MDD							1.00	.015	.125	-.548*	-.151	-.059
OMC								1.00	-.241	.142	-.104	-.032
CBR									1.00	-.241	-.302	-.432
ARF										1.00	.009	.153
Tmax											1.00	.353
Tmin												1.00

** Significant at 0.01* Significant at 0.05
Source: Author's Computation (2018)

CHAPTER SIX

IMPACT OF CLIMATE ON ROAD SUBBASE AND SUBGRADE FAILURE

6.0 Introduction

Impact of climate on road sub base and sub grade failure

The result of multiple correlations (Table 31) showed that R^2 for multiple regression ranges between 7.60% for MDD at warm humid (zone 4) and LL at Hot humid (zone 3) where 49% was recorded. While that of multiple regressions was 48% for LL at hot humid at (zone 4) while the least is 1.90% for MDD at warm humid (zone 3). In most cases the results of stepwise regression were nil. In most of the zones, some of the variables did not enter into the stepwise regression models revealing the assumption between climatic factors and geotechnical properties were relatively and are weak. Suggesting that road failure in Nigeria is not mainly caused by weather and climate. Others factors such as erosion of road shoulders, misuse and abuse of road pavement by telecommunication operators etc (rutting reveling longitudinal cracks among others) also played a role in causig instability in road foundation in Nigerian road. The regression equations for the explanation are presented in equations 1-24 in table 31.

6.1 Impact of climate on road subbase and subgrade failure for hot dry (zone 1).

There result of multiple correlations (Table 32) R^2 for subbase and subgrade shows the magnitude of climatic factor very weak. The coefficient determination were recorded for particle size distribution R^2 is 23%,liquid limit 12%, plasticity index 21%,maximum dry density 25%,optimum moisture content 5%,and carlifornia bearing ratio 5% respectively.In most cases the stepwise regression did not enter into the stepwise regression model revealing the assumption between climatic factor and geotechnical properties were relatively weak suggesting that road subbase and subgrade failure in hot dry morphoclimate is not mainly caused by climatic

factors alone there are other factors that also contribute to road subbase and subgrade failure.The regression model for the explanation is presented in equation 1-6 in Table 32

6.2 Impact of climate on road subbase and subgrade failure for temperature dry (zone 2).

The result of multiple correlation for temperate dry also show the same pattern of a very weak magnitude of climatic factors.The coffecient determination of R^2 were recorded for particle size distribution R^2 is 35.2%,liquid limit 14.5%, plasticity index 9.8%,maximum dry density 12%,optimum moisture content 10.3%,and carlifornia bearing ratio 3.3%. In all cases the stepwise regression did not enter the regression model also revealing the assumption between climatic factors and geotechnical properties are not the main causes of road subbase and subgarde failure in temperate dry morphoclimatic zone.The regression model for the explanation is presented in equation 7-12 in table 32

6.3 Impact of climate on road subbase and subgrade failure for hot humid (zone 3)

The result of multiple correlation for hot humid is presented is presented in Table 29 the following coefficient determination for R^2 were recorded for particle size distribution R^2 is 8.6%, liquid limit 23.9%, plasticity index 9.6%, maximum dry density 1.9%, optimum moisture content 1.4%, and carlifornia bearing ratio 19.6% .Stepwise regression recorded nill in most cases except liquid limit which recorded 23.5% suggesting that climatic and geotechnical properties have more impact on road subbase and subgrade failure in hot humid morphoclimatic zone. The regression equation for the explanation is presented in equation 13-18 in table 32

6.4 Impact of climate on road subbase and subgrade failure for warm humid (zone 4)

The result of multiple correlations is presented in table 31 explain the magnitude of climatic factors and geotechnical properties for road subbase and subgrade in the warm humid

morphoclimatic zone. The coefficient determination for R^2 were recorded as follows for particle size distribution R^2 is 11.1%, liquid limit 14.6%, plasticity index 17.1%, maximum dry density 22.7%, optimum moisture content 21.2%,and carlifornia bearing ratio 7.6%. Stepwise regression recorded nill because it did enter the regression model in most cases except liquid limit which recorded 47.9% also revealing the assumption that climatic factors and geotechnical properties were the main causes of road subbase and subgrade failure apart from other evnvironmantal factors according to the stud. The regression equation for the explanation is presented in equation 19-24 in Table 32.

Table 31: Magnitude of climatic variables on geotechnical properties

Variables		R^2 (%)	R(%)	Std error	Variable entered
PSD Zone.1	Entered	22.80	47.70	15.826	Rainfall, MaxT and MinT
	Stepwise	Nil			
PSD Zone 2	Entered	35.20	45.20	14.786	Rainfall, MaxT and MinT
	Stepwise	Nil			
PSD Zone 3	Entered	8.60	29.30	19.853	Rainfall, MaxT and MinT
	Stepwise	Nil			
PSD Zone 4	Entered	11.10	33.30	5.669	Rainfall, MaxT and MinT
	Stepwise	Nil			
LL Zone 1	Entered	21.10	47.70	15.826	Rainfall, MaxT and MinT
	Stepwise	Nil			
LL Zone 2	Entered	14.50	38.10	4.203	Rainfall, MaxT and MinT
	Stepwise	Nil			
LL Zone 3	Entered	23.90	49.00	3.646	Rainfall, MaxT and MinT
	Stepwise	Nil			
LL Zone 4	Entered	14.60	38.20	5.825	Rainfall, MaxT and MinT
	Stepwise	49.00	22.90	5.735	Rainfall, MaxT and MinT
PI Zone 1	Entered	20.60	45.40	10.780	Rainfall, MaxT and MinT
	Stepwise	Nil			
PI Zone 2	Entered	9.80	31.30	3.721	Rainfall, MaxT and MinT
	Stepwise	Nil			
PI Zone 3	Entered	9.60	31.0	4.456	Rainfall, MaxT and MinT
	Stepwise	Nil			
PI Zone 4	Entered	17.10	41.40	3.440	Rainfall, MaxT and MinT
	Stepwise	12.10	34.90	3.436	Rainfall, MaxT and MinT
MDD Zone 1	Entered	25.20	12.50	8.659	Rainfall, MaxT and MinT
	stepwise	Nil			
MDD Zone 2	Entered	12.00	34.60	0.0524	Rainfall, MaxT and MinT
	stepwise	Nil			
MDD Zone 3	Entered	1.90	13.70	8.217	Rainfall, MaxT and MinT
	stepwise	Nil			
MDD Zone 4	Entered	22.70	7.60	0.979	Rainfall, MaxT and MinT
	stepwise	Nil			
OMC Zone 1	Entered	15.40	39.20	0.067	Rainfall, MaxT and MinT
	stepwise	Nil			
OMC Zone 2	Entered	10.30	32.10	2.392	Rainfall, MaxT and MinT
	stepwise	Nil			
OMC Zone 3	Entered	1.40	11.80	4.010	Rainfall, MaxT and MinT
	stepwise	Nil			
OMC Zone 4	Entered	21.20	46.10	3.272	Rainfall, MaxT and MinT
	stepwise	Nil			
CBR Zone 1	Entered	4.50	21.30	10.288	Rainfall, MaxT and MinT
	stepwise	Nil			
CBR Zone 2	Entered	3.30	18.10	6.380	Rainfall, MaxT and MinT
	stepwise	Nil			
CBR Zone 3	Entered	19.60	44.30	7.830	Rainfall, MaxT and MinT
	stepwise	Nil			
CBR Zone 4	Entered	7.60	27.60	4.853	Rainfall, MaxT and MinT
	stepwise	Nil			

Source: Authors' computation (2018)

Table 32: Multiple regression models for Hot Dry, Temperate Dry, Hot Humid and Warm Humid.

Multiple Regression Equation for Hot Dry(Zone 1)		R^2= ;	SE
i. PSD= 64.527+ $0.320_{Rainfall}$-13.672_{MaxT}+14.913_{MinT}……....	eqn1	R^2= 22.8%;	SE=15.83
ii.LL= 25.633-$0.69_{Rainfall}$+5.410_{MaxT}-0.585_{MinT}.....	eqn2	R^2= 21.1%;	SE=15.82
iii.PI=165.943+$0.77_{Rainfall}$+2.511_{MaxT}-8.650_{MinT}…….….....	eqn3	R^2= 20.6%;	SE=10.8
iv.MDD= 1.495-$0.01_{Rainfall}$+0.36_{MaxT}-0.49_{MinT}…….….....	eqn4	R^2= 25.2%;	SE=8.7
v. OMC= 1.449+$4.492_{Rainfall}$+0.12_{MaxT}-0.22_{MinT}…….....	eqn5	R^2= 15.4%;	SE=0.67
vi.CBR= 80.439-$0.101_{Rainfall}$-0.322_{MaxT}-1.937_{MinT}…….....	eqn6	R^2= 4.50%;	SE=10.3
Multiple Regression Equation for Temperate Dry (Zone 2)			
vii.PSD= 45.527+ $0.320_{Rainfall}$-14.672_{MaxT}+12.913_{MinT}……...	eqn 7	R^2= 35.2%;	SE=14.79
viii.LL=34.271+$0.09_{Rainfall}$+0.269_{MaxT}+0.232_{MinT}……...	eqn 8	R^2= 14.5%;	SE=4.20
ix. PI= 8.909-$0.09_{Rainfall}$+0.59_{MaxT}-0.18_{MinT}…… ……	eqn9	R^2= 9.8%;	SE=3.72
x. MDD= 2.371+$0.525_{Rainfall}$+0.04_{MaxT}+0.02_{MinT}.....	eqn10	R^2= 12.0%;	SE=0.05.
xi. OMC= 36.206+$0.01_{Rainfall}$-0.85_{MaxT}-0.549_{MinT}…….....	eqn11	R^2= 10.0%	SE=2.39
xii.CBR= 17.871-$0.09_{Rainfall}$+0.14_{MaxT}+1.427_{MinT}…….....	eqn12	R^2= 3.3%;	SE=6.38
Multiple Regression Equation for Hot humid (Zone 3)			
xiii.PSD= 38.417+$0.230_{Rainfall}$-0.432_{MaxT}+0.245_{MinT}……..	eqn13	R^2= 25.2%;	SE=8.65
xiv.LL= 21.283+$0.11_{Rainfall}$+3.041_{MaxT}-0.623_{MinT}……....	eqn14	R^2= 23.9%;	SE=3.64
xv.PI=25.515+$0.51_{Rainfall}$+0.512_{MaxT}-0.203_{MinT}……..	eqn15	R^2= 9.6%;	SE=4.45
xvi. MDD=1.978+$0.413_{Rainfall}$+0.11_{MaxT}+0.12_{MinT}……..……....	eqn16	R^2= 1.9%;	SE=15.8.21
xvii.OMC=21.664-$0.33_{Rainfall}$-0.445_{MaxT}-0.165_{MinT}…….....	eqn17	R^2= 1.4%;	SE=4.01
xiii.CBR=24.280-$0.33_{Rainfall}$-2.949_{MaxT}+1.32_{MinT}…….…...	eqn18	R^2= 19.6%	SE=7.83
Multiple Regression Equation for Warm humid (Zone 4)			
xix.PSD= 35.121+$0.20_{Rainfall}$+0.720_{MaxT}+4.08_{MinT}…….....	eqn19	R^2= 11.1%;	SE=5.67
xx. LL=57.117-$0.03_{Rainfall}$+1.286_{MaxT}-0.2403_{MinT}…….....	eqn20	R^2= 14.6%;	SE=5.83
xxi.PI=-9.486-$0.17_{Rainfall}$+1.030_{MaxT}+0.213_{MinT}…….....	eqn21	R^2= 17.1%;	SE=3.44
xxii.MDD=2.234+$0.009_{Rainfall}$-0.12_{MaxT}-0.10_{MinT}……	eqn22	R^2= 22.7%	SE=0.9.7
xxiii.OMC= 94.444-$0.07_{Rainfall}$+0.806_{MaxT}+0.354_{MinT}…….	eqn23	R^2= 21.2%;	SE=3.27
xxiv.CBR= 55.539-$0.12_{Rainfall}$-0.826_{MaxT}+2.111_{MinT}…….....	eqn24	R^2= 7.6%;	SE=4.85

Source: Author's computation (2018)

Table 33 Spatial Variation of geotechnical properties in different morphoclimatic zones in Nigeria

Variables	ANOVA Properties	SS	F-cal	F-tab	Decision Rule
PSD	Between Group	24374.593	14.9	1.76	There is significant difference
	Within Group	53148			
	Total	77522.593			
LL	Between Group	1425.716	15.8	2.2	There is significant difference
	Within Group	489.99			
	Total	1915.706			
PI	Between Group	1506.575	26.9	2.1	There is significant difference
	Within Group	99.035			
	Total	1605.61			
MDD	Between Group	3.6375	9.5	2.6	There is significant difference
	Within Group	0.7625			
	Total	4.40			
OMC	Between Group	397.086	17.5	4.1	There is significant difference
	Within Group	47.31375			
	Total	444.399			
CBR	Between Group	1971.181	65.9	12.1	There is significant difference
	Within Group	79.868			
	Total	2051.048			

Source: Authors' computation (2018).

Table 33 showed that significant differences exist in the spatial pattern of geotechnical properties (PSD, LL.PI, MDD OMC and CBR) in Nigeria. This imply that the dominance of these properties vary from one morphoclimatic zone to the other.

CHAPTER SEVEN

COMPONENTS OF ROAD FOUNDATION FOR SUBBASE AND SUBGRADE FAILURE IN NIGERIA

7.0 Introduction

This chapter explains the nature of climatic variables and geotechnical properties that directly affect foundation failure of road subbase and subgrade in the four morphoclimatic zones in Nigeria. However, this chapter attempts to identify the climatic variable or geotechnical properties that determine foundation failure of roads in Nigeria.

7.1 Components of foundation failure of subbase along Birnin-Yauri-Malando-Wara Road

Road subbase failure can be explained by the twelve variables considered in this study is presented in Table 34.These variables were further reduced to 5 orthogonal components. These components include particle size distribution, liquid limit, plastic limit and carlifornia bearing ratio, the cumulative percentage variance altogehther contributed 81.2 % to the variance in road failure. Particle size distribution falls within A-2-4-2-6, A-7 (Table 7) is an indication that, the foundation subbase falls within silty to sokoto shale clayey materials which are often regarded as threat to engineering strctures such as road. Although other factors such as poor engineering, poor drainage and other environmental factors contributed to road subbase failure which several works have reported and identified by various work in hot dry morphological zones (Omenge, Nnama and Aitebomo 1989, Hijab et al 2012 among others).

