JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING CHAIR

ASSESSMENT OF IMPACTS OF ENVIRONMENTAL FACTORS (TEMPERATURE AND MOISTURE) ON THE PERFORMANCE OF FLEXIBLE PAVEMENT:

THE CASE OF TARCHA- OMO RIVER HIGHWAY

A Research Thesis Submitted to the School of Graduate Studies of Jimma University, Jimma Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

By

Kebede Haile Folla

October, 2021

Jimma, Ethiopia

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DECLARATION

I the undersigned, declare that this Research entitled **"Assessment of Impacts of Environmental Factors (Temperature and Moisture) on the Performance of Flexible Pavement: The Case of Tarcha- Omo River highway segment"** is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere. All sources of materials used for the thesis proposal have been duly acknowledged.

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This thesis has been submitted for examination with my approval as university adviser for the above mentioned title.

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ABSTRACT

The structural behavior of pavements can be affected by seasonal variation in environmental factors such as temperature and moisture content. In Ethiopia the design, construction and maintenance process of roads mostly give attention to structural thickness of pavement layers, on which the designers and authoring focus on expected future traffic. However it is critical to admit in practical the variation of pavement material properties due to seasonal environmental changes, especially the temperature and moisture. This study focused on assessment of the impacts of environmental factors(temperature and moisture) on performance of flexible pavement in generally and particularly on Tarcha - Omo River highway, hence doing this study, the objectives were: to investigate the impact of temperature on the performance of selected highway, analyze the impact of moisture on the performance of pavement through laboratory based investigation and to examine the efficiency of the drainage system in removing excess water from the pavement structure of selected highway by collecting all primary data from the project site and secondary from, standard specification, Ethiopian roads authority, Omo River-Tarcha road upgrading project. An assessment was done by using both field observation and laboratory tests to characterize materials toward the factors. The field observation was made to investigate the condition of drainage system in removing water from pavement and surrounding. The sample of base course, sub base and sub grade were collected from three different sampling stations and laboratory tests were conducted and finally compared with standards to check the moisture sensitivity of materials. NMC, Compaction, Particle size distribution, CBR and Atterberg's Limit were tests conducted. Statistical Microsoft Excel 2007 software was employed to analyze the data. The assessment showed that temperature and moisture has considerable impact on performance of flexible pavement and the pavement failed due to moisture variation on pavement base, sub base and subgrade, due to, inadequate drainage facility, lack of effective protection work and excessive water in the sub grade in first section and temperature in second section of study. Therefore Standard of construction and design should be improved. More research should be carried out on the engineering geo-techniques of study road.

Key words: - *environmental effect, flexible pavement, moisture variation, temperature*

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ACRONYM

AADT Average Annual Daily Traffic

AASHTO American Association of State Highway and Transportation Officials

AC Asphalt Concrete

BC Base course

CBR California Bearing Ratio

CRSG China Railway Seventh Group

DQ Drainage Quality

E Elastic Modulus

ECDSWC Ethiopian Construction Design and Supervision Works Corporation

ERA Ethiopian Roads Authority

GB Granular Base Course

GC Granular Capping Layer

Gs Granular Sub base

h_{asp} Asphalt thickness

hr hour

K Modulus of Subgrade reaction

Kg Kilogram

KN Kilo Newton

LL liquid limit

MDD	Maximum Dry Density
MEPDG	Mechanistic Empirical Pavement Design Guide
ml	milliliter
Mpa	Mega Pascal
M_R/Mr	Resilient Modulus
NMC	Natural Moisture Content
NP	Non-Plastic
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	plastic limit
S	Saturation
SB	sub-base
SG	sub-grade
T_{air}	Air Temperature
T_{asp}	Asphalt Temperature
TRL	Transport Research Laboratory
Ua	Pore-air Pressure
USA	United States of America
Uw	Pore-water Pressure
W	Moisture Content

CHAPTER ONE
INTRODUCTION

1.1 Background

The road network is an important element of the national infrastructure and its construction, operation, and maintenance constitute a large part of the national annual budget. The road network in Ethiopia provides the dominant mode of freight and passenger transport and thus plays a vital role in the economy of the country. The network comprises a huge national asset that requires adherence to appropriate standards for design, construction and maintenance in order to provide a high level of service. As the length of the road network is increasing, appropriate choice of methods to preserve this investment becomes increasingly important (*ERA, 2013)*

According to *(Mukabi et al., 2003)* ,in the design of pavement structures, seasonal variations are difficult problem, particularly in flexible pavement. Generally speaking, there are two sources of climatic variations that reduce the life of the pavement structure: the soil moisture and the ambient temperature. The former causes a reduction in the subgrade strength, whereas the latter results in a decrease in the asphalt-layer stiffness and associated strength. The combination of both clearly affects the overall pavement deterioration, and this has economic impacts including both maintenance and rehabilitation costs along with user costs

Environmental changes have a direct impact on the structural capacity of the pavement, and consequently its performance. While the subgrade soil and the unbound materials are sensitive to moisture variation, the Asphalt Concrete (AC) layers are more sensitive to temperature variations. Quantifying the effect of these two environmental factors, moisture and temperature, is necessary for incorporation in the pavement design process *(Fouad and Hassan, 2004)*

According to *(El-Maaty, 2017b)* Temperature of the asphalt concrete (AC) and water content in the base layer and the subgrade are the most critical factors that influence flexible pavement performance. A change in the pavement temperature directly affects the stiffness of the asphalt-bound layers, which alters the stress state throughout the pavement. This change in stress state can, in turn, affect the stiffness of the underlying unbound layers since they usually exhibit stress dependence. The structural capacity of the entire pavement system is thus affected by changes in pavement temperature. Likewise, moisture induced change in the base and subgrade may cause increased strains in the AC layer (*Zuo.Gang, 2003)*. Mechanistic-empirical pavement design methods for flexible pavements are based on the assumption that the pavement life is inversely proportional to the magnitude of the traffic-induced pavement strains. These strains vary with the stiffness of the asphalt layer and underlying base layer and subgrade. The stiffness of the asphalt layer varies with temperature and the stiffness of the unbound base layer and subgrade varies with water content. Because these relationships are nonlinear, the additional pavement life consumed at higher than-average temperatures or water contents is not offset by savings at lower than-average temperatures or water contents. Since the variation in temperature and water content can take place at different times, the effects cannot simply be considered separately and the results superimposed *(AASHTO, 2009, Qiang LI et al., 2011).* And it also suggested that the combined effects of temperature and water content variations should be accounted for in the estimation of pavement life, particularly in moderate to warm climates where. Hence, environmental factors are the major constraints in the pavement life after it has been constructed. These factors mostly determine the service life of the road pavement structure constructed. The purpose of this study is to evaluate the impact of environmental factors on the performance of pavement structure through field observation and laboratory tests, to come with recommendations for the problems.

1.2 Statement of problem

Even though great developments have been achieved with the enhancement of computers that allows for more advanced analysis and design procedures, the problem related to environmental factors to pavement structure still requires a better findings and solutions over worldwide even in developed worlds like USA *(Gudipudi et al., 2017*)

Recently, road infrastructure development has been a sensitive issue for Ethiopia government. The budget invested in this sector tends to increase, although the pavements to be maintained dramatically have increased, and those pavements must be maintained within that limited budget.

In undertaking comprehensive evaluation of the structural capacity of an existing pavement structure for rehabilitation design and construction, it is important to establish design input parameters that take into account the in-situ material and composite pavement response relative to environmental changes *(Mukabi et al., 2003)*.

In Ethiopia the design, construction and maintenance process of roads mostly give attention to structural thickness of pavement layers, on which the designers and authoring focus expected future traffic *(Mukabi et al., 2003, Garoma, 2016).* Therefore it is critical to concede in practical the variation of pavement material properties due to seasonal environmental changes, especially the temperature and moisture.

The problems normally faced on pavement includes, Traverse and longitudinal crack, deformation, pumping, pothole, raveling, edge break and rutting on the selected highway segment for the study. Therefore the aim of this study was to assess the impacts of environmental factors (temperature and moisture) on the performance of pavement structures after the construction has been taken and, the characteristics of pavement base, sub base and sub grade materials as well as AC layer towards the factors in resisting the stress upcoming from moving traffic that can be generally expressed in terms of their stiffness.

1.3 .Research Questions

- What is the impact of temperature on the performance of pavement structures of selected highway segment?
- What is the impact of moisture on the performance of pavement structure?
- How the drainage system is effective in removing excess water from the pavement structure in selected highway segment?

1.4 .Objective

1.4.1 General Objective

The purpose of the study is to assess the impact of environmental factors (Temperature and moisture) on performance of pavement structures.

1.4.2 Specific Objectives

The specific objectives of the study were:

1. to investigate the impact of temperature on the performance of pavement structures of selected highway segment.
2. to analyze the impact of moisture on performance of pavement through laboratory based investigation.
3. to examine the efficiency of the drainage system in removing excess water from the pavement structure for possible mitigation.

1.5 Significance of the study

The study analyzed the impact of environmental factors (Temperature and moisture) and their seasonal variation on performance of pavement structures which provide helpful information for road agencies, consulting firms and for contractors.

- ❖ In addressing the possible measurements to be taken in order to assure the serviceability of the road and safety for traffic.
- ❖ To assess knowledge gaps and to identify future research needs and to assess and analyze results.
- ❖ Besides, the results will help decision makers and especially the authoring (ERA), road sector contractors and the design, supervision firms of the sector.
- ❖ As reference for future research in the selected highway segment.

1.6 Scope and limitation of the study

This study is geographically limited to Tarcha Town - Omo River Asphalt road. Generally the research focused on evaluating the impact of environmental factors (Temperature and moisture) and their seasonal variation on performance of pavement structures on the selected highway segment having length of 50 km.

The study was limited on the environmental factors (Temperature and Moisture) that can affect the performance of flexible pavement structure. The research considered and focused on the basis of the sampled base course, sub base and subgrade materials used during the construction of selected highway segment and conducted laboratory experiments in order to identify the impacts on stiffness and other engineering properties of sampled pavement materials. The data was recorded, from three places for base course, sub base and sub grade materials and further the laboratory, investigated and analyzed with standard specifications. The adequacy of side drainage along the study at the time of data collection was analyzed. The study did not include the effect heavy vehicles on pavement structure, effect of maintenance practices and frequency depending on the AADT and material quality, so it was recommended for further researches.

CHAPTER TWO
LITERATURE REVIEW

2.1 .Flexible Pavement and its Construction

Modern flexible pavements normally comprise one or more bound layers overlying one or more unbound aggregate layers which, in turn, rest on the subgrade. In almost all cases the uppermost layers are bound by bitumen. In the case of an embankment the subgrade is comprised of imported fill. In the case of a cutting it will often be the natural rock or soil at that location *(Garoma, 2016).*

Road pavements are designed to limit the horizontal strain/ stress created at bottom of asphalt and vertical strain created at top of the subgrade level by the traffic travelling on the pavement surface so that the subgrade is not subject to significant deformations. The pavement spreads the concentrated loads of the vehicle wheels over a sufficiently large area at subgrade level. At the same time, the pavement materials themselves should not deteriorate to any serious extent within a specified period *(Ankit Gupta, 2014).*Figure 2.1 provides typical flexible pavement profiles. Considering these from the bottom upwards, the following layers are, typically encountered:

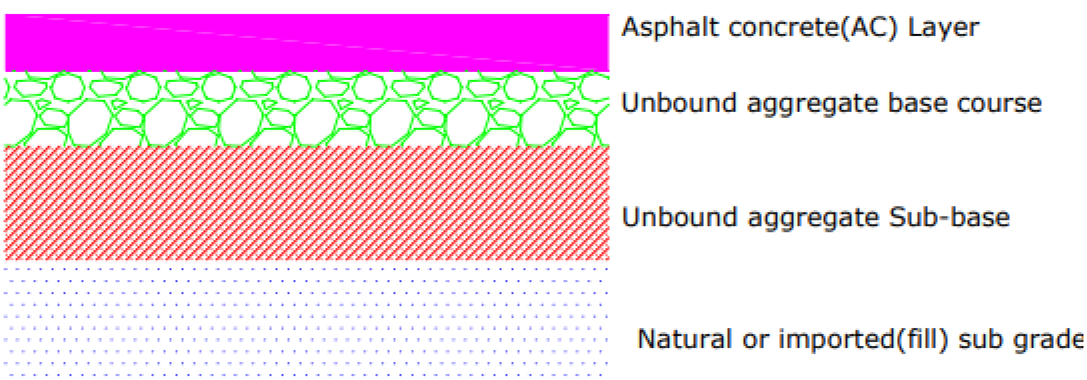

Figure 2.1 Typical flexible pavement profiles

The pavement foundation consists of the natural ground (subgrade), and often a capping layer, the role of which is to improve the leveling, homogeneity and bearing capacity of the subgrade, and often also to ensure frost protection.

The sub-base layer is normally comprised of an aggregate layer which acts as a platform for construction and compaction of the higher pavement layers and continues to function during the life of the pavement as an intermediate distributor of stress from the higher layers of the pavement down to the foundation.

The pavement base is usually comprised of treated materials in high-traffic pavements or may be untreated in low traffic pavements. These layers provide the pavement with the mechanical strength to withstand the loads due to traffic and distribute these loads to the weaker lower pavement layers. The surface course (and possibly a binder course below) is the top layer of the pavement, exposed to the effects of traffic and climate. It must resist traffic wear and also protect the structural layers, in particular against infiltration of water *(Zumrawi, 2016)*.

According to *(Dawson, 2008)*, The pavement construction is there to provide an almost fixed, plane surface on which wheel vehicles may pass without difficulty. To meet this requirement the surface: Must not deflect much transiently – otherwise vehicles will be travelling in a depression of their own making and using excess fuel in a vain attempt to climb out of it; Must not deform plastically – otherwise ruts will form, hindering steerage, leading to increased fuel and wheel costs due to a greater contact with the wheel and tending to feed rainwater to the wheel path thereby promoting aquaplaning; Must provide adequate skidding resistance – to enhance safety; and Must continue to meet these requirements for a long time; so that the pavement is economic and so that users are not unduly affected by pavement rehabilitation needs. He emphasized that as far as the lower unbound layers and subgrades are concerned, they have to provide the necessary support to the upper layers so that those layers do not flex too much under trafficking as this could lead to those upper, bound, layers failing prematurely by fatigue. The upper layers need to be thick enough so that they spread the traffic loading so that the lower layers are not over-stressed and can provide their function successfully (Figure 2.2). Successful pavement design is all about satisfying these two needs in the most efficient manner given the properties of the available materials.

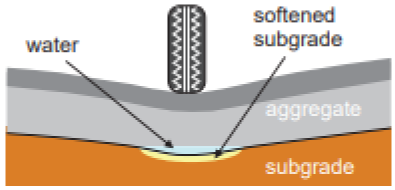

Figure 2.2 Malfunction of the lower pavement layers *(Dawson, 2008).*

A depression in an impermeable sub-grade allows water in the aggregate layer to collect there, leading to subgrade softening and consequent rutting of the whole pavement: source *(Dawson, 2008)*

2.2.PAVEMENT PERFORMANCE

Performance is a broad, general term describing how pavement condition changes or how pavement structures serve their intended functions with accumulating use *(S.M, 2004, AASHTO, 2009)* defines the pavement performance as the ability of a pavement to satisfactorily serve traffic over time. It further defines the serviceability of a pavement as the ability to serve the traffic for which it was designed. Integration of both definitions will yield a new understanding of the performance, which can be interpreted as the integration of the serviceability over time *(Ankit et al., 2016).* Hence the main task for a pavement engineer is not only to design and construct a pavement but also to monitor the performance of the pavement in service so as to schedule the maintenance and rehabilitation works. The factors that are found affecting the performance of the pavements are presented in Figure 2.3.