Table 34: components Explaining Road Failure on Sub base (SB) for Birnin-Yauri - Malando-Wara Road

	Components				
Variables	1	2	3	4	5
Particle size distribution(PSD)	.749*	.160	.267	.080	-.104
Moisture content	.251	-.076	.874*	-.057	.137
Specific gravity	.362	.638	.307	-.297	-.343
Liquid limit	.723	.320	-.009	.273	.331
Plasticit limit	.547	.259	-.011	.691*	.086
Plasticity index	.651	-.232	.205	-.542	.181
Maximum dry density	.323	.258	-.428	-.362	.600*
Optimum moisture content	.412	-.584	.079	.365	-.107
California bearing ratio (CBR)	.482	.114	-.270	-.216	-.667
Rainfall	-.712	-.440	.349	-.018	.070
Maximum temperature	-.501	.710*	.263	-.018	.179
Minimum temperature	-.632	.647	.055	.179	-.120
Variable Indices	PSD	Tmax	MC	PL	CBR
Total Eigen Value	2.55	2.28	1.84	1.61	1.52
% of Variance	21.22	18.56	15.29	13.48	12.68
%Cumulative	21.22	39.77	55.06	68.51	81.19

Source: Author's Computation (2018)

* components defining variables

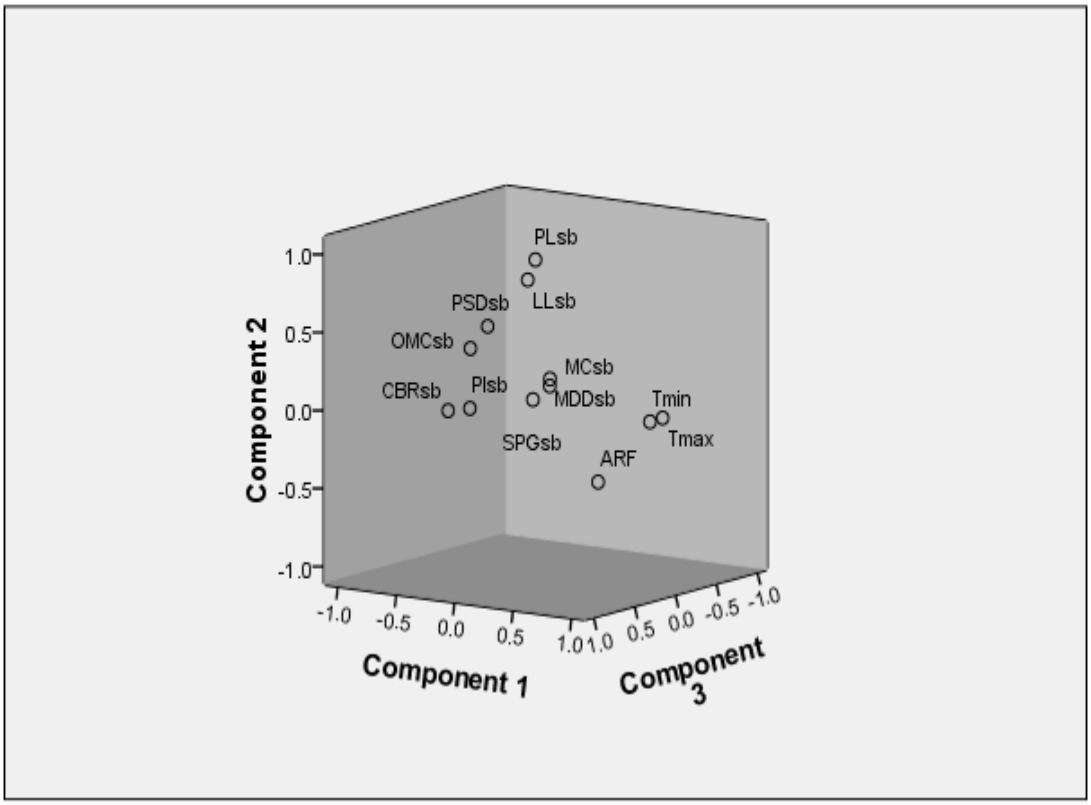


Figure 21 Component Plot for road sub base (SB) for Birnin Yauri Road.

Source: Authors Compulation (2018)

7.2 Components of foundation failure of subgrade along Birnin-Yauri-Maland-wara road

Road subgared failure can also be explained by twelve variables considered for this study is presented in Table 35 and these variables were further reduced to four orthogonal components namely plastic limit(PL), liquid limit(LL), moisture contents(MC) and particle size distribution(PSD). The percentage cumulative variance altogether contributed 75% to the explanation of road sugrade failure accoding to the study. PSD falls within A-2-4 to A-5-7(Table 7) which is also an indication that soils were silty and clayey foundation materials which is non plastic in nature due to the sandy which translate to high CBR, moisture contents is relatively

low which is adequate for the road foundation for the study but with increasing moisture due to precipitation the foundation of subgrade will be saturated with water causing instability in the foundation of road subgrade. Other factors also play a role in the subgrade failure on the road foundation along Birnin Yauri Road is explained by 7 components the finding also agrees with Hijab (2012).

Table 35s Components Explaining Road failure on Sub grade (SG) for Birnin Yauri- Malando-Wara Road

Variables	Components			
	1	2	3	4
Particle size distribution(PSD)	-.430	-.600	.075	.276
Moisture content	.527	.021	.679*	-.017
Specific gravity	.203	-.451	.463	.717*
Liquid limit	.536	.690*	.210	.047
Plasticit limit	.717*	-.472	.379	-.062
Plasticity index	-.047	.900	-.047	.184
Maximum dry density	.519	.170	.461	-.367
Optimum moisture content	.605	-.093	-.411	.070
California bearing ratio (CBR)	.498	.116	-.490	.304
Rainfall	-.572	-.504	.151	-.332
Maximum temperature	-.550	.395	.521	.024
Minimum temperature	-.681	.481	.264	.249
Variable Indices	PL	PI	MC	SPG
Total Eigen Value	2.68	2.62	2.24	1.40
% of Variance	22.37	21.81	18.68	11.65
Cumulative (%)	22.37	44.18	62.85	74.50

Source : Author's Computation (2018)

* components defining variables

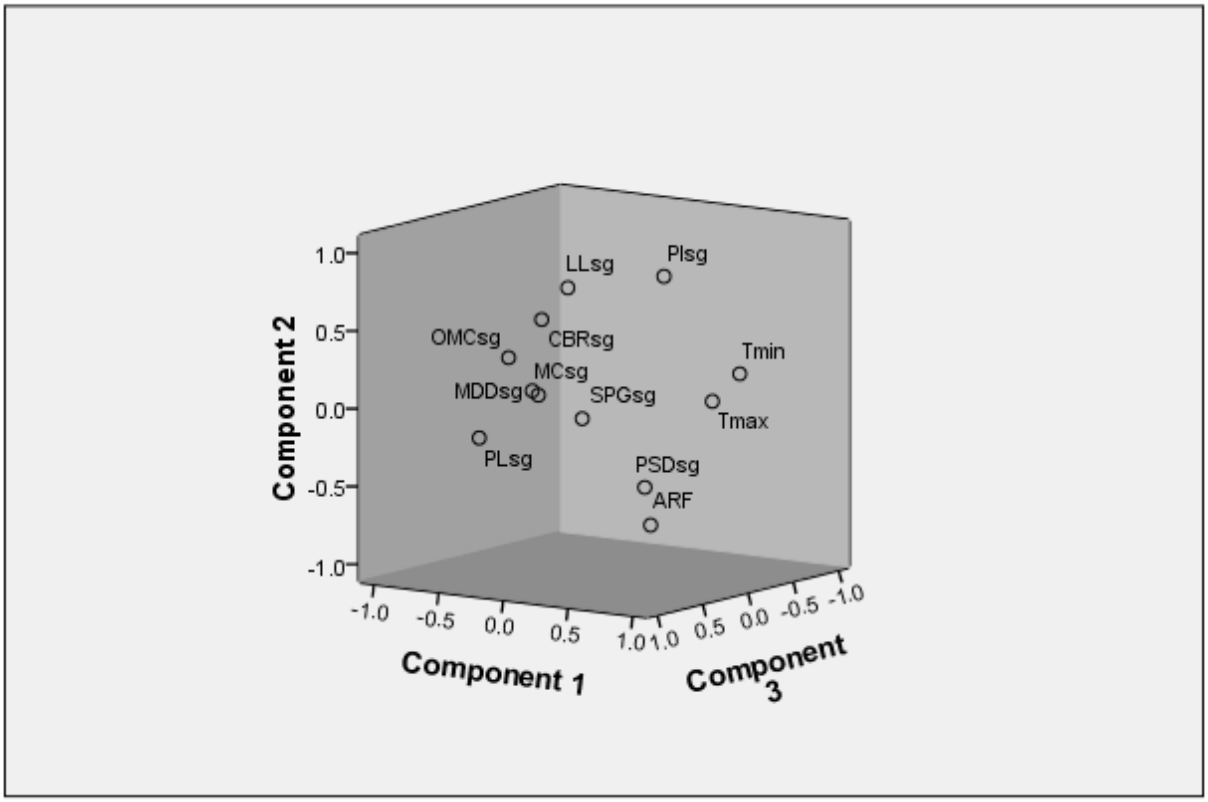


Figure 22: Component Plot for road sub grade (SG) for Birnin Yauri Road.
Source: Authors Computation (2018)

7.3 Components of foundation of road subbase along Kano-Katsina- GwarzoRoad

Road subase failure along Kano-Katsina-Gwarzo road is also explained by 12 variables considered in this study is presented in Table 36. These variables were further reduced to four orthogonal components namely PSD, NMC, PI and max tempture these components altogether contributed 81% to the variance that explained road subsubase failure. PSD falls within A-2-4 A-2-6 A-4 (Table 8) is also an indication that road subase foundation is clayey and sandy in nature which becomes non plastic due to sandy nature and when under precipitation becomes dry and causing various forms of failure such as potholes among others the natural moisture condition is

also an indication that moisture contents is good for road foundation but becomes problems especially during rainfall when in contact with clayey materials. Other factors of road subgrade foundation failure could be as aresults of environmental factors, excessive traffic loading which also explained reasons for road subbase failure Ndefor (2015) find out that excessive traffic loading by heavy vehicles causes more

Table 36: components Explaining Road Sub base failure for Kano- Katsina road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD)	.749*	.160	.267	.080	-.104
Natural Moisture Content(NMC)	.251	-.076	.874*	-.057	.137
Specific Gravity(SPG)	.362	.638	.307	-.297	-.343
Liquid Limit(LL)	.723	.320	-.009	.273	.331
Plasticity Limit(PL)	.547	.259	-.011	.691*	.086
Plasticity Index(PI)	.651	-.232	.205	-.542	.181
Maximum Dry Density	.323	.258	-.428	-.362	.600
Optimum Maximum Content(OMC)	.412	-.584	.079	.365	-.107
California Bearing Ratio(CBR)	.482	.114	-.270	-.216	.667*
Rainfall	-.712	-.440	.349	-.018	.070
Maximum Temperature	-.501	.710*	.263	-.018	.179
Minimum Temperature	-.632	.647	.055	.179	-.120
Variable Indices	PSD	Tmax	MC	PL	CBR
Total Eigen Value	2.55	2.28	1.84	1.61	1.52
% of Variance	21.22	18.56	15.29	13.48	12.68
Cumulative (%)	21.22	39.77	55.06	68.51	81.19

Source: Author's Computation (2018);

Note: * Components defining variables

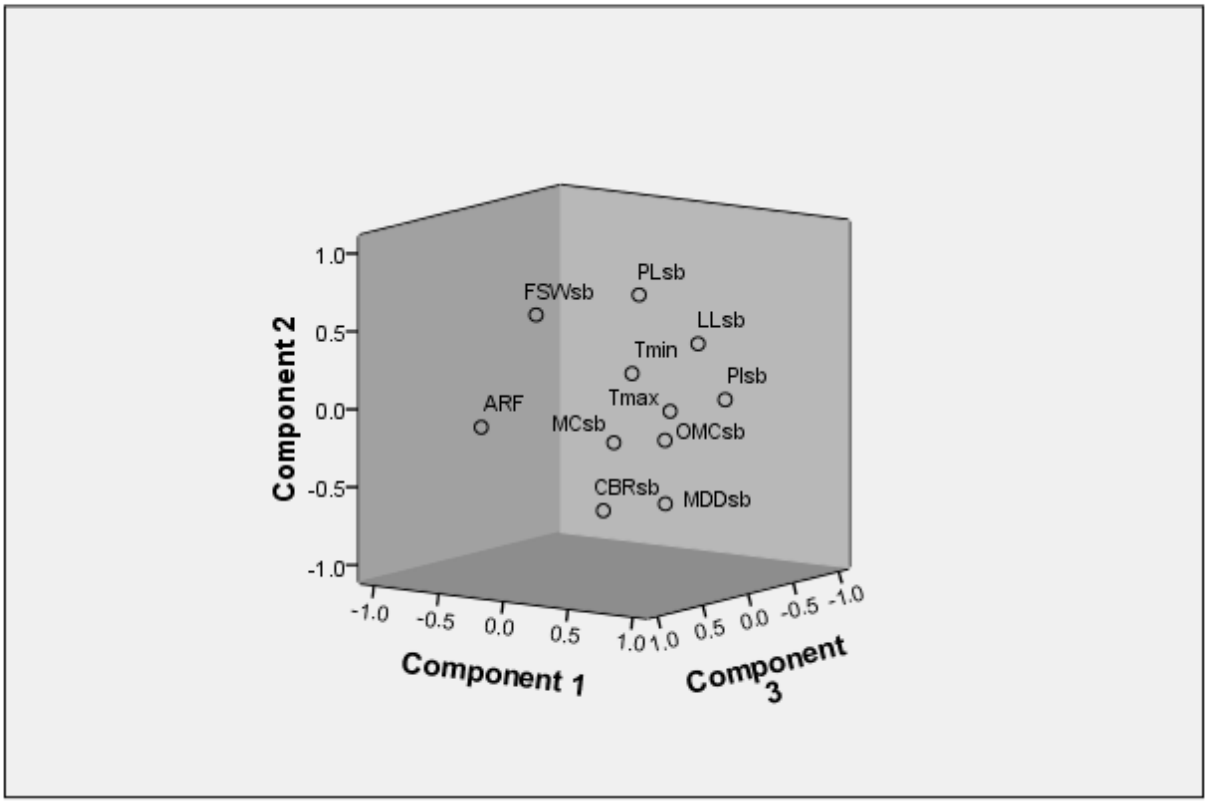


Figure 23: Component Plot for road sub base (SB) for Kano-Gwarzo Road.
Source: Author's Computation (2018)

7.4 Components of foundation failure for subgrade along Kano-Katsina- Gwarzo road

Road subgarde failure along Kano-Garzo-Katsina road can also be explained by twelve variables, these variables were fuether reduced to four components (Table 37) namely PL, MDD, PSD and Minimum temperature all these components cotributed 79.4% of the variance that explained road subgrade failure in the study area. Foundation soil of subgrade falls within A-2-4, A-2-6, A-7-5 suggesting that foundation soils are highly funded on clayey and sandy soils according to the study other factors such as environmental and human factors also contributed to

the factors of road subgarde failure in the study area.This findings agree with a similar study carried out in hot morphoclimatic zone by Hijab,(2012).