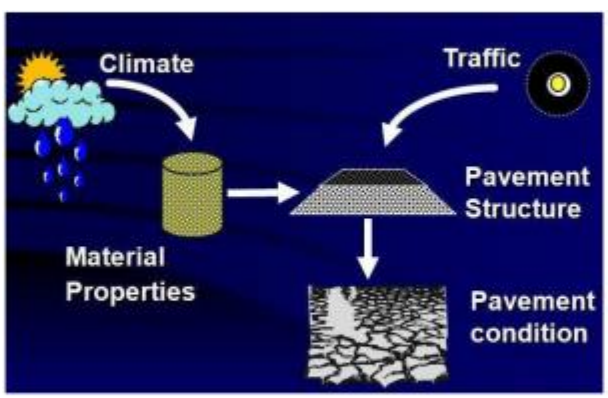

Figure 2.3 Factors influencing pavement performance: source *(Ankit et al., 2016)*

2.3.Flexible Pavement and Materials properties

Surface Course: Obviously, surface course is the layer in contact with traffic loads and normally contains the highest quality of materials. Surface course play an important role in characteristics of friction, smoothness, noise control, rut and shoving resistance and drainage. Furthermore, surface course serves to prevent the entrance of excessive quantities of surface water into the underlying base, sub base, and subgrade. The top structural layer of material is sometimes subdivided into two layers *(FIKRU, 2018)*.

1. Wearing Course: This is the top layer in pavement structure and direct contact with traffic loads. A properly designed preservation program should be able to identify pavement surface distress while it is still confined to the wearing course.

2. Binder Course: The purpose of this layer is to distribute load from wearing course. This layer provides the bulk of the HMA structure.

Base Course: The base course is a course of specified material and design thickness, which supports the structural course and distributes the traffic loads to the sub base or subgrade. It provides additional load distribution and contributes to drainage and frost resistance. A wide range of materials can be used as unbound road bases including crushed quarried rock, crushed and screened, mechanically stabilized, modified or naturally occurring `as dug' gravels. Their suitability for use depends primarily on the design traffic level of the pavement and climate.

Sub base: The sub base is constructed between the base course and the subgrade. The sub base generally consists of lower quality materials than the base course but better than the subgrade soils. The sub base consists of granular material - gravel, crushed stone, reclaimed material or a combination of these materials. It enables traffic stresses to be reduced to acceptable levels in the subgrade, it acts as a working platform for the construction of the upper pavement layers, and it acts as a separation layer between subgrade and base course. Under special circumstances, it may also act as a filter or as a drainage layer. For a pavement constructed over a high quality, stiff subgrade may not need the additional features offered by a sub base.

Subgrade layer: Subgrade support is characterized by the subgrade resilient modulus (Mr).The Resilient Modulus (Mr) is a measurement of the stiffness of the roadbed soil (AASHO, 1993). A material's resilient modulus is actually an estimate of its modulus of elasticity (E). While the modulus of elasticity is stress divided by strain for a slowly applied load, resilient modulus is stress divided by strain for rapidly applied loads, like those experienced by pavements. It is recognized that many agencies do not have equipment for performing the resilient modulus test. Therefore, suitable factors are reported which can be used to estimate Mr from standard CBR and soil index test results or values. A widely used empirical relationship developed by Heukelom and Klomp (1962) and used in the 1993 AASHTO Guide is *Equation 2.1* and Table 2.1 summarizes the properties of unbounded materials *(AASHTO, 2009)*

E/Mr. (psi/MPa) = 1500*CBR/10.342CBR [AASHTO 93] -------------------- 2.1

Table 2. 1 Properties of unbounded materials: source *(AASHO, 1993)*

Code	Description	Summary of specification
GB1	Fresh, crushed rock	Dense graded, un weathered crushed stone, non-plastic parent fines
GB2	Crushed weathered rock, gravel or boulders	Dense grading,<6, soil or parent fines
GB3	Natural coarsely graded granular material, including processed and modified gravels	Dense grading, PI<6 CBR after soaking >80
GS	Natural gravel	CBR after soaking>30
GC	Gravel or gravel-soil	Dense graded; CBR after soaking>15

2.4.Review of Ethiopian Roads Authority (ERA) pavement design Manual.

This manual gives recommendations for the structural design of flexible pavement and gravel roads in Ethiopia. The manual is intended for engineers responsible for the design of new road pavements and is appropriate for roads that are required to carry up to 30 million cumulative equivalent standard axles in one direction. This upper limit is suitable at present for the most trafficked roads in Ethiopia. According *(Bona, 2018)* ERA manual which also known as overseas road notes was developed by Transport Research Laboratory (TRL) to design flexible pavement thickness besides understanding the behaviors of road building material, also interaction in pavement structural layers design. In advance, overseas road notes is confident to be applying in tropical and sub-tropical regions associated with climate and various types of material and reliable road maintenance to give satisfactory service, a flexible pavement must satisfy a number of structural criteria or considerations; some of the important considerations are:

1. The subgrade should be able to sustain traffic loading without excessive deformation; this is controlled by the vertical compressive stress or strain at this level.

2. Bituminous materials and cement-bound materials used in road base design should not crack under the influence of traffic; this is controlled by the horizontal tensile stress or strain at the bottom of the road base.

3. The road base is often considered the main structural layer of the pavement, required to distribute the applied traffic loading so that the underlying materials are not overstressed. It must be able to sustain the stress or strain generated within itself without excessive or rapid deterioration of any kind.

4. In pavements containing a considerable thickness of bituminous materials, the internal deformation of these materials must be limited; their deformation is a function of their creep characteristics,

5. The load spreading ability of granular sub base and capping layers must be adequate to provide a satisfactory construction platform.

2.5. Pavement and Environment

Pavement design has evolved over the years in terms of how the support provided by different pavement layers is quantified. Initially, the modulus of subgrade reaction (k) was utilized to quantify the support provided by the subgrade. However, K was obtained under static loading conditions, which does not adequately represent the cyclic loading experienced by a pavement due to vehicular traffic load. The resilient Modulus (M_R), which is the measure of the stiffness of a material, represents a fundamental material property, which is especially important for pavement design since it serves as a key input parameter for the Mechanistic Empirical Pavement Design Guide (MEPDG) *(Mehrotra, 2014b).*

The purpose of the pavement is to provide a surface so that a vehicle can use it as a route of transportation. Pavement that is both smooth and durable is a product of proper material selections and construction. The subgrade deserves a major focus when examining the design of pavement systems. Important properties of the subgrade include moisture conditions, ease of compaction, dry density, stiffness and strength. Given that soil properties can vary seasonably, the moisture content within the soil demands careful scrutiny *(Kelly, 1999).*

Pavement structures are primarily designed to distribute the traffic induced stresses and strains over the load bearing layers to intensity level which the material can withstand. In mechanistic-empirical pavement design, inputs such as material properties, traffic loads and structural layer thicknesses are related to the pavement response such as stresses and strains, using mechanistic principles. The pavement response is then used to predict pavement performance using laboratory and field based data and measurements. Pavement design dependency on field and laboratory performance and observations is mainly due to the complex nature of pavement systems and the many system boundary conditions which affect its performance. These boundary conditions are mainly the interaction of climatic factors such as temperature and moisture (water) content, the mechanical behavior of bound and unbound materials, and the traffic load spectrum and frequency. Due to the complexity of pavement systems, the theory alone has not yet been able to realistically predict pavement performance and pavement engineering is still dealing with fundamental difficulties in many aspects of the design process *(salour, 2015b).*

According to *(Mukabi et al., 2003, salour, 2015b)*,Environmental factors are known to highly affect the concepts of design, actual construction and ultimate performance of highway pavement structures. Pavement structures and their surrounding environment are in continuous interaction. Similar to their surrounding environment, pavement structures can also be characterized by temperature, moisture content and acting pressure regimes which are governed by the physical laws of the pavement porous mineral system. These parameters undergo daily and seasonal variations as well as a spatial distribution as they are interconnected to the constantly evolving environment that surrounds the pavement system. The two main environmental factors in pavement engineering are temperature and moisture content that governs all other factors.

According to *(Ankit et al., 2016)*, Environmental conditions have been found to exert significant impact on the performance of flexible pavements. External factors such as precipitation, temperature, humidity, freeze-thaw cycles, and depth of water table are the main environmental factors that have exerted major influences on the pavement performance. The internal factors, such as the susceptibility of the pavement materials to moisture and freeze-thaw damage, infiltration potential of the pavement, control the extent to which the pavement will react to the applied external environmental conditions.

(Momen R.Mousal, 2016), the key parameter that was selected to reflect the environmental effects is the layer elastic modulus. The elastic modulus of a flexible layer changes with surrounding environment. While an asphalt layer may be more sensitive to temperature, a clayey soil subgrade layer will be less sensitive to temperature variation but more affected by the change in moisture. Thus, the environmental parameters that are considered to affect the variation of the pavement properties are moisture for unbound materials and temperature for asphalt bound materials.

The environment can affect pavement performance in several ways. Temperature and moisture changes can have an effect on the strength, durability and load carrying capacity of pavement and roadbed materials *(AASHO, 1993)*.

Environmental conditions are the upper boundary in a soil column model and the water would be an effective lower boundary. There are six main climatic aspects in a coupled soil-climate model: precipitation, wind speed, air temperature, relative humidity, atmospheric pressure and solar radiation; the capillary rise also affects the resultant moisture content in the soil *(Lulu, 2017, Ankit et al., 2016)*. These parameters are interconnected among them and are used to predict the behavior of boundary phenomena like infiltration and evaporation.

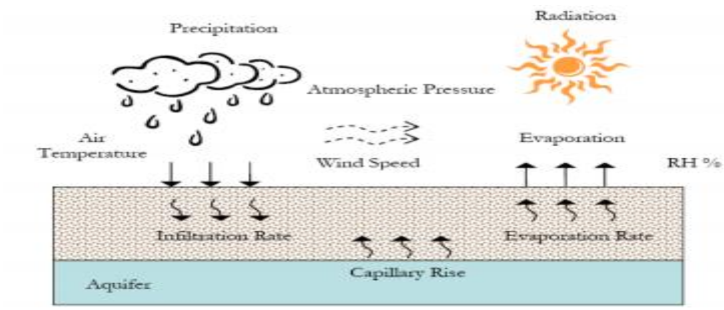

Figure 2.4 Environmental parameters on soil: source *(Ankit et al., 2016)*

2.6. Pavement and Temperature

According to (*Houston W.N et al., 2006)*, Temperature serves as the link between the environmental effects on unbound layers and bound layers. Temperature changes directly control freezing and thawing, which in turn produces dramatic changes in the M_R of unbound layers. Moduli of bound layers, particularly asphaltic layers, are likewise directly controlled by temperature, which also controls thermal cracking of the pavement. Furthermore, temperature and time couple to produce aging effects. Thus, temperature is a key variable in all of these processes which control the response of pavement sections to traffic loads

Pavement temperature is mainly governed by the pavement system boundary conditions and the system's available energy. The temperature of the materials of the pavement layers and its variation highly depends on the surrounding environmental conditions, the location within the pavement system and the thermodynamic properties of each material. While the temperature at the lower depths in the pavement system is almost constant throughout the year, being nearly equal to the mean annual atmospheric temperature, the temperature in the top part of the system usually shows considerable daily and seasonal variations due to a more direct pavement-atmosphere interaction as well as exposure to surface solar radiation *(salour, 2015b).*

According to *(Qiao et al., 2013)*, Pavement temperature is dependent on energy balance, predominately on the pavement surface. The pavement absorbs heat from solar energy, which is nearly constant over the service life of pavements, and which has leading influence on pavement temperature.

George, K. P. and Husain, 1986 as cited in *(Ankit et al., 2016)*, used a simplified approach, in which the effective monthly temperature of the asphalt layer was estimated empirical equation;

$$Tasp = Tair\left[1 + \frac{76.2}{hasp+304.8)}\right] - \left[\frac{84.7}{(hasp+304.8)}\right] + 3.3 \qquad 2.1$$

The approach was of significance as it is generally found difficult to find the temperature of the asphalt layer once laid and compacted.

It has been widely accepted that temperature mainly impacts the asphalt layer, where increase in temperature can reduce the stiffness of asphalt materials, which in turn limit the stress strain response of the pavement and reduce the ability of pavement structures to distribute loads from moving traffic *(AASHTO, 2009)*.

According to *J.Antonio et al, 2011* as cited in *(El-Maaty, 2017a)*, temperature can influence the structural bearing capacity of flexible pavement in the following sides

1. The modulus of asphalt mixture reduces with increasing the pavement temperature thus the structural bearing capacity reduces.
2. Higher stress is transmitted to under layers according to the reduction of asphalt mixture modulus. However, material properties of base are relevant to stress level. Granular material of base course will be consolidated under the high stress level; however, cohesive soil will be more debility. Thence the temperature of asphalt mixture will straightway influences material properties of base and sub base.
3. Stress induced by temperature variation: according to microscopic mechanical model, in the case of temperature increase, the contact force among the granules of granular base will be bigger, leading to the increase of volume stress.
4. The increase of pavement temperature will decrease the pore water tension in upper layer. It can result in water in base transfers to upper layer which decreases pore water pressure. Effective stress of base or subgrade will be lower. Simultaneously, the modulus of material is reduced.

The chemical properties of materials and the stiffness of the asphalt mixture layer can be changed as a result of temperature changes *(Taha et al., 2013*). According to Park and Kim (2001) as cited in *(Taha et al., 2013)* used back calculation to study the effect of temperature on the Young's modulus values of the asphalt mixture. It appears that the stiffness modulus values differ depending on the ambient temperature of the asphalt mixture. Therefore, temperature correction for the deflection in testing using equipment such as a Falling Weight Deflectometer (FWD) is required. The test is normally conducted at temperatures between 0 and 40ºC with a vehicle speed of 55 km/h.

Thus the most commonly used empirical formula to determine the modulus of asphalt layer is given by (AASHO, 1993) and illustrated in *Equation 2.2*

$$\mathrm{E1(t)} = 15000 - 7900 \times \log(t) \qquad 2.2$$

Where, E1(t) = The elastic modulus of the asphalt mixture layer at temperature t(t≥1°C)

2.7. Pavement and Moisture

Moisture condition in pavement structures continuously changes throughout the year (*Erlingsson et al, 2002*; Doré and Zubeck, 2008; *Erlingsson et al, 2009a*) as cited in *(salour, 2015b)*. The moisture content of the unbound material that is usually set close to the optimum during the compaction in the construction phase will eventually change towards a natural equilibrium state *(Zapata, 2009)*. Similar to the temperature condition of the pavement, the moisture is also governed by the boundary conditions of the system. The natural equilibrium moisture content is greatly dependent on the material properties and distance to the groundwater table level and its variation. Generally, the moisture condition at the bottom of the pavement system is relatively stable. However, at the upper sections in pavement systems, moisture condition can vary widely from very dry conditions to fully saturated states due to climatic events. The moisture condition of the upper section of the pavement greatly depends on the surface characteristics as well as its longitudinal and transverse position within the pavement system *(Dore and Zubeck, 2008)*.The moisture content of the materials close to the pavement edges and in the vicinity of surface cracks usually shows higher variations due to climatic events such as rainfall. The moisture variation in pavement structure all over the service life is the result of four sources: infiltration of precipitation water, lateral moisture transfer, capillary rise and frost action *(salour, 2015b)*.In addition to these, in *(ERA, 2013)* it is explained, the moisture content of the sub grade soil will change depending on climate, soil properties, depth of water table, rainfall and drainage.

2.7.1. Effects of moisture variation on flexible pavement structure

It is well known that moisture variation can have a significant effect on the performance and bearing capacity of pavement structures. Excess moisture in pavement structure results in accelerated pavement deterioration when combined with heavy axel loads.

According to *(salour, 2015b)* Variation in the moisture content in pavement layers, can affect the mechanical properties of the material through different mechanisms. In coarse-grained materials, increase in moisture content can reduce the inter-particle friction and contact forces due to water lubrication effects between the contact areas of the particles. In unbound materials with high fines content (e.g. subgrade soils), moisture variation can additionally affect the state of stress of the material through pore suction and pore pressure effects.