Table 37: component explaining road subgrade failure for Kano-Gwarzo-road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD	.533	-.114	.652*	.005	.383
Natural Moisture Content(NMC)	.728*	.447	.001	.381	.110
Specific Gravity(SPG)	-.026	.622	-.424	.534	.027
Liquid Limit(LL)	.730	.044	-.296	.000	-.089
Plasticity Limit(PL)	-.159	.618*	.523	-.139	.054
Maximum Dry Density	.529	-.591	.078	.267	-.003
Optimum Maximum Content(OMC)	.351	-.058	-.228	-.765	-.310
California Bearing Ratio(CBR)	-.201	-.760	-.280	.275	.324
Rainfall	-.542	-.135	.581	.158	-.077
Maximum Temperature	.719	-.124	.353	.026	-.211
Minimum Temperature	.090	.164	-.182	-.424	.845*
Freeswell	-.159	.618	.523	-.139	.054
Variable Indices	LL	SPG	PSD	SPG	MinT
Total Eigen Value	2.64	1.97	1.60	1.39	1.14
% of Variance	23.96	17.94	14.53	12.61	10.33
Cumulative (%)	23.96	41.90	56.44	69.05	79.39

Source: Author's Computation (2018);
Note: * Components defining variables

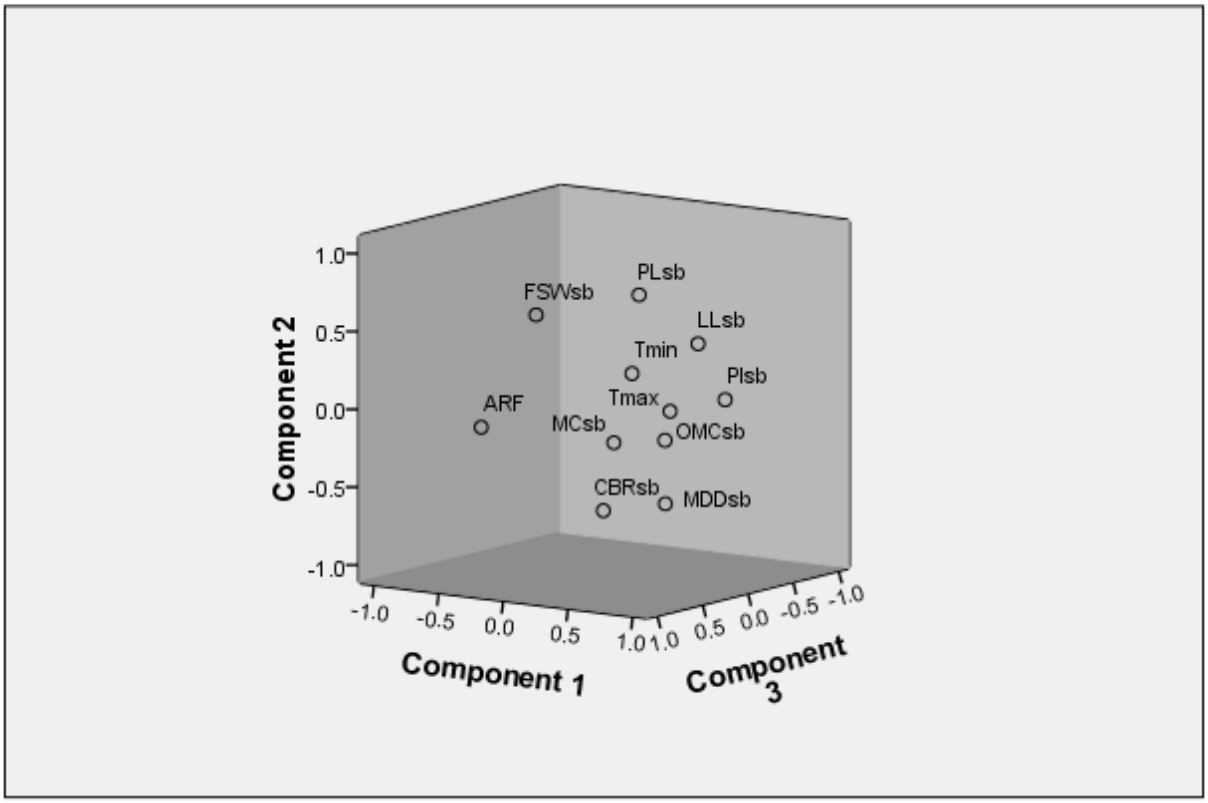


Figure 24: Component Plot for road subgrade (SG) for Kano-Gwarzo Road
Source: Author's Computation (2018)

7.5 Components foundation of road subbase failure along Akwanga-Toto-Abaji-Abuja road

Road subase foundation failure for Akwanga-Toto-Abaji-Abuja road can also be explained by eleven variables considered for the study (Table 38) namely PI, PL, moisture contents and minimum temperature these variables altogether contributed 80% variance to the explanation of road subbase failure.PL, PI are above the stipulated standard for the construction of road and bridges in Nigeria as stipulated by FMW&H (1997). Moisture content very high due to the geology of the study area and the non plastic nature of foundation soil is due to sandy nature of the study area. The clayey nature of foundation soils in the study area can be classified as low to

medium according to ofenie and Aniekan (2015) when in contac with moisture are capable of causing road subbase failure in the study area.

Table 38: Componets Explaining Road Subbase failure (SB) for Akwanga-Abuja Road

	Components				
Variables	1	2	3	4	5
Moisture content	.433	-.114	.652*	.005	.283
Liquid limit	.728*	.447	.001	.381	.110
Plastic limit	-.026	.622*	-.424	.534	.027
Plasticity index	.730	.044	-.296	.000	-.089
Freeswell	-.159	.618	.523	-.139	.054
Maximum dry density (MDD)	.529	-.591	.078	.267	-.003
Optimum moisture content (OMC)	.351	-.058	-.228	-.765	-.310
Carlifornia bearing ratio (CBR)	-.201	-.760	-.280	.275	.324
Rainfall	-.542	-.135	.581	.158	-.077
Maximum temperature	.719	-.124	.353	.026	-.211
Minimum temperature	.090	.164	-.182	-.424	.745*
Variable Indices	PI	PL	MC	OMC	MinT
Total Eigen Value	2.64	1.97	1.60	1.39	1.14
% of Variance	23.96	17.94	14.53	12.61	10.46
Cumulative (%)	23.96	41.90	56.44	69.05	79.51

Source : Author's Computation (2018)

* Components defining variables

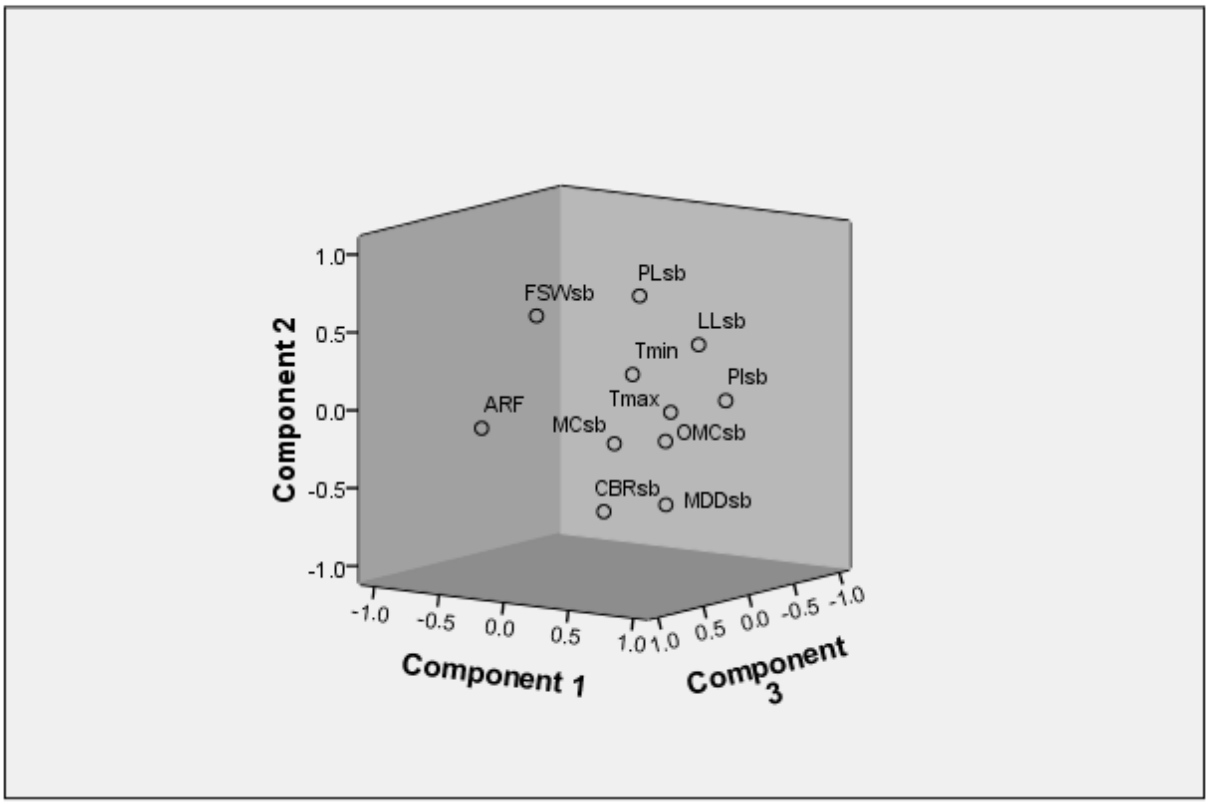


Figure 25: Component Plot for road sub base (SB) for Akwanga-Abuja Road.

Source: Author's Computation (2018)

7.6 Components of foundation failure for road subgrade (SG) for Akwanga- Abaji-Abuja Road.

Road subgrade foundation failure along Akwanga-Abaji-Abuja road can also be explained by eleven considered for this study. These variables were further reduced to three orthogonal components (Table 39) namely PL, OMC, and optimum moisture contents these variables altogether contributed 72% of variables in road subgrade failure along the road. Plastic limit, liquid limit recorded high above the specification for road and bridges (FMW&H.1997) Other factors could be responsible for road subgarde failure alon the road which several works have reported.

Table 39: Componets Explaining Road Subgrade (SG) for Akwanga-Abuja Road

Variables	Components			
	1	2	3	4
Moisture content	-.313	.602*	-.525	-.060
Liquid limit	.679	.246	.342	.251
Plastic limit	.792*	-.380	.151	.072
Plasticity index	-.614	.514	-.166	.218
Freeswell	.422	.491	-.278	.394
Maximum dry density (MDD)	.430	.488	-.551	-.189
Optimum moisture content (OMC)	-.378	-.311	.630*	.355
Carlifornia bearing ratio (CBR)	-.493	.061	.140	-.705
Rainfall	-.711	.266	.057	.318
Maximum temperature	.315	.495	.483	-.499
Minimum temperature	.423	-.495	-.163	-.065
Variable Indices	PL	MC	OMC	CBR
Total Eigen Value	3.10	1.97	1.50	1.29
% Variance	28.15	17.92	13.67	11.71
Cumulative (%)	28.15	46.08	59.75	71.46

Source : Author's Computation (2018)