(Zhang, 2004) summarized the detrimental effects of water, when entrapped in the pavement structure, can be as follows:

1. It reduces the strength of unbounded granular material and subgrade soils.

2. It causes pumping of with subsequent faulting, cracking, and general shoulder deterioration. With the high hydrodynamic pressure generated by moving traffic, pumping of fines in the base course of flexible pavements may also occur with a resulting loss of support.

3. Water causes differential heaving over swelling soils.

Hence, variation of moisture in combination to heavy axle loads can have result the following deterioration on flexible pavement generally and selected highway specifically.

1. **Rutting**

Rutting is the displacement of pavement material that creates channels in the wheel path. Very severe rutting will actually hold water in the rut. Rutting is usually a failure in one or more layers in the pavement. The width of the rut is a sign of which layer has failed. A very narrow rut is usually a surface failure, while a wide one is indicative of a subgrade failure. Inadequate compaction can lead to rutting. Minor surface rutting can be filled with micro paving or paver-placed surface treatments. Deeper ruts may be shimmed with a truing and leveling course, with an overlay placed over the shim. If the surface asphalt is unstable, recycling of the surface may be the best option. If the problem is in the subgrade layer, reclamation or reconstruction may be needed.

2. Longitudinal and Transverse crack

A longitudinal crack takes after a course roughly parallel to the centerline. Then again, a transverse crack runs generally opposite to the roadway centerline. Both are brought about by shrinkage or withdrawal of the black-top or bituminous surface. The progression of longitudinal cracks might be quickened because of inadequately developed path joints. Longitudinal and transverse cracks are measured in straight meter. The severity and length of every break are recorded after identification. In the event that the break does not have the same seriousness level along its whole length, every bit of the split having an alternate severity level is to be recorded independently. If a bump or sag occurs at a crack it is also recorded as a distortion.

3. Potholes

At the point when potholes are not joined by distortion of the contiguous surface, they usually result from a cracked pavement surface which has permitted dampness to enter and mollify the asphalt or infiltrate on a level plane under the pavement layer. Once water has entered, the cracked surfacing is prone to disintegrate and lift out under the action of traffic, particularly after rain, thereby initiating the formation of a pothole. As a general rule, repairs to potholes are carried out before the onset of inclement weather. Any pothole which is likely to be a potential hazard to traffic should be repaired immediately after detection.

4. Raveling

Raveling is loss of material that covered asphalt surface or is the progressive disintegration of HMA layer as a result of the dislodgement of aggregate particles. This dislodgement is the loss of bonding between the aggregate particles and the asphalt binder. The aggregates are sometimes coated with dust particles that result in lack of bonding. This will make the aggregate to bind with the dust rather than the binder. These defects indicate that asphalt materials may be hardness or the asphalt mixture that was used is poor or the temperature of the area is high.

5. **Edge cracking**

Edge cracks typically start as crescent shapes at the edge of the pavement. They will expand from the edge until they begin to resemble alligator cracking. This type of cracking results from lack of support of the shoulder due to weak material or excess moisture. They may occur in a curbed section when subsurface water causes a weakness in the pavement. At low severity the cracks may be filled. As the severity increases, patches and replacement of distressed areas may be needed. In all cases, excess moisture should be eliminated, and the shoulders rebuilt with good materials.

6. **Block Cracking**

The shrinkage of the pavement surfacing and daily temperature fluctuations causes block cracking. These breaks divide the asphalt into rectangular pieces. The appearance of this distress for the most part demonstrates that the pavement has solidified significantly. Block cracking for the most part happens over a huge segment of the asphalt territory and may in some cases happen just in non-traffic territories. Block cracking is measured in square meter of surface area. It normally happens at one severity level in a given pattern segment; notwithstanding, any ranges of the asphalt segment having particularly distinctive levels of damage are measured and recorded independently.

7. **Pumping**

Pumping is seeping or ejection of water beneath the pavement through cracks. In some cases, it is detectable by deposits of fine material left in the pavement surface that were eroded (pumped) from the support layers and have stained the surface.

2.7.1.1. Effects of water content on Resilient Modulus (Mr) of base course, sub base and subgrade

Design and construction of pavements are performed with the aim of keeping the structure drained, but unfortunately water often finds its way into the structure, affecting its performance. Increased moisture content reduces the resilient modulus of granular material, their frictional strength and resistance to deformation *(Saevarsdottira and Erlingsson, 2013, ROKADE et al., 2012, Mehrotra, 2014b)*. In the Mechanistic-empirical pavement design guide (MEPDG) it is stated that the change in moisture content is the most important factor for the amount of rutting of unbound materials, as increased moisture content causes a decrease in the resilient modulus. If all other conditions remain the same increased moisture content will lead to a greater elastic (resilient) strain and therefore more rutting. One of the reasons for a reduced resilient modulus with increased moisture content is the lubricating effect of water, causing lower inter-particle forces *(Qiang LI et al., 2011)*. Another reason is that, if the soil has a low conductivity, excess pore water pressure might accumulate with repeated loading causing the effective stresses to decrease, leading to a reduction in the strength and stiffness of the material and less resistance to permanent deformation. Several studies have been carried out to investigate the impact moisture has on the mechanical properties of aggregates. The effects of moisture are more significant on materials with a high proportion of fines and densely graded. *(Ksaibati, 2011)* found that the coarsest grading material experienced a small reduction in resilient modulus when brought close to saturation, whereas material with an increased fine content and more evenly distributed showed a substantial decrease in the resilient modulus as the water content increased. For a material with a fuller grading coefficient, n = 0.8, the average loss from dry to soaked conditions was approximately 10–15% with the retention limit state in between. *(Mehrotra, 2014a)* also got the same results when testing coarse-grained aggregates with large-scale dynamic triaxial tests and found that the effect of moisture is most pronounced on material having the highest fines content and well-graded materials.

Excessive water content in the pavement base, sub-base, and subgrade soils can cause early distress and lead to a structural or functional failure of pavement. Water-related damage can cause one or more of the following forms of deteriorations: Reduction of subgrade and base/sub-base strength, Differential swelling in expansive subgrade soils, Stripping of asphalt in flexible pavements, and Movement of fine particles into base or sub-base course materials resulting in a reduction of the hydraulic conductivity considerably *(ROKADE et al., 2012)* . According to them, the loss of MR at different pavement granular and subgrade layers due to extreme moisture intrusion can represent a flood. A road structure may be inundated for several days after a flood; and as a consequence, it becomes weaker with very low MR at untreated layers and may considerably lose shear strength.

Resilient modulus, Mr of soil is an important material parameter. The resilient modulus of cohesive soils is not a constant stiffness property, but highly dependent upon factors such as the state of stress, soil structures, and water content. Due to complexity of conducting resilient modulus testing, there have been numerous efforts to develop predictive equations by incorporating state variables such as confining stress, bulk stress, deviator stress, and soil physical properties. In view of the sensitivity of the resilient modulus of soils to the water content and stress state and the likelihood of the soils' moisture variation underneath the pavement, it is important to develop a simple and accurate prediction equation for predicting the variation of resilient modulus due to changes in stress and moisture content of cohesive soils from conducted CBR value *(ROKADE et al., 2012)*.

2.7.1.2.Stress

If a given load is applied to a material a contact stress will occur. This stress is equal to the load divided by the loading object's contact area. Stress essentially provides a method of normalizing load and area for testing and design purposes. When a wheel load is applied to a pavement, locations under the load experience different levels of stress based on their depth from the surface and distance from the applied loading. In the pavement system there is Vertical stress at a point due to the applied load. The intensity of internally distributed forces experienced within the pavement structure at various points (stress) can be expressed as force per unit area (pa) Shane Buchanan, 2007 as cited in *(Garoma, 2016).*

$$\delta = \frac{Load}{Area} = \frac{P}{A} \qquad 2.2$$

Its units are Mpa,Psi,Ksi and it can be: bearing, shearing and axial stress.