* Components defining variables

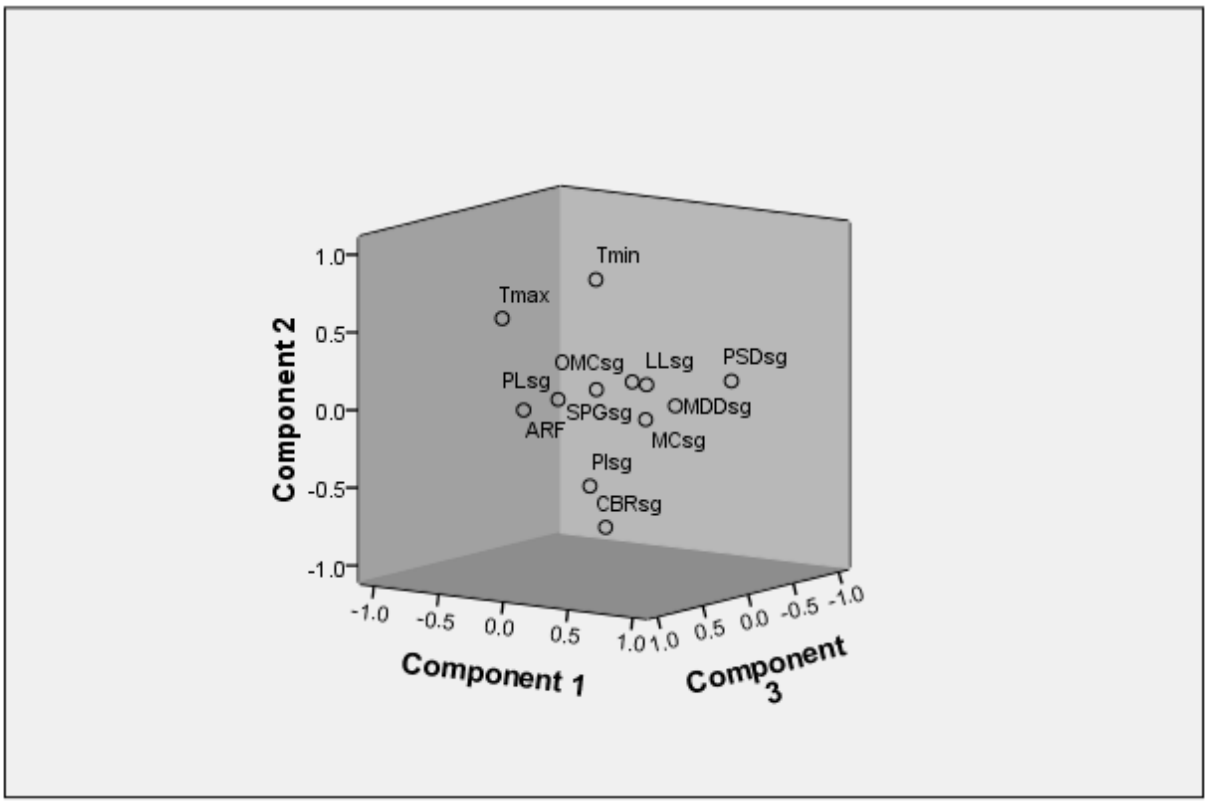


Figure 26: Component Plot for road subgrade (SG) for Akwanga-Abuja Road

Source: Author's Computation (2018)

7.7 Components of foundation of road subbase (Sb) for Katchi-Kwoi-Nasarawa road

Road subbase for Katchia-Kwoi-Nassarawa road can be explained by by twelve variables which were further reduced to four orthogonal components (Table 40) namely maximum temperature, platic limit, particle size distribution and CBR. These components altogether contributed 78% to he explanation of the variance for road subbase failure. PSD falls within A-2-4 to A-7-5 ASHTO classification which also an indication that soil were sandy-silt and clayey in most cases some area recorded high PSD, CBR PL PI which is an indication that these areas did not comply with standard practice for road construction(FMW&H.1997). These could be attributed to poor

engineering construction.These studies agree with Madedor and Lah (1985), Hijab (2012). Although other factors such as environmental factors could also contribute to road dubbase failure in the study area.

Table 40: Components explaining road Sub base failure for Katchi-Nassarawa-Kwoi road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD	.013	.141	.827*	.191	-.259
Natural Moisture Content(NMC)	.698	-.112	.347	.386	.154
Specific Gravity(SPG)	-.689	.277	.100	.055	.391
Liquid Limit(LL)	.612	-.173	.060	-.615	.306
Plasticity Limit(PL)	.319	.822*	-.048	-.115	-.060
Plasticity Index(PI)	-.191	.282	.711	-.493	.068
Maximum Dry Density	-.350	-.045	.538	.248	.343
Optimum Maximum Content(OMC)	.267	.598	-.124	-.116	.470
California Bearing Ratio(CBR)	-.422	-.567	.215	.670*	.012
Rainfall	-.020	.588	.032	-.162	-.641
Maximum Temperature	.813*	.024	.475	.059	-.063
Minimum Temperature	.514	.517	-.280	.516	.095
Variable Indices	NMC	MinT	PI	LL	RF
Total Eigen Value	2.34	1.97	1.94	1.68	1.38
% of Variance	19.53	16.44	16.18	13.99	11.53
Cumulative (%)	15.94	35.97	52.15	66.13	77.66

Source: Author's Computation (2018);
Note: * Components defining variables

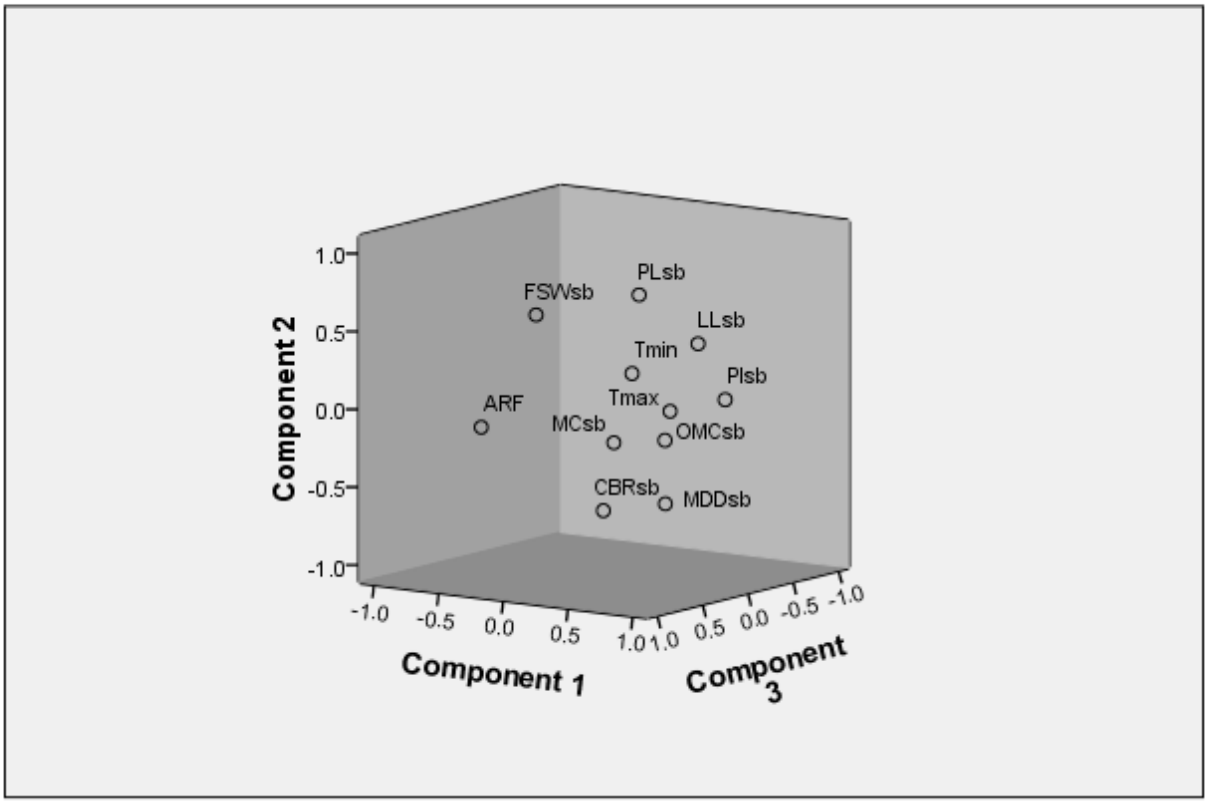


Figure 27: Component Plot for road sub base (SB) for Katchia-Kwoi-Nassarawa Road
Source: Author's Computation (2018)

7.8 Components of road foundation of road subgrade (SG) for Katchi-Kwoi-Nasarawa road

Road subgrade foundation failure along Katchi-Kwoi-Nassarawa road is explained by thirteen variables considred for the study. These variables were further reduced to four orthogonal components (Table 41) namely liquid limit, maximum temperature, plasticity index, and maximum dry density, these components altogether contributed 83% to the explanation of the variance of road sub accounted to for a total of 83% of variance in road subgarde failure along the study area. Plasticity index, liquid limit and maximum dry density have a higher value above the benchmark for road construction and bridges (FMW&H, 1997). These findings agree

with the study carried out by Fatokun and Bolarinwa (2008).Other factors could be responsible for road subgrade failure which is not accounted for in this study.

Table 41: Component Explaining Road Subgrade Katcia-Nassarawa-Kwoi road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD	.576	.028	.507	.287	.115
Natural Moisture Content(NMC)	.243	.629	.599	.068	-.089
Specific Gravity(SPG)	.785	.085	-.385	-.303	-.325
Liquid Limit(LL)	.785*	.085	-.385	-.303	-.325
Plasticity Limit(PL)	-.699	.550	-.280	-.032	-.004
Plasticity Index(PI)	.019	-.304	-.312	.772*	.229
Free swell	-.515	.619	.040	-.358	.138
Maximum Dry Density	.514	.057	-.209	.107	.745*
Optimum Maximum Content(OMC)	-.126	-.368	.659*	-.020	-.437
California Bearing Ratio(CBR)	.398	.391	.621	.213	.031
Rainfall	.352	. 518	-.368	.413	-.395
Maximum Temperature	- 068	826*	-.133	.278	.012
Minimum Temperature	.068	.129	.160	-.508	.565
Variable Indices	SPG	FSW	OMC	PI	MDD
Total Eigen value	2.49	2.45	2.33	1.79	1.71
% of Variance	19.17	18.84	17.89	13.73	13.12
Cumulative (%)	19.17	38.00	55.90	63.63	82.75

Source: Author's Computation (2018);
Note: * Components defining variables

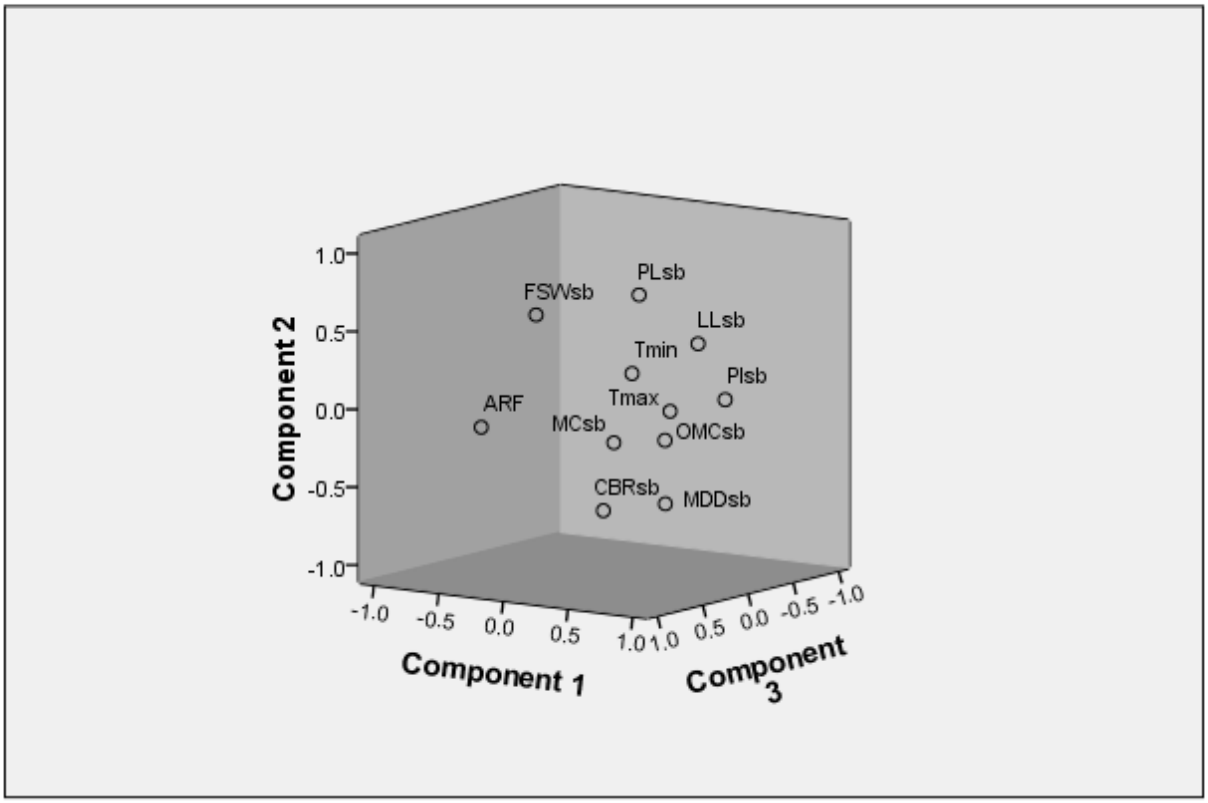


Figure 28 Component Plot for road sub base (SB) for Katchia-Kwoi-Nassarawa Road
Source: Author's Computation (2018)

7.9 Components of foundation of road subbase for lorin-Ajase-Ipo- Iloffa road

Road foundation subbase failure along Ilorin-Ajase-Ipo road is explained by tweve variables considered for this study.These variables were further reduced to five orthogonal components namely (Table 42) namely; maximum temperature, plastic limit, particle size distribution, liquid limit and rainfall all these variables together contributed 78% of the variance that explain road subbase failure along the road.Results shows that PSD falls within A-2-6,A-7-5,A-7-6 ASHTO soil classification this implies that foundation of road are funded on clay-silt materials which is sucestible to failure when in contact to moisture.This findings agree with Kekere et.al (2012), Ifabiyi and Kekere (2013).

Table 42: Components explaining road subbase (SB) failiure for Ilorin-Ajase- Ipo-Iloffa Road.

Variables	Components				
	1	2	3	4	5
Particle size distribution (PSD)	.013	.141	.827*	.191	-.259
Moisture content	.698	-.112	.347	.386	.154
Specific gravity	-.689	.277	.100	.055	.391
Liquid limit	.612	-.173	.060	.615*	.306
Plastic limit	.319	.822*	-.048	-.115	-.060
Plasticity index	-.191	.282	.711	-.493	.068
Maximum dry density (MDD)	-.350	-.045	.538	.248	.343
Optimum moisture content	.267	.598	-.124	-.116	.470
Carlifornia bearing ratio	-.422	-.567	.215	.270	.012
Rainfall	-.020	.588	.032	-.162	.641*
Maximum temperature	.813*	.024	.475	.059	-.063
Minimum temperature	.514	.517	-.280	.516	.095
Variable Indices	MaxT	PL	PSD	LL	RF
Total Eigen Value	2.34	1.97	1.94	1.68	1.38
% of Variance	19.53	16.44	16.18	13.99	11.53
Cumulative (%)	15.94	35.97	52.15	66.13	77.66

Source**:** Author's Computation (2016),
Note: * Components defining variables

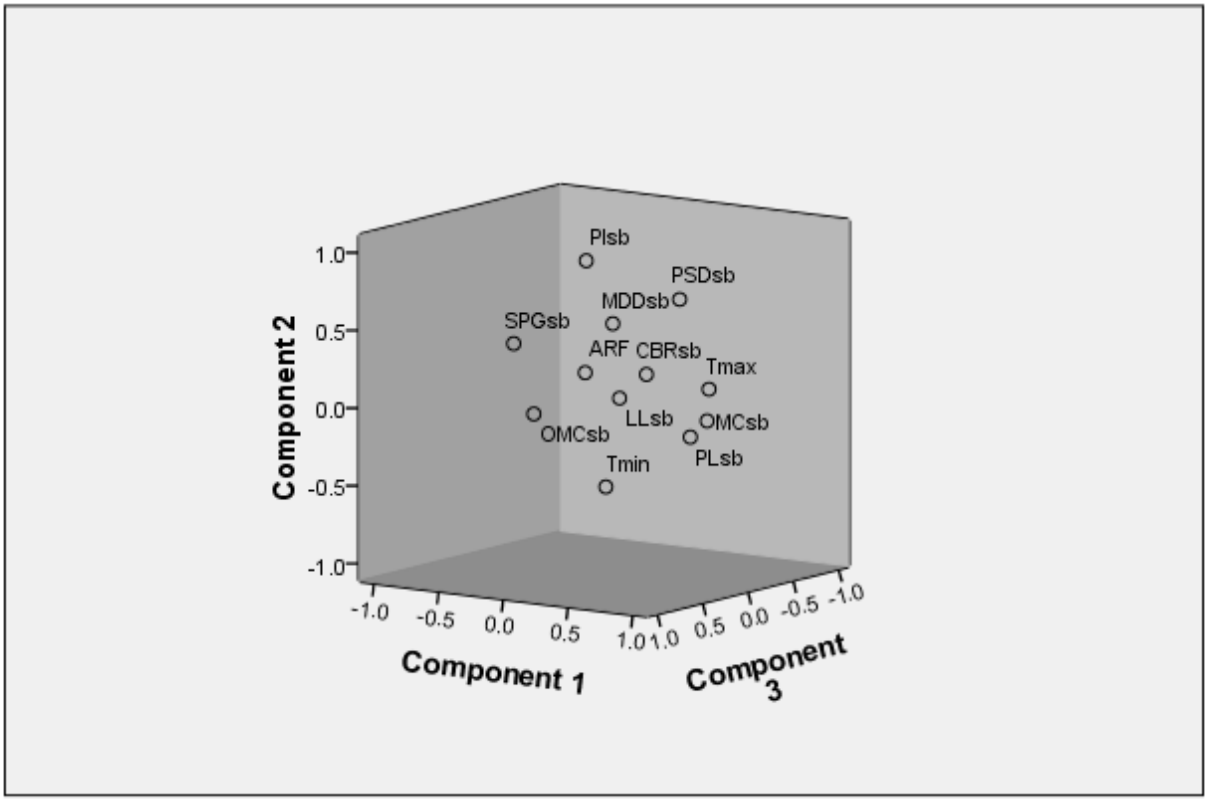


Figure 29: Component Plot for road sub base (SB) along. Ilorin-Ajase-Ipo- Iloffa road
Source: Author's Computation (2018)

7.10 Components of foundation of road subgrade failure for Ilorin-Ajase-Ipo- Iloffa road

Road foundation failure for subgrade along Ilorin-Ajase-Ipo-Illofa road is explained by twelve variables (Table 43).These variables were further reduced to five orthogonal components namely PSD, MDD, MAX temperature PI and SPG all these components altogether contributed 74% to the explanation of the variance responsible for road subgrade failure in the study area. Particle size distribution falls within A-2-6, A-7-5, A-7-6 ASHTO classification of foundation soil hence the foundation soil composed of clayey materials of mortiillionite types which are not good for infrasrtructure and this makes road subgared failure a common phenomena in the study

area which a lot work studies have identified. Athough other factors such as heavy traffic loading, and environmental factors accounted for 25% which the present study did not cover.

Table 43: Components Explaining Road failure on Sub grade (SG) along Ilorin-Ajase-Ipo-Iloffa Road

Variables	Components				
	1	2	3	4	5
Particle size distribution (PSD)	-.031	-.400	.657*	.496	-.157
Moisture content	-.426	-.481	.010	.395	-.042
Specific gravity	.309	.374	.374	.242	.682*
Liquid limit	.482	-.065	.056	.524	-.402
Plastic limit	.574	.325	-.235	.175	-.014
Plasticity index	.440	-.372	-.366	.628*	.281
Maximum dry density (MDD)	.616*	.056	.582	-.223	.075
Optimum moisture content	-.308	.073	.458	-.063	.406
Carlifornia bearing ratio	.574	-.475	-.253	-.175	.307
Rainfall	-.603	.042	-.417	.324	.444
Maximum temperature	.169	.833*	-.329	.205	-.115
Minimum temperature	-.302	.594	.299	.405	-.112
Variable Indices	MDD	MaxT	PSD	PI	SPG
Total Eigen Value	1.91	1.89	1.84	1.79	1.43
(%) of Variance	15.94	15.73	15.33	14.82	11.95
Cumm (%)	15.94	31.67	46.99	61.82	73.76

Source : Author's Computation (2016) * components defining variables

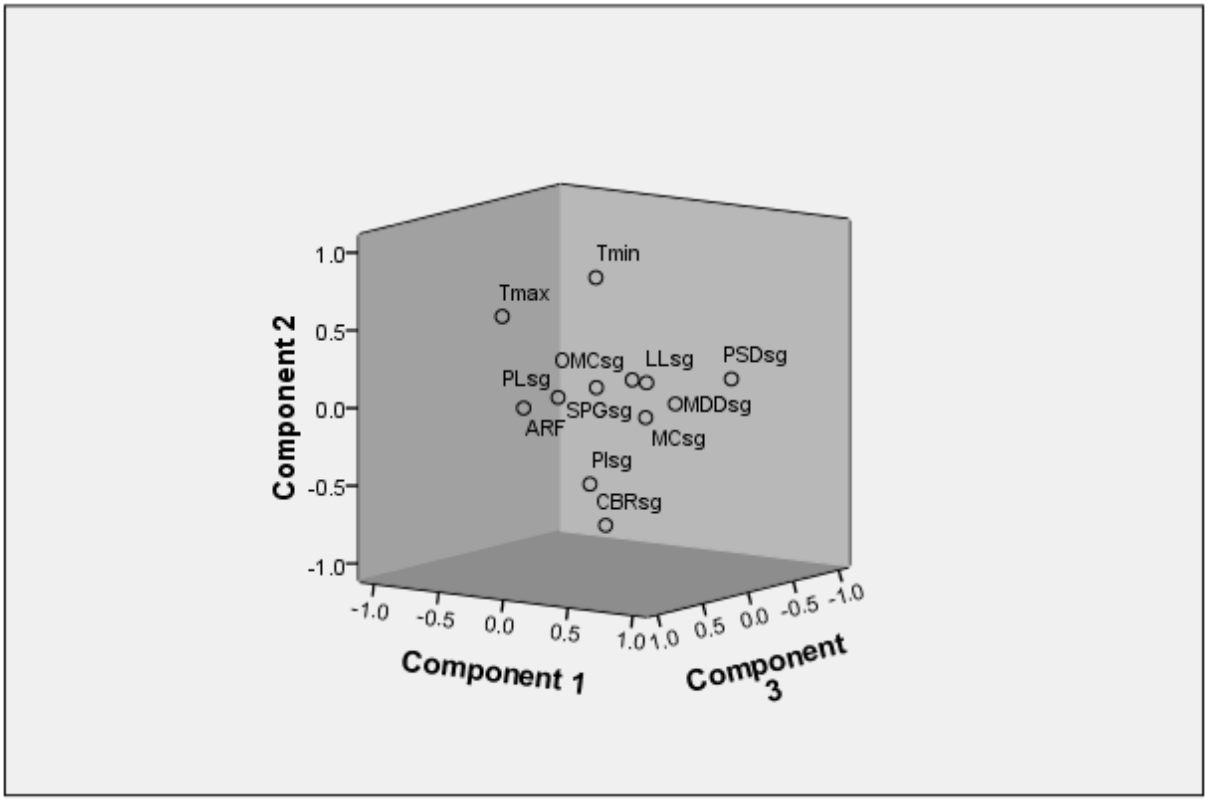


Figure 30: Component Plot for road grade (SG) along Ilorin-Ajase-Ipo -Ilofa Road**.**
Source: Author's Computation (2018)

7.11 Components of foundation of road subbase failure for Anyingba-Dekina-Ofa road

Road subbase foundation failure about twelve variables were considered for this study.This variables were further reduced to three orthogonal components namely maximum temperature, rainfall, and particle size distribution (Table 44). These variables altogether contributed 77% to the explanation of variance responsible for road subbase failure. The value of PSD in most locations in the study area (Table 11) are above standard specification for the construction of road and bridges(FMW&H,1997) hence, they falls within A-2-4-2-6-A-2-7 according to ASHTO soil classification which shows foundation materials are sandy to silty which are not good

foundation materials. Although other factors explain reasons for road subbase failure which other studies have identified.

Table 44: components Explaining Road Subbase failure for Anyinbga-Dekina road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD	.013	.141	.827*	.191	-.259
Natural Moisture Content(NMC)	.698	-.112	.347	.386	.154
Specific Gravity(SPG)	-.689	.277	.100	.05 5	.391
Liquid Limit(LL)	.612	-.173	.060	-.615	.306
Plasticity Limit(PL)	.319	-.822	-.048	-.115	-.060
Plasticity Index(PI)	-.191	.282	.711	-.493	.068
Maximum Dry Density	-.350	-.045	.538	.248	.343
Optimum Maximum Content(OMC)	.267	.598	-.124	-.116	.470
California Bearing Ratio(CBR)	-.422	-.567	.215	.270	.012
Rainfall	-.020	.688*	.032	-.162	-.641
Maximum Temperature	.813*	.024	.475	.059	-.063
Minimum Temperature	.514	.517	-.280	.516	.095
Variable Indices	NMC	MinT	PI	LL	RF
Total Eigen Value	2.34	1.97	1.94	1.68	1.38
% of Variance	19.53	16.44	16.18	13.99	11.53
Cumulative (%)	15.94	35.97	52.15	66.13	77.66

Source: Author's Computation (2018);
Note: * Components defining variables

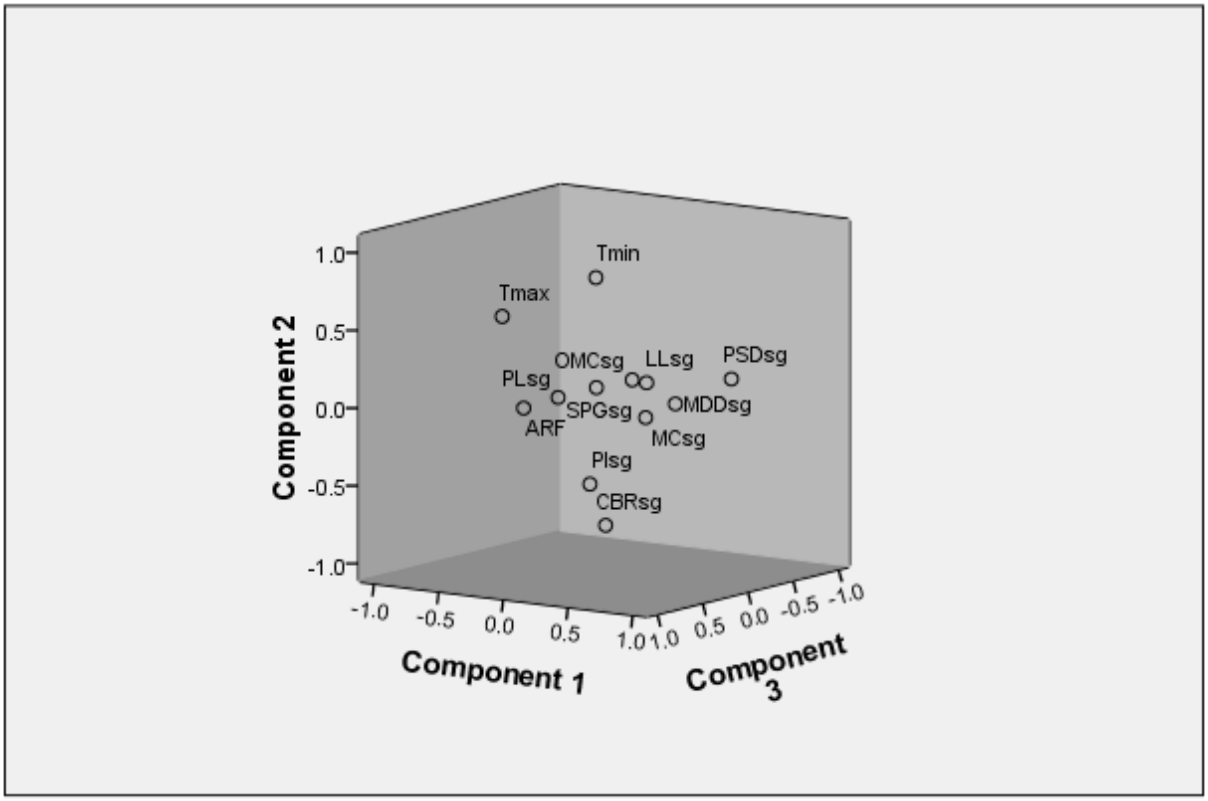


Figure 31: Component Plot for subbase for Ayingba-Dekia – Ofa Raod
Source: Author's Computation (2018)

7.12 Components explaining road subgrade failure for Anyingba-Dekina-Ofa road

Road subgrade foundation failure twelve variables were considered in this study.This variables were reduced to four orthogonal components namely MDD, maximum temperature, PSD and LL (Table 45).This variables altogether contributed 73% to the variance explaining road subgrade failure. PSD, MDD and LL did not confirm with standard specification for the construction of road and bridges (FMW&H, 1997) in most locations (Table 11) this could explain the reasons for road subgrade foundation failure in the study area. Although other factors such poor engineering construction, environmental factors (Ola 1980, 1983; Ogundipe, 2008) could also explain the reasons for road subgrade failure according to the study.