2.7.1.3.Strain

It is described as the ratio of an object's deformation to its original dimension in the same direction. Strain can be calculated for any desired direction (e.g., vertical, horizontal, longitudinal, etc.).The unit displacement due to stress, usually expressed as a ratio of change in dimension to the original dimension (mm/mm) or Strain Ratio of deformation caused by load to the original length of material.it can be obtained from the following formula

$$\varepsilon = \frac{change\ in\ length}{original\ length} = \frac{\Delta L}{L} \qquad 2.3$$

2.7.1.4. Resilient Modulus

The Mr is a key property in the pavement design, and an input design parameter especially when the MEPDG pavement design procedures are utilized. Mr is defined as the ratio of maximum cyclical stress to elastic strain under repeated cyclical loading *(AASHO, 1993)*.

Resilient modulus, MR, generally corresponds to the degree to which a material recovers from external shock or disturbance. This property of the material is actually an estimate of its modulus of elasticity, E. In case of slowly applied load, slope of the stress-strain curve in linearly elastic region yields E, whereas, for rapidly applied loads (e.g., load experienced by pavements), this would yield Mr *(Garoma, 2016)*. The resilient modulus can be expressed as

$$\mathrm{Mr} = \frac{\sigma}{\varepsilon r}, \qquad 2.4$$

Where σ is the applied stress and εr is the recoverable axial strain

The Mr is mainly used to quantify the support the pavement receives from the subgrade layer. It was initially introduced as an input parameter in the 1986 AASHTO Guide for Design of Pavement Structures. Its' popularity was preceded by the usage modulus of subgrade reaction. However, since pavement experience cyclical loading (due to moving traffic loads), Mr was thought to better describe the support provided by the subgrade for a pavement. Mr is similar to modulus of elasticity as it is determined based only on elastic deformation. This also leads to Mr being analogous to the stiffness of a subgrade. Under repeated loading Mr is determined based on the recoverable strain (i.e., elastic strain). However, it should also be noted that as the number of loading cycle's increases, there is an accumulation of plastic strain (i.e., non-recoverable deformation) *(A. Patel et al., 2011)*. Figure 2.5 shows the interdependency of stiffness (Mr) of elastic materials on stress and strain.

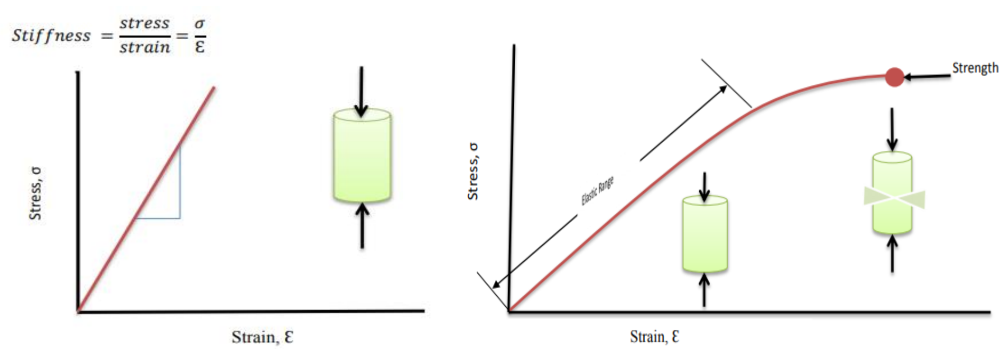

Figure 2.5 The relationship between Stress, strain and stiffness of material: source (Garoma, 2016)

a) stress Vs strain for elastic Materials b) stress Vs strain in compression

Pavements under repeated loading experience both elastic and plastic strain while Mr is based on the elastic strain. Plastic deformation manifests itself in a pavement as rutting (permanent deformation) and is an undesirable property as it could lead to a loss in serviceability and/or failure. Generally, the larger the Mr value the better the subgrade soil would be considered. A large Mr value would indicate that the subgrade can handle certain cyclical loading with little deformation (i.e., subgrade is stiff).

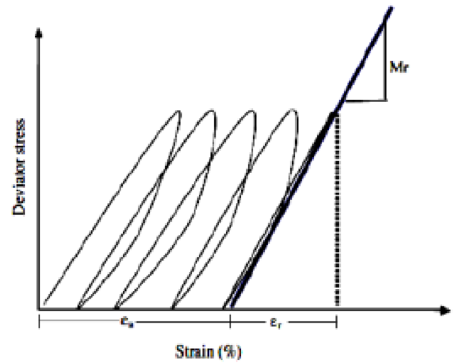

Figure 2. 6 Graphical Representation of Resilient Modulus: source *(Mehrota, 2014b)*

2.7.2. Factors Effecting Resilient Modulus

2.7.2.1.Stress State

According to *(Mehrotra, 2014b)* it has been shown that the resilient modulus (Mr) of a subgrade, sub base and base course material is affected by the stress state experienced the pavement structures. Generally, the stress state of a pavement material (i.e bounded and non-bounded) is defined by the confining pressure and deviatoric stress experienced by the subgrade, sub base and base course. However, it should be noted that for unsaturated subgrades, matric suction is an important factor in defining the stress state of a subgrade. Increasing confining pressure serves to increase the Mr of pavement materials, as it increases the bulk stress experienced by the materials, therefore providing a stiffening effect to the specimen. Increasing deviatoric stress tends to decrease the Mr of materials specimens because it increases the shear stresses experienced by the material specimen. The effect of confining pressure is more pronounced on granular soils, while the effect of deviatoric stress is more pronounced on cohesive soils

2.7.2.2.Moisture Condition

Subgrades for pavements can generally be prepared two different ways, if possible they are compacted at close to optimum moisture content (OMC) and maximum dry density (MDD) but sometimes this is not feasible and pavements are constructed on subgrades under existing in-situ conditions. Either way, post construction the moisture content of the subgrade comes to equilibrium with its' surrounding conditions *(Mukabi et al., 2003, Mehrotra, 2014a, Gudipudi et al., 2017*) and then varies thereafter due to seasonal variation. Considering that moisture content of a subgrade is not constant, even if the subgrade is prepared at a specified moisture content and density, it is important to realize the impact of moisture content on the Mr value Fine-grained subgrades generally experience a decrease in Mr with an increase in moisture content *(Mehrotra, 2014b)*. Subsequently, a decrease in Mr leads to increased deflection of the pavement, which results in a shortening of the service life of the pavement. To study the impact of moisture changes on Mr, laboratory studies have been performed where either the specimens are compacted at varying moisture contents or compacted at certain moisture content and then subjected to post-compaction moisture changes. It should be noted, that in the field, subgrades are subjected to post compaction moisture changes and varying moisture contents at compaction may not accurately simulate the field conditions. This is because the changes in compaction moisture content effects the soil structure *(A. Patel et al., 2011)*. Figure 2.7 displays the impact of moisture content on the Mr value.

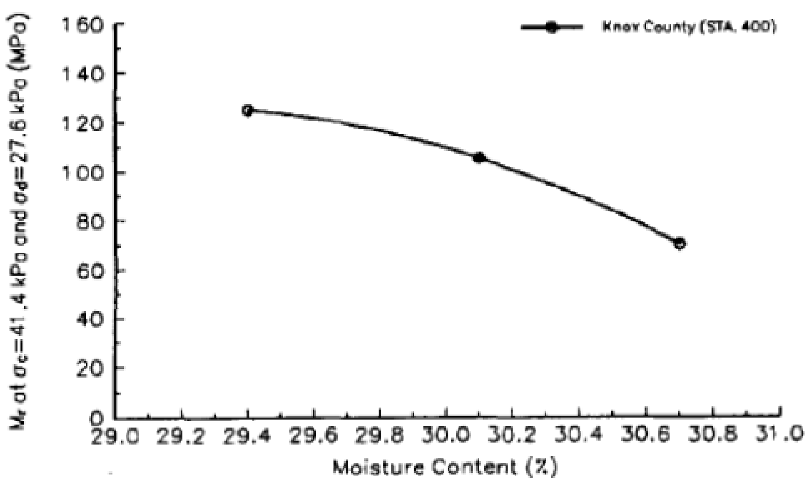

Figure 2. 7 Impact of post-compaction moisture increase on Mr *(Mehrotra, 2014b)*

While, it is well understood that the increase in moisture content results in a decrease in Mr, it should also be realized that the effect of changes in moisture content on Mr is different for different soil types. *Drumm (1997)* as cited in *(Mehrotra, 2014a)* found that while A-7 soils tended to have larger Mr values at optimum conditions, compared to A-4 and A-6 soils, they also exhibited a larger decrease in Mr once the moisture content increased to values greater than optimum. He also suggested that another route of evaluating the impact of moisture condition on Mr is by considering the relationship between Mr and degree of saturation (S) of a soil specimen. While, at first glance, the relationship between Mr and degree of saturation may seem to be similar to that between moisture content and Mr, it is important to observe that evaluating the degree of saturation also involves the effect of density. The degree of saturation is dependent on both the moisture content of the soil and its' density, and therefore provides a better description of the soil state.