Table 45: Components Explaining Road subgrade failure along Ayingba-Dekina-Ofa road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD	-.031	-.400	.657*	.496	-.157
Natural Moisture Content(NMC)	-.426	-.481	.010	.395	-.042
Specific Gravity(SPG)	.309	.374	.374	.242	.682
Liquid Limit(LL)	.482	-.065	.056	.624*	-.402
Plasticity Limit(PL)	.574	.325	-.235	.175	-.014
Plasticity Index(PI)	.440	-.372	-.366	.128	.281
Maximum Dry Density	.616*	.056	.582	-.223	.075
Optimum Maximum Content(OMC)	-.308	.073	.458	-.063	.406
California Bearing Ratio(CBR)	.574	-.475	-.253	-.175	.307
Rainfall	-.603	.042	-.417	.324	.444
Maximum Temperature	.169	.833*	-.329	.205	-.115
Minimum Temperature	-.302	.594	.299	.405	-.112
Variable Indices	MDD	MaxT	PSD	PI	SPG
Total Eigen Value	1.91	1.89	1.84	1.79	1.43
(%) of Variance	15.94	15.73	15.33	14.82	11.95
Cumm (%)	15.94	31.67	46.99	61.82	73.76

Source : Author's Computation (2018)
* Components defining variables

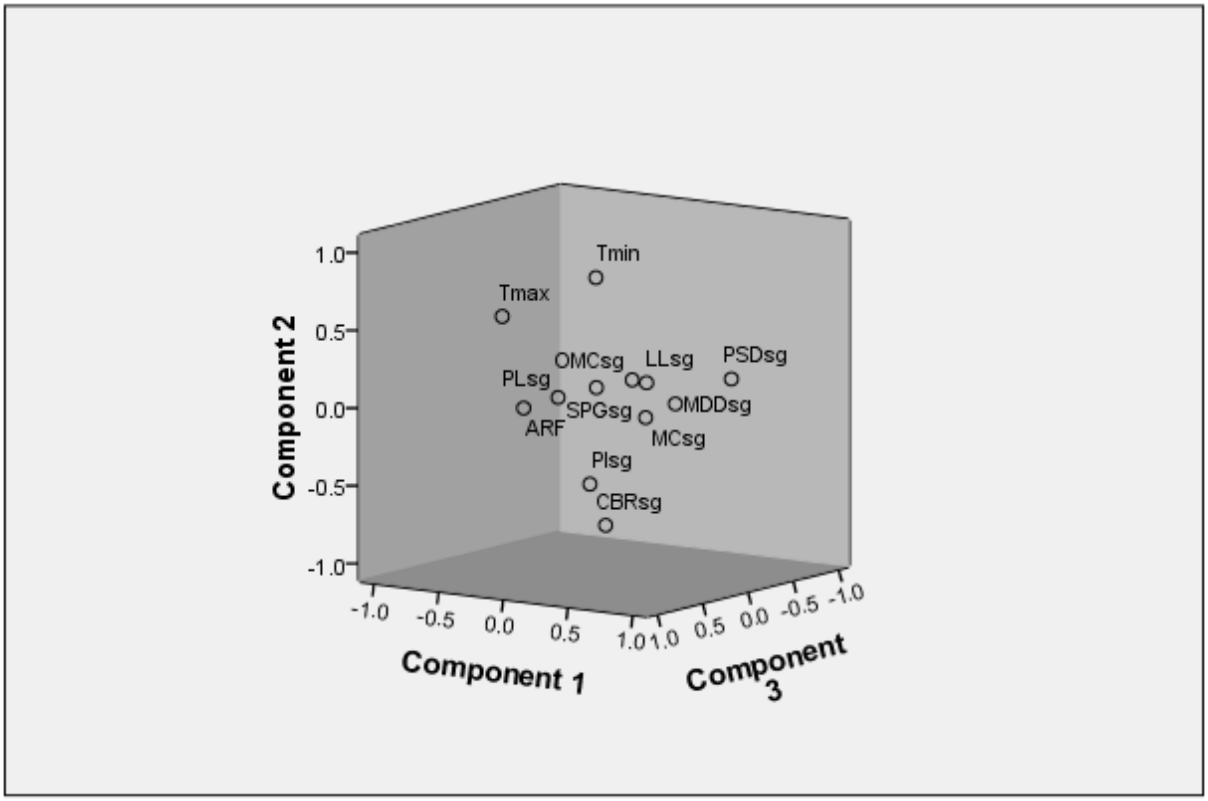


Figure 32: Components Plot for subgrade Ayingba-Dekina-Ofa Road.
Source: Author's Computation (2018)

7.13 Components of foundation of subbase failure for Edo-Agbor-Umunede-Asaba road

Road foundation for subbase failure for Edo-Agbor- Umunede –Asaba road the study considered thirteen variables in the study.These variables were reduced to five orthogonal components namely LL, MC, OMC ,PI and MDD (Table 46).These variables altogrhter contributed 83% to the explanation in the variance of road subbase failure in the study area.The foundation materials are partly sandy-silt to clayey materials which were classified as low to medium(Offonoie and Aniekan 2005) although moisture contents(MC) and optimum moisture contents (OMC) maintain a threashold level for a typical flexible pavement roads of this nature but this materials are susceptible to failure with increasing precipitation. This finding agrees

with the works of Okechwukwu and Celestine (2001), Ndefor (2012). There are other factors such as high traffic loading, environmental factors among others may contriburte to road subbas failure in the study area

Table 46: Components Explainng Road Subbase failure along Edo-Agbo -Asaba Road

Variables	Components				
	1	2	3	4	5
Particle size distribution (PSD)	.576	.028	.507	.287	.115
Moisture content	.243	.629*	.599	.068	-.089
Specific gravity	.785	.085	-.385	-.303	-.325
Liquid limit	.785*	.085	-.385	-.303	-.325
Plastic limit	-.699	.550	-.280	-.032	-.004
Plasticity index	.019	-.304	-.312	.772*	.229
Freeswell	-.515	.619	.040	-.358	.138
Maximum dry density (MDD)	.514	.057	-.209	.107	.745*
Optimum moisture content	-.126	-.368	.659*	-.020	-.437
Carlifornia bearing ratio	.398	.391	.621	.213	.031
Rainfall	.352	.518	-.368	.413	-.395
Maximum temperature	-.068	.826	-.133	.278	.012
Minimum temperature	.388	129	.160	-.508	.565
Variable Indices	LL	MC	OMC	PI	MDD
Total Eigen value	2.49	2.45	2.33	1.79	1.71
% of Variance	19.17	18.84	17.89	13.73	13.12
Cumulative (%)	19.17	38.00	55.90	63.63	82.75

Source: Author's Computation (2018)

* Components defining variables

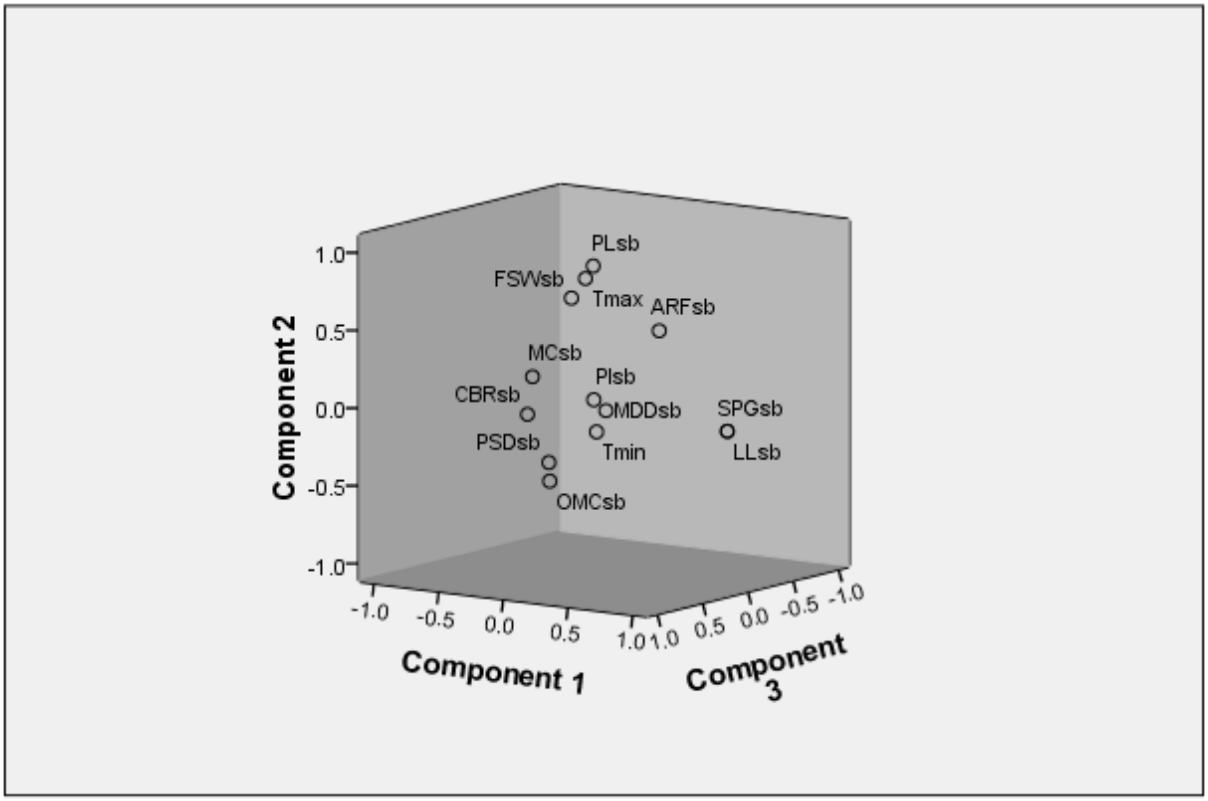


Figure 33: components Plot for Edo-Umunede-Asaba road
Source: Author's Computation (2018)

7.14 Components of foundation of road subgrade failure for Edo-Umunede-Asaba road

Road foundation subgrade failure for Edo-Agbor- Umunede-Asaba road can also be explained (table 47) by thirteen variables considered for this study. These variables were reduced to four orthogonal components namely LL, OMC, MDD and minimum temperature, these components altogether contributed 73.1% to the explanation of road subgared foundation failure.However the MDD exhibited low-medium clayey materials accoding to Offonomie and Aniekan (2005).Clayey materials are also prone to damage with increasing moisture during precipitation hence various form of road failure emergeges.This findinds agree with the work of Oyediran and

Durojaiye (2011), Aghamelu and Okogbue (2011) although other factors such as environmental factors among other factors could be responsible for road subgrade failure in the study area.

Table 47: Components Explaining Road subgrade along Edo-Agbor-Asaba road

Variables	Components				
	1	2	3	4	5
Particle size distribution (PSD)	.002	.218	.577	-.096	.542
Moisture content	-.352	-.316	.590	-.175	-.414
Specific gravity	-.144	.490	-.143	-.519	-.143
Liquid limit	.895*	.143	-.078	-.024	.038
Plastic limit	-.010	.435	.545	.249	.441
Plasticity index	.898	-.142	-.018	-.060	.216
Freeswell	-.102	.202	-.741	.467	.142
Maximum dry density (MDD)	-.059	-.556	-.067	.623*	-.048
Optimum moisture content	-.457	.676*	-.052	.122	-.246
Carlifornia bearing ratio	-.338	-.354	.222	.365	.178
Rainfall	.417	.623	.108	.224	-.358
Maximum temperature	.084	.504	.325	.597	-.207
Minimum temperature	-.529	.309	-.334	-.116	.601*
Variable Indices	LL	OMC	FSW	MDD	MinT
Total Eigen Value	2.52	1.84	1.82	1.73	1.59
% of Variance	19.37	14.18	14.01	13.27	12.19
Cumulative (%)	1937	33.54	47.55	60.82	73.01

Source: Author's Computation (2018)

* Components defining variables

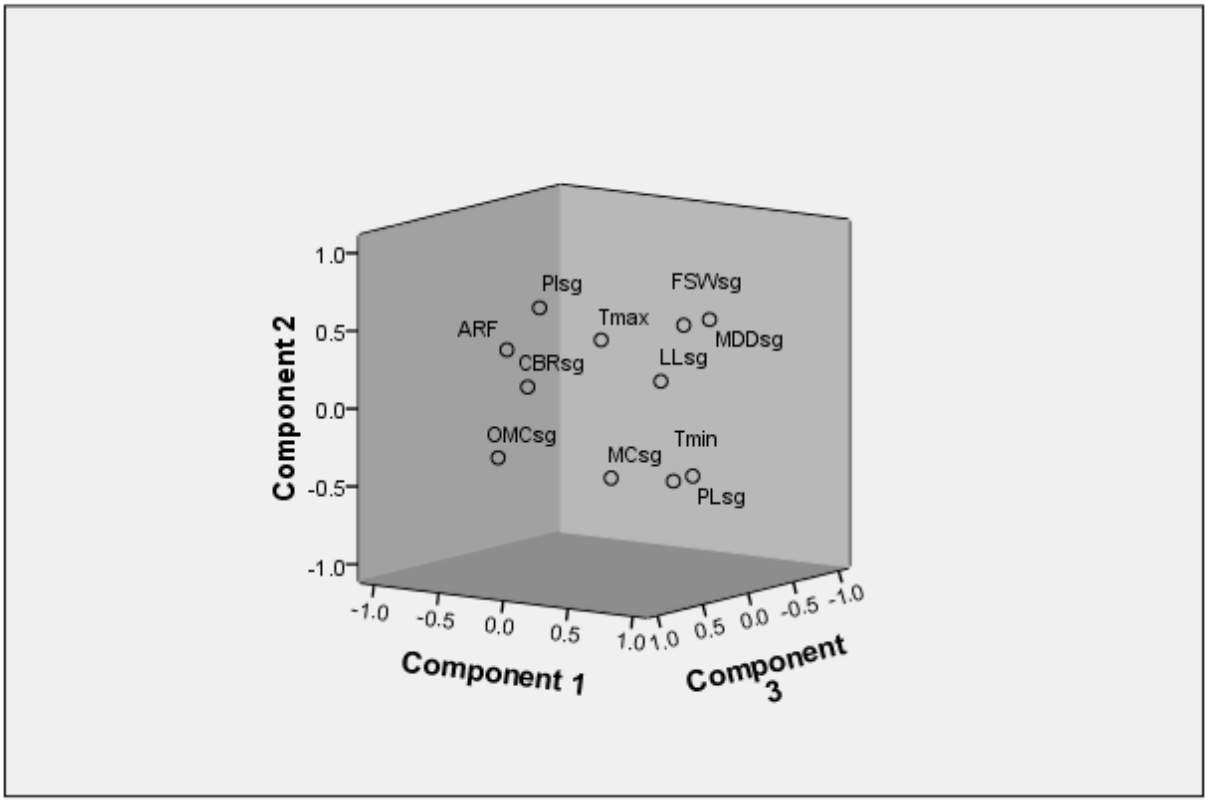


Figure 34: components Plot for Edo-Umunede-Asaba road
Source: Author's Computation (2018)

7.15 Components of foundation for road subbase failure for Port Hacourt –Elele-Umanelu road

Road foundation for subbase failure along portharcourt-Elele-Umunelu road can also be explained is explained by twelve variables which are considered for this study. This variables were further reduced to five orthogonal components namely max temp, PL, PSD, LL and rainfall (Table 48), these variables altogether contributed 78% to the variance explaining road subbase foundation of the road PSD varaiation in some of the locations (Table 10a-d) showed that some locations did not confirm to standard (FMW&H, 1997).The distribution of PSD shoed some locations are characterized with peat organic silt clay which posses a serious threat to engineering structures such as road.This findings agree with the findimgs of Ajayi, (1985),

Adesunloye (1987). However, other factors such as poor soils, poor engineering construction among others also contributed to road subbase failure.