2.7.2.3.Matric Suction

For unsaturated subgrades, it is imperative to evaluate the impact of suction on Mr since suction is a fundamental property of unsaturated soils that affects the stress state of unsaturated soils. According to *(Mehrotra, 2014b)*, it was observed that there is a relationship between suction and deflection of a pavement, such that deflection decreased with increasing suction values. The matric suction impacts the effective stress for unsaturated soils; and since effective stress controls the strength and deformation characteristics for soils, it is expected that suction will also impact Mr for unsaturated soils. An increase in suction will increase the stiffness of the soil and hence increase Mr of unsaturated soils. Soil suction is composed of two components, matric suction and osmotic suction. However, *Khoury et al. (2003)* as cited in *(Mehrotra, 2014b)* demonstrated that the changes in Mr for unsaturated soils are mainly attributed to changes in matric suction.

Knowing that, matric suction is defined as the different between pore-air pressure and pore-water pressure (ua – uw). The magnitude of suction present in a soil is related to the moisture content, which is varying in a pavement subgrade over time. It is therefore important to evaluate the impact of suction in order to account for the effect of seasonal variation on Mr for unsaturated subgrades. Figure 2.8 provides a useful illustration of the dependency of Mr on moisture content and suction, and the interdependence of the two relationships (Mr-moisture content, Mr-suction).

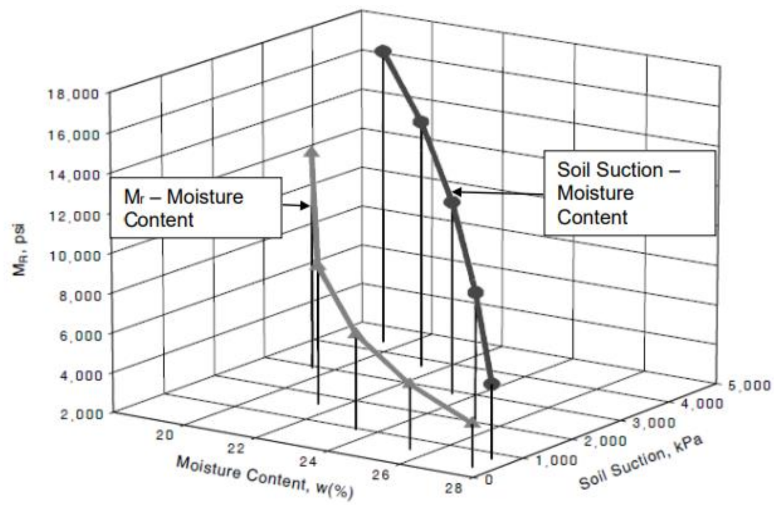

Figure 2. 8 A 3-D plot of Mr variation with moisture content and soil suction: source *(Mehrotra, 2014b)*

2.7.3. Sources of water in pavement

There are many sources of the water that reaches the pavement structure and its immediate vicinity. To evaluate the various sources, the pavement designer should consider the entire profile and cross section of the highway and the surface and subsurface drainage systems that are to be used for the operation and structural integrity of the overall facility. The pavement structure designer may not be directly involved with the other aspects of the facility, cannot predict the possible sources of water and amount without knowledge of the surface and subsurface drainage geometry. Free water enters the structural section and the adjacent area from many sources. According to *(Zhang, 2004)* the most abundant and often overlooked source is undoubtedly atmospheric precipitation, by which surface water is supplied from rain(usually the largest amount), snow, hail, condensing mist, dew, and melting ice. This water reaches the structural section in several ways:

1. Cracks in the pavement. New pavements can be constructed so that they are virtually impermeable, but they cannot be constructed without joints or without cracks forming well before the desired life of the pavement structure is attained.

2. Infiltration through the shoulders.
3. Infiltration from the side ditches.

4. Free water from pavement base. If the base is not properly drained, it may act as a source of free water for the sub base and subgrade.

5. High groundwater table.

6. Condensation of water vapor (small amounts). The first four sources can be particularly significant if the surface drainage is not properly designed or maintained. He also stated that, any free-water surface can act as a source of capillary water, which will move from the free-water surface when a capillary potential exists. The distance it moves depends primarily on the pore-size distribution in the soil. Capillary water can be changed to free water and vice versa. These changes may be affected by changes in temperature and changes in the pore-size distribution of the soil. Free-water surfaces and capillary fringe water are both sources for water vapor. Under changing temperature and pressure conditions, water vapor can change back to either free water or capillary water.

The various sources (and causes) of water ingress to, and egress from, a pavement are listed in Table 2.2 *(ERA, 2013)*.It is also pointed out in *(ERA, 2013)* the two moisture zones in the pavement which are of critical significance are the equilibrium zone and the zone of seasonal moisture variation. In sealed pavements over a deep water table, moisture contents in the equilibrium zone normally reach an equilibrium value after about two years from construction and remain reasonably constant thereafter. In the zone of seasonal variation, the pavement moisture does not reach equilibrium and fluctuates with variation in rainfall. Generally, this zone is wetter than the equilibrium zone in the rainy season and it is drier in the dry season. Thus, the edge of the pavement is of extreme importance to ultimate pavement performance, with or without paved shoulders, and is the most failure-prone region of a pavement when moisture conditions are relatively severe. Figure 2.9 describes zones of moisture in pavement *(ERA, 2013)*

Table 2. 2 Sources of water ingress to, and egress from a road pavement *(ERA, 2013)*

Means of Water Ingress	Explanation
Through the pavement surface	Through cracks due to pavement failure
	Penetration through intact layers
From the subgrade	Artesian head in the subgrade
	Pumping action at formation level
	Capillary action in the sub-base
From the road margins	Seepage from higher ground, particularly in cuttings
	Reverse falls at formation level
	Lateral/median drain surcharging
	Capillary action in the sub-base
	Through an unsealed shoulder collecting pavement and ground run-off
Through hydrogenesis (the aerial well effect)	Condensation and collection of water from vapor phase onto underside of an impermeable surface
Means of Water Egress	Explanation
Through the pavement surface	Through cracks under pumping action through the intact surfacing
Into the subgrade	Soak away action
	Subgrade suction
To the road margins	Into lateral/median drains under gravitational flow in the subbase
	Into positive drains through cross-drains acting as collectors

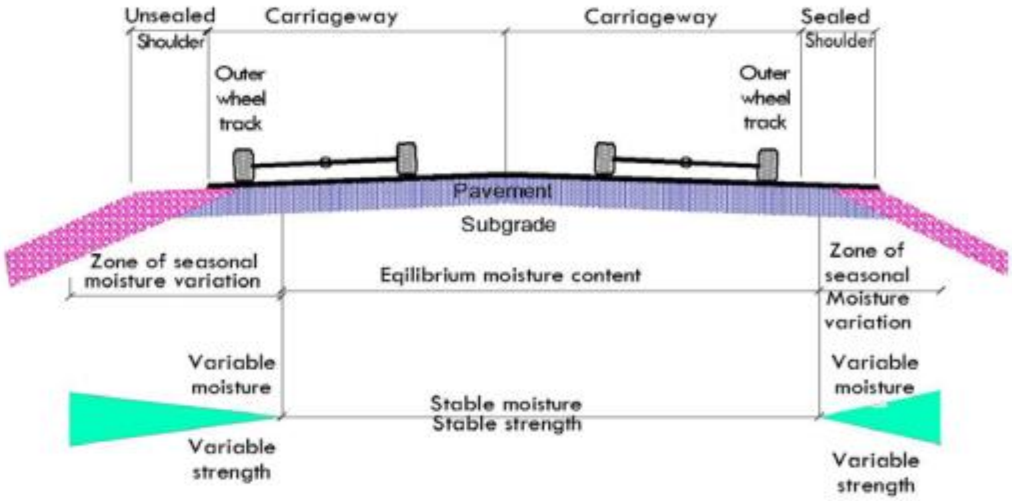

Figure 2.9 Moisture Zones in Road Pavement *(ERA, 2013)*

2.7.4. Effects of Drainage on pavement system performance

One of the most important aspects of the design of a road is the provision made for protecting the road from surface water and groundwater. Water on the pavement slows traffic and contributes to accidents from hydroplaning and loss of visibility from splash and spray. If water is allowed to enter the structure of the road, the strength and deformation resistance of the pavement and sub grade will be weakened, and it will be much more susceptible to damage by the traffic. Water can enter the road as a result of rain penetrating the surface, or as a result of the infiltration of groundwater. When roads fail, it is often due to inadequate drainage. Water can also have a harmful effect on shoulders, slopes, ditches, and other features. Failures can arise spectacularly as, for example, when cuttings collapse or when embankments and bridges are carried away by flood-water. High water velocities can cause severe erosion, possibly leading to the road being cut. On the other hand, low velocities at drainage structures can lead to silt being deposited which, in turn, can lead to blockage. Blockages often results in further erosion or overtopping and possibly wash-out *(Lemessa, 2016)*. A drainage system includes the pavement and the water handling system. They must be properly designed, built, and maintained. The water handling system includes: road surface, shoulders, drains and culverts; curb, gutter and storm sewer. When a road fails, whether it's concrete, asphalt or gravel, inadequate drainage often is a major factor. Poor design can direct water back onto the road or keep it from draining away. Too much, water remaining on the surface combines with traffic action to cause potholes, cracks and pavement failure.

The highway drainage system includes the pavement and the water handling system which includes pavement surface, shoulders, drains and culverts. These elements of the drainage system must be properly designed, built, and maintained. When a road fails, inadequate drainage often is a major factor. Poor design can direct water back onto the road or keep it from draining away. Too much water remaining on the surface combine with traffic action may cause potholes, cracks and pavement failure. *(Abhijit et al., 2011)* investigated the effect of poor drainage on road pavement condition and found that the increase in moisture content decreases the strength of the pavement. Therefore, poor drainage causes the early failure of the pavement. *(Zumrawi, 2016)* investigated moisture damage in asphalt pavements due to poor drainage. He found that the loss of strength and durability due to the effects of water is caused by loss of cohesion (strength) of the asphalt film, failure of the adhesion (bond) between the aggregate and asphalt, and degradation of the aggregate particles subjected to freezing. Moisture damage generally starts at the bottom of an asphalt layer or at the interface of two asphalt layers. Eventually, localized potholes are formed or the pavement ravels or ruts. Surface raveling or a loss of surface aggregate can also occur, especially with chip seals. Occasionally, binder from within the pavement will migrate to the pavement surface resulting in flushing or bleeding.

(Toryila et al., 2016) carried out a framework for quantification of the effect of drainage quality on structural and functional performance of pavement by identifying a simple framework for quantification of the effect of drainage quality on structural as well as functional performance of the pavement. They presented the structural and functional performance of the pavement in predicted terms of deflection and roughness respectively.

(GetachewKebede and TameneAdugna, 2015) on their research assessed the pavement damage due to improper drainage, identified areas most prone to flooding problems, assessed the existing condition of road and surface drainage infrastructure, examine the impacts of road surface drainage structures integration on road performance and related social as well as environment issues and make recommendations on urban road and

drainage structures integration, their provision and management. They conducted a cross-sectional study in Ginjo Guduru Kebele of Jimma town from January to August 2014. From the study made, generally, they observed that the road surface drainage found to be inadequate due to insufficient road profile, insufficient drainage structures provision, improper maintenance and lack of proper interconnections between the road and drainage infrastructures thereby resulting to the damages to road surface material and flooding in the area.

To determine whether a drainage system is adequate or not, Jitendra et al (2013) as cited in *(Toryila et al., 2016)* presented a table of AASHTO classification of drainage system as shown in Table 2.3.

Table 2. 3 AASHTO Relationship between layer's drain ability and subjective drainage quality rating: source *(Toryila et al., 2016)*

S.No	Drainage Quality (DQ)	Water Removal From Layer Within
1	Excellent	2 hour
2	Good	1 day
3	Fair	7 days
4	Poor	1 month
5	Very poor	Water will not drain

2.7.5. Effects of weather related factors on pavement structure

It is well known that environmental changes are the major factor in pavement deterioration. The effect of seasonal variation on pavement performance is generally considered to be very important. While the modulus of the bituminous layers is more sensitive to the temperature variation, the modulus of unbound materials is sensitive to the variation of moisture content. These two environmental factors, temperature and moisture content, must be incorporated in the design process of flexible pavements particularly in seasonal frost areas where pavements are likely to heave during winter and then lose part of their bearing capacity during spring *(Mehrotra, 2014a)*.

According to *(Zumrawi, 2016)* weather related factors include rainfall and annual variations in temperature are an important consideration in pavement deterioration.

Rainfall has a significant influence on the stability and strength of the pavement layers because it affects the moisture content of the subgrade soil. The effect of rain on road pavements can be destructive and detrimental as most pavements are designed based on a certain period of rainfall data. In addition, rainfall is well established as a factor affecting the elevation of the water table, the intensity of erosion, and pumping and infiltration. Long periods of rainfall of low intensity can be more adverse than short periods of high intensity because the amount of moisture absorbed by the soil is greater under the former conditions. He further emphasized that water is the critical factor that cause road failures. Once water has entered a road pavement, the damage initially is caused by hydraulic pressure. Vehicles passing over the road pavement impart considerable sudden pressure on the water, this pressure forces the water further into the road fabric and breaks it up. This process can be very rapid once it begins. When vehicles pass over the weak spot, the pavement will start to crack and soon the crack generates several cracks. Water will then enter the surface voids, cracks and failure areas. This can weaken the structural capacity of the pavement causing existing cracks to widen. Eventually, the water will descend to the subgrade, weakening and hence lowering the CBR value of the subgrade on which the road pavement design was based upon. According to him, climatic changes in temperature and rainfall can interact together. Rainfall can alter moisture balances and influence pavement deterioration while the temperature changes can affect the aging of bitumen resulting in an increase in embrittlement of the bitumen which causes the surface to crack, with a consequent loss of waterproofing of the surface seal.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Description of the Study Area

The selected highway segment Tarcha– Omo River is section of link road described in Ethio road map as B52 that connects Dawuro zone with its neighboring zones and regions. This road has been upgraded to asphalt few years and some kilometers are up today under construction. The road is found in south Nations Nationalities and Peoples Regional state Dawuro zone. It has economic value in integrating Dawuro Zone with neighbor Zones, Regional offices and also with central government. It is the back bone in integrating south east Zones with Dawuro zone for trade and other economic activities. Dawuro Zone is located in 7°00'00"N latitude and 37°09'60" E. The length of highway segment selected for this study was 50 km from Tarcha Town - Omo River. The study was conducted in section of selected highway section that crosses Loma and Mareka districts in Dawuro Zone of Southern Nations, nationalities and Peoples Regional State (SNNPRS) Ethiopia. Figure 3.1 shows the location of selected highway for study. The section of study section lies between 6°54'29.96" to 6°55'16.78" N and 37°13'49.11" to 37°14'18.05" E. The study area was sectioned in to two. The first section is from Tarcha Town to Yalo Municipality and the second section extends from Yalo municipality to Gibe III (Halala Kela). The section of study area lies between 2286 and 2565 msl a total annual rainfall range from 1355.40 to 2565.50 mm with mean monthly temperature varying from 11.7 to 23.5°C for the first study section and 21.56 to 33.12°C for the second. The rain fall is a bimodal type: the short rainy season is between March and May, and the long rainy season is between June and September *(Getahun and Bobe, 2015)*. The rain