Table 48: Components Explaining Road Subbase failure along Port Hacourt –Elele-Umanelu road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD	.013	.141	.827*	.191	-.259
Natural Moisture Content(NMC)	.698	-.112	.347	.386	.154
Specific Gravity(SPG)	-.689	.277	.100	.055	.391
Liquid Limit(LL)	.612	-.173	.060	.615*	.306
Plasticity Limit(PL)	.319	.822*	-.048	-.115	-.060
Plasticity Index(PI)	-.191	.282	.711	-.493	.068
Maximum Dry Density	-.350	-.045	.538	.248	.343
Optimum Maximum Content(OMC)	.267	.598	-.124	-.116	.470
California Bearing Ratio(CBR)	-.422	-.567	.215	.270	.012
Rainfall	-.020	.588	.032	-.162	.641*
Maximum Temperature	.813*	.024	.475	.059	-.063
Minimum Temperature	.514	.517	-.280	.516	.095
Variable Indices	NMC	MinT	PI	LL	RF
Total Eigen Value	2.34	1.97	1.94	1.68	1.38
% of Variance	19.53	16.44	16.18	13.99	11.53
Cumulative (%)	15.94	35.97	52.15	66.13	77.66

Source: Author's Computation (2018);
Note: * Components defining variable

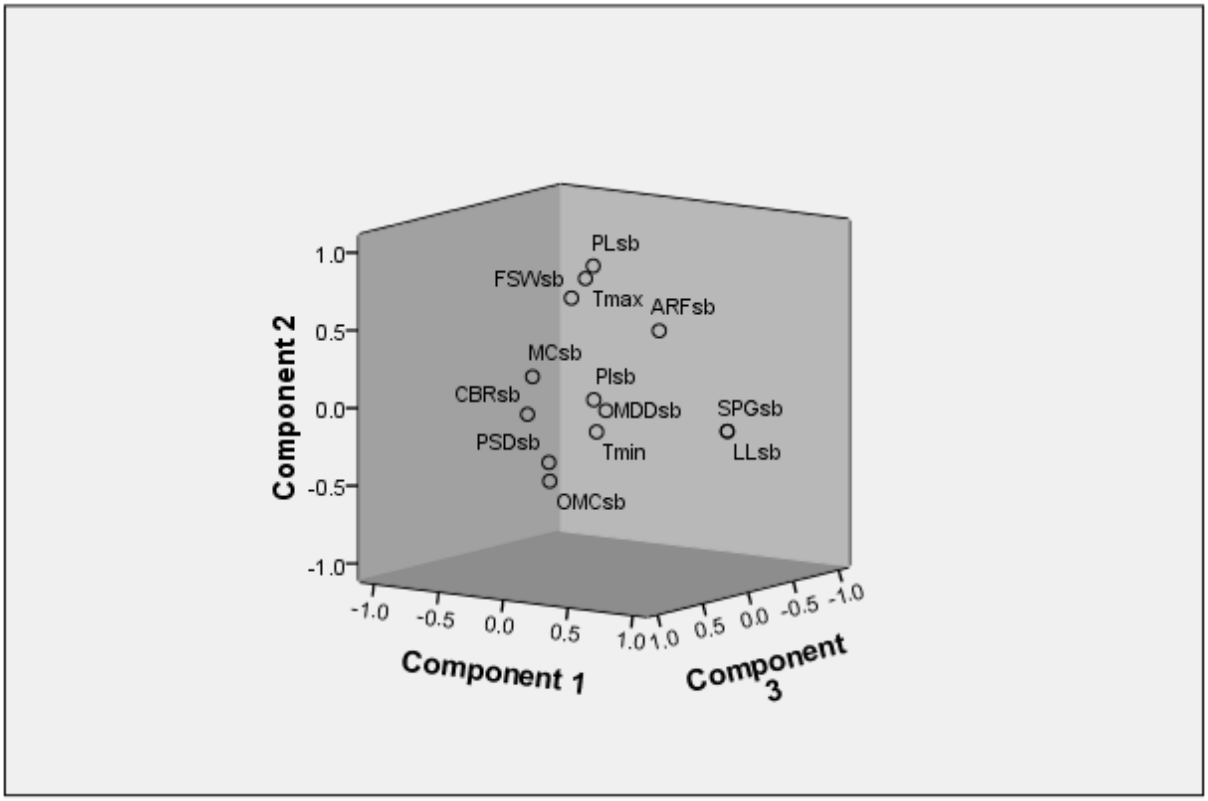


Figure 35: Components Plot for Edo-Umunede-Asaba road
Source: Author's Computation (2018)

7.16 Components of foundation failure of road subgrade failure for Port Hacourt –Elele-Umanelu road

Road foundation subgrade failure along port Harcourt-Elele-Umunelu road can be explained by thirteen variable considered for this study.These variables were reduced to four orthogonal components namely LL, max Temp, OMC and PI these components make up 83% to the explanation of the variables responsible for road subgrade failure. Other factors such as environmental factors human induced factors which several studies have identify also contributed road subgrade failure along road. Table 49 showed the variable explaining road failure along the road.

Table 49 Component Explaining Road subgrade failure for Port Hacourt –Elele-Umanelu Road

Variables	Components				
	1	2	3	4	5
Particle Size Distribution(PSD	.576	.028	.507	.287	.115
Natural Moisture Content(NMC)	.243	.629	.599	.068	-.089
Specific Gravity(SPG)	.254	.085	-.385	-.303	-.325
Liquid Limit(LL)	.785*	.085	-.385	-.303	-.325
Plasticity Limit(PL)	-.699	.550	-.280	-.032	-.004
Plasticity Index(PI)	.019	-.304	-.312	.772*	.229
Free swell	-.515	.619	.040	-.358	.138
Maximum Dry Density	.514	.057	-.209	.107	.745
Optimum Maximum Content(OMC)	-.126	-.368	.659*	-.020	-.437
California Bearing Ratio(CBR)	.398	.391	.621	.213	.031
Rainfall	.352	. 518	-.368	.413	-.395
Maximum Temperature	- 068	826*	-.133	.278	.012
Minimum Temperature	.068	.129	.160	-.508	.565
Variable Indices	SPG	FSW	OMC	PI	MDD
Total Eigen value	2.49	2.45	2.33	1.79	1.71
% of Variance	19.17	18.84	17.89	13.73	13.12
Cumulative (%)	19.17	38.00	55.90	63.63	82.75

Source: Author's Computation (2018);

Note: * Components variables

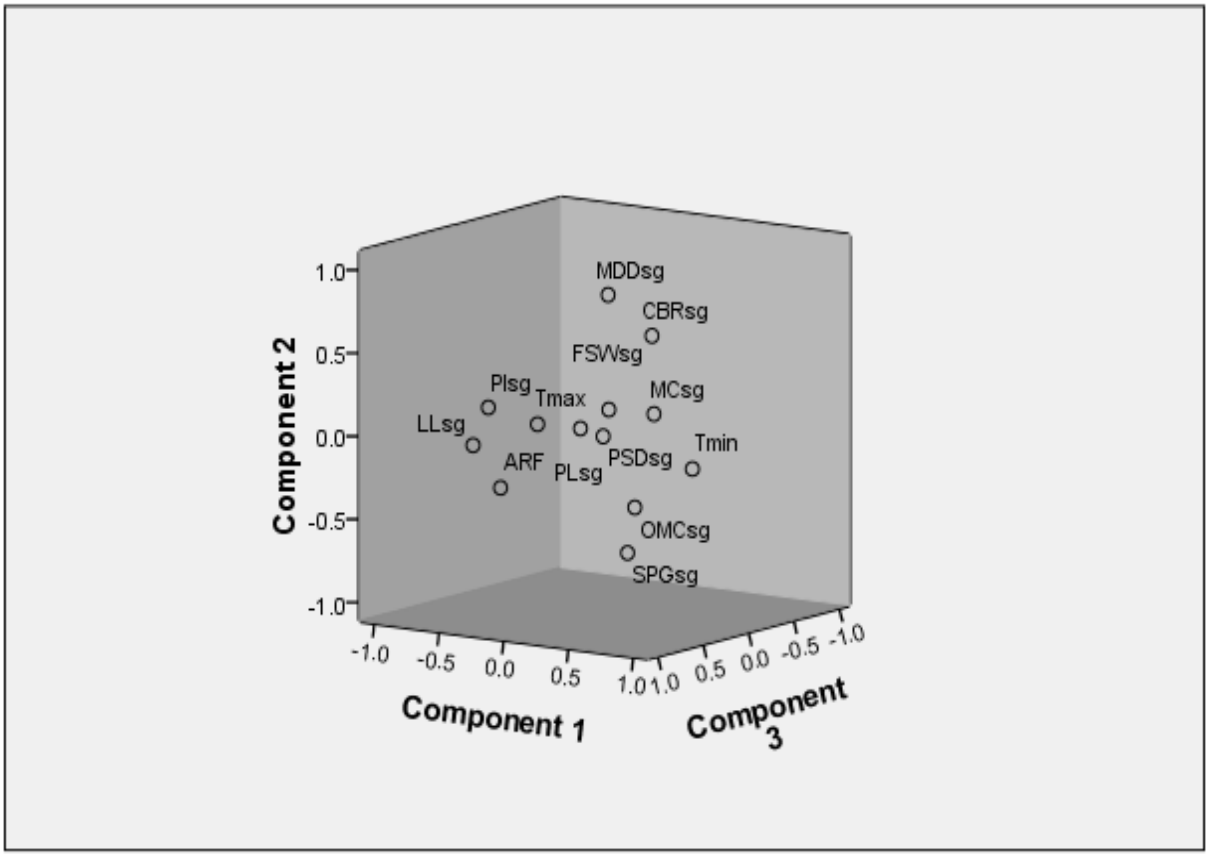


Figure 36: Component Plot for portharcourt –Elelu-Umanelu Road.
Source: Author's Computation (2018)

CHAPTER EIGHT

8.0 SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

8.1 Summary of findings

The following findings were reported in this study.

i. The pattern of geotechnical properties differ from one zone to another in many locations in the study area geotechnical properties of soils did not meet the standard for road and bridges construction (FMWH, 1997) in Nigeria.

ii. In many instances strong strong relationship exist between climatic variables and geotechnical properties in different morphoclimatic zones in Nigeria.

iii. The study revealed that, significant differences exist in the spatial pattern of geotechnical properties (PSD, LL, PI, MDD, OMC and CBR) in Nigeria.

iv. Climatic variables and geotechnical properties moderately to weakly predict the behavior of subbase and subgrade in the study area.

v. The study also identified the components explaining road sub base and sub grade failure in each morphoclimatic zone.

8.2 Conclusion

The results above showed that many of the road projects in Nigeria do not comply with minimum bench mark for road construction as stipulated by FMWH (1997). This explains reasons for many failed portions along almost all roads in Nigeria. Hence, a reasonable percentage of the explanation for this is the high clayey content of soils in some sections of the road under study and climatic condition of each zone could be responsible for road foundation failure in Nigeria.

8.3 Recommendations

Following the outcome of the study the following recommendations were put forward.

i. Most of the road did not meet the standard specification due to problem soils hence, standard materials should be used in areas with heavy clayey materials to prevent failure.

ii. Construction of road in low land areas especially in Hot Dry and warm humid zones should have a higher sub base to prevent severe erosion of road shoulders.

iii. Most of the road suffers deterioration in sub base and subgrade because of irregular maintenance. Hence, there should be regular maintenance of these roads

iv. There should be strict enforcement of laid down specification for road construction standard by relevant government agencies.

v. The use of weighbridge should be re-introduce to check excessive weight of hauladges of vehicles on Nigeria road.

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Appendix 1: Capital Project on Highway Development/ Maintenance in South-East Geopolitical Zone

	State	Project Title	Road (km)	Contract sum ₦	Award Date	Remark
1.	Anambra	(i) Rehabilitation of Awka Aguulu –kwulobia – uga – Imo S/B Road with spur to Oko	44	743, 538, 757.50	25/11/99	Ongoing
		(ii) Construction of bridge across Anambra River linking aguleri – Oloucha in Anambra	6	1,446,378,420.00	08/11/99	Ongoing
2.	Enugu	(i) Completion & Rehabilitation of Enugu P/Harcourt Rd	225	5,100,000.000.00	15/02/01	Ongoing
		(ii) Adoru-Nsukka-adani Rd	73	1,045,050,006.00	08/11/99	Ongoing
3.	Imo	(i) Owerri-Obowo-umnalia Rd	55	1,006,467,000.00	08/11/99	Ongoing
		(ii) Ihube – Umuelemaili Rd I&II	97	1,595,830,698.00	08/11/99	Ongoing
		(iii) Rehabilitation of Iluala-orlu- Umuduru Rd.	51.4	800,030,728.00	03/12/99	Ongoing
4.	Eboniyi	(i) Reconstruction of Okigwe Afikpo Rd.	66	6,733,091,310.745	12/04/01	Ongoing
		(ii) Abakaliki- Afikpo Rd.	68	1,210,886,962.00	08/11/99	Ongoing
5.	Abia	(i) Isiukwuato – olokoro – ikwuano – akwaibom S/B	47	672,614,896.00	14/02/00	Ongoing
		(ii) Umualiia – Bende – Ohafia	46	850,000,000.00	08/11/99	Ongoing
		(iii) Rehabilitation of Ubekala Jimihun Ntegha Junction – Isiala Ngwa – Enugu – P/Harcourt Dual	28	248,983,500.00	18/01/99	Ongoing
		(iv) Rehabilitation of Umualiia- Arian – Iko Ekpene Rd sect I umualiia - Umudike Rd.	33	153,331,816.87	05/02/97	Ongoing

Source: CBN (2003) and modified by Kekere, 2015.

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Appendix 2: Capital Project on Highway Development/ Maintenance in South -South Geopolitical Zone

	State	Project Title	Road (km)	Contract sum ₦	Award Date	Remark
1.	Akwa Ibom	(i) Aba – Ikot Ekpere- Oyo – Oron Rd	43	735,839,072.00	08/11/99	Ongoing
	Akwa Ibom	(ii) Rehabilitation of umuahia – Arian – Ikot Epene Road. Section 2 Ariam – Ikot Ekpene Rd.	45	177, 645, 933.00	05/02/99	Completed
2	Cross/R	(i) Calabar – Ikom Road, Section II	72	943,416,393.15	08/11/99	Ongoing
		(ii)Design and construction of adiabo bridge across Calabar River	06	1,977,577,455.00	15/05/98	Completed
		Construction of 2 bridges at km 1+ 186 and km 2+ 497 along Calabar – ikot neto Road	0.216	185,690,190.00	17/10/97	Ongoing
3.	Delta	(i) Completion of Warri – Benin Dualisation section I & II	94.8	6,255,749,960.16	15/9/00	Ongoing
		(ii) Asaba – Ebu – alia – Uromi road section I	40	796,866,475.00	08/11/99	Ongoing
		(iii) Rehabilitation of Ometa adagbarassa – ugolo- Ugwagba Okan Junction Road.	11	145,829,329.00	10/11/97	Completed
4.	Bayelsa	(i) Design & construction of Tombia Bridge on amassoma – tombia okutukutu Rd.	0.592	2,470,387,581.70	15/09/00	Ongoing
		(ii) Transfer of the construction of Yenogua Primary Road	17	5,356,754,056.63	16/12/00	Ongoing
5.	Rivers	(i) International airport with spur to Eagle	49.8	1,861,553,925.00	23/11/9	Ongoing
		(ii) Completion of th construction of bocha – Ndoni link Road and Bridges	18.6	2,479,970,894.00	23/11/99	Ongoing
		(iii) Design and construction of fly over in P/Harcourt	0.59	2,000,000,000.00	2/1/99	Completed
		(iv) Dualisation of petroleum refinery Rd route 25 and Rehabilitation of East/West Road	53	1,626,832,853.21	14/12/98	Completed
6.	Edo	(i) Asaba – Ebu – Ahia – Uromi Road Sect II with spur to Emu	31	553,523,465.25	08/11/99	Ongoing
		(ii) Construction of Asphalt overlay of Irrua – Uromi – ubiaja – Ilushi Rd.	40.31	818,053,582.50	08/11/990	Ongoing
		(iii) Benin By pass sect I & II	45	10,000,000,000.00	08/11/99	Ongoing
		(iv) Rehabilitation and construction of Igueben- Ewohin Rd	14	151,477,178.00	06/01/99	Completed
		Rehabilitation and construction of Auchi – Ekperi – Agene bode Road & spur (v) Fugar township Rd and drainage structure	24.6	604,369,392.00	03/12/98	Completed

Source: CBN (2003) and modified by Kekere, 2015

Appendix 3: Capital Project on Highway Development/ Maintenance in South-West Geopolitical Zone

	State	Project Title	Road (km)	Contract sum ₦	Award Date	Remark
1.	Lagos	(i) Resurfacing of Ojuelegba fly over stadium fly over western avenue	2.53	212,359,691.00	08/11/99	Completed
		(ii) Iganmu Bridge and approaches	40	52,719,239.16	08/11/99	Completed
		(iii) Compete Rehabilitation & a/O of adeniyi adele Rd	2.54	259,617,108.66	06/1/99	Completed
2.	Osun	(i) Rehabilitation of spur to olla town on ede- ejigbo Rd	0	47,287,834.65	18/04/00	Ongoing
		(ii)Rehabilitation of Oshogbo-Ilesha Rd. & construction of Bridges	32	735,339,532.62	08/11/99	Ongoing
		(iii) Rehabilitation and asphalt overlay of Oshogbo - ilobu – Oyo s/B Road, R.35	21	500,000,000.00	08/11/99	Ongoing
3.	Ondo	(i) Ose Bridge, I Owo-Ikare Rd, & OSe Bridge 2, Okene owo Rd.	16	659,830,991.52	08/11/99	Completed
		(ii) Rehabilitation of Ogbese okeluse sobe Rd	30	701,809,670.10	08/11/99	Ongoing
4.	Ekiti	(i) Ifaki- ikole- omuo S/B Road	37	530,332,456.00	08/11/12	Ongoing
		(ii) Ado Ekiti – Igede – Akure Rd	50	786,102,759.80	08/11/99	Completed
		(iii) Ado Ekiti – Igbede Rd	21	250,000,000.00	08/11/99	Ongoing
		(iv) Igede – Itawure – Effon alaaye Rd	46.6	362,541,217.50	08/11/99	Ongoing
5	Ogun	(i) Dualisation of Olta Abeokuta Rd	59.2	11,930,342,386.63	15/09/00	Ongoing
		(ii) Completion of rehabilitation and asphalt overlay of Ilaro – Abeokuta – Bakalari – Oyo Rd	39	40,424, 639.00	08/11/99	Ongoing
		(iii) Papalanto- Lagos Ibadan expressway	49	292,114,630.50	08/11/99	Ongoing
6.	Oyo	(i) Dualisaation of Ibadan – Ilorin Rd Section I	44	14,976,350,002.85	15/02/01	Ongoing
		(ii) Mayo – Iseyin Rd	45	764,008,822.50	08/11/99	Completed
		(iii) Iseyin- Alaga Rd	26	675,282,726.96	08/11/99	Ongoing
		(iv) Ibadan Ife Rd (additional works on drainage way of Ajia spur Rehabilitation)	70	1,208,574,607.00	28/02/08	Completed

Source: CBN (2003) and modified by Kekere, 2015

Appendix 4: Capital Project on Highway Development/ Maintenance in North-Central Geopolitical Zone

S/N	State	Projects Title	Road (Km)	Contract sum ₦	Award Date	Remark
1.	Niger	(i) Kontagora – Rijau Rd	86	167,831,480.25	11/12/01	Ongoing
		(ii) Bida – SCCI – Nupeko pategi Rd	45	3,118,770,477.90	06/07/01	Ongoing
		(iii) Rehabilitation of Minna – zungeru – tegina Rd route F 215 and Tegina Kontangora	90	179,619,300.00	12/06/01	Ongoing
		(iv) Mina – sarkin Pawa Kaduna	62.85	5,322,982,084.50	15/09/00	Ongoing
		(v) Minna Western by pass	13.5	313,870,095.00	08/11/99	Completed
2.	Kwara	(i) Dualisation of Ibadan – Ilorin Rd Sect III	40.3	12,740,867,218.00	12/04/01	Ongoing
3.	Plateau	(i) Panyam – sherdam Rd sect I	48	2,409,569,886.80	08/11/99	Ongoing
		(ii) Von – man chok Rd	40	2,095,019,850.00	08/11/99	Ongoing
		(iii) Panyam – shedam Rd sect II	39	1,725,051,472.00	08/11/99	Completed
4.	Benue	(i) Design and reconstruction of bridges at km 57 + 550 along Awajir – Ogoja Rd	0.03	49,151,886.53	21/08/01	Ongoing
		(ii) Design and reconstruction of brigdge at km 10 + 000 along Awajir – Ogaja Rd	0.015	28,463,297.63	21/08/01	Ongoing
		(iii) Design and reconstruction of bridges at km 25+ 900 along Awajir ogaga Rd.	0.03	45,613,659.29	21/08/01	Ongoing
		(iv) Katsina – ala- zaki Biam – Buruku Rd	102.5	2,729,354,781.25	15/09/00	Ongoing
		(v) Construction of Awajir Ogua Road sect I awajir – Tse agberagba Ogoja Rd		344,367,381.00	30/11/97	Completed
5.	Nassarawa	(i) Reconstruction of Nassarawa – loko Rd with Alushi loop	40	2,318,643,233.36	14/09/01	Ongoing
6.	Kogi	(i) Rehabilitation of Magongo – Ogori Rd	6	72, 957,772.13	14/09/01	Ongoing
		(ii) Aiyetoro Eggan Rd	55	961,883,220.38	08/11/99	Ongoing
7	Abuja (FCT)	Dualisation of Abuja – Keffi Road	49.5	10,497,777,777.00	15/02/01	Ongoing

Source: CBN (2003) and modified by Kekere, 2015

Appendix 5: Capital Project on Highway Development/ Maintenance in North- East Geopolitical Zone

	States	Project Title	Road (km)	Contract sum ₦	Award Date	Remark
1.	Adamawa	(i) 2, Nos, of Narrow bridges along Mayo Belwa- Joda Ganye Rd	0.066	360,947,171.97	08/11/99	Ongoing
		(ii) Ganye- Sugu -	13.2	3,001,633,798.18	08/11/99	Ongoing
		(iii) Emergency repairs pf damage culvert at km 7 + 200 on sebore Kariahi Rd.	-	5,495,910.00	09/10/99	Completed
2.	Bauchi	(i) Rehabilitation of Bauchi- Jos Rd.	117.5	1,787,573,253.24	27/09/01	Ongoing
		(ii) Bauchi – Tafawa Balewa – Dawki Rd sect III with spur to Bogoro	51.52	1,001,417,409.46	08/11/99	Ongoing
3.	Brono	(i) Maiduguri- Monguno – kukawa – Baga- Damasak	25	654,435,841.50	24/11/99	Ongoing
4.	Gombe	(i) Gombe – Dukku – Daraza Rd sect I	70	1,600,000,000.00	31/04/01	Ongoing
		(ii) Gombe- Dukku – Darozo Rd sect II	58	1,400,000,000.00	31/04/01	Ongoing
		(iii) Construction of Mararaba Tumi – pindiga Kashere futuk – Yalo Rd.	68	2,309,973,435.00	10/12/99	Ongoing
		(iv) Gombe Biu Rd	131	1,584,721,215.00	08/11/99	Ongoing
5.	Taraba	(i) Rehabilitation of Mararaba – Bali Rd.	101	5,733,213,803.02	23/12/00	Ongoing
		(ii) Construction of Rafin kada- Dongo Rd including the bridge at Donga	20	2,790,213,803.02	23/12/00	Ongoing
6.	Yobe	(i) Rehabilitation & A/overlay of Gashua Yusufari Rd.	30	1,754,739,294.00	08/11/99	Ongoing
		(ii) Buniyadi- Gulani Rd	75	2,790,048,160.80	08/11/99	Ongoing

Source: CBN (2003) and modified by Kekere, 2015

Appendix 6: Capital Project on Highway Development/ Maintenance in North-West Geopolitical Zone

	State	Project Title	Road (km)	Contract sum	Award Date	Remark
1.	Kaduna	(i) Saminaka – Kafaf ka fancha Rd	114	1,950,000,000.00	08/11/99	Ongoing
		(ii)Kaduna – kachia – Gimi Rd	292	2,621,935,297.00	08/11/99	Ongoing
		(iii) Construction of approach Rd/Bridge over River Wonderfull Kafanchan	0.536	81,500,000.00	06/01/99	Ongoing
		(iv) Rehabilitation and Resurfacing of Kaduna western Bye- pass	24	640,470,739.70	20/03/97	Ongoing
2.	Jigawa	(i) Rehabilitation and asphalt overlay of Hadejia – Gamayin Rd	22	235,431,000.00	06/01/99	Completed
		(ii) Rehabilitation of Gamayin – Bauchi S/R – Katagun km 0+ 000 – km 38 + 000	38	365, 651,220.00	05/08/98	Ongoing
3.	Kano	(i) Construction of Kano ring road Eastern by pass phase II and dualisation	10.98	1,232,258,431.00	06/01/99	Completed
4.	Kastina	(i) Rehabilitation of Malumfashi – Dabai – Danja – Batsari Rd (with spur from Dabai)	100	1,716,308,823.50	31/03/00	Ongoing
		(ii) Kankia – Dutsinma – Safana – Batseri – Katsina Rd	160	2,384,680,575.00	08/11/99	Ongoing
5.	Kebbi	(i)Rehabilitation of Rijau – Riban - Wasagu Rd sect I & II	87.5	1,617,358,625.00	08/11/99	Ongoing
6.	Sokoto	(i) Rehabilitation of sokoto – aoronyo – Dam site Rd	95	2,846,288,991.00	08/11/99	Ongoing
7.	Zamfara	Manchi – Anka – Kebbi state Border Rd.	197	2,222,572,706.97	08/11/99	Ongoing

Source: CBN (2003) and modified by Kekere, 2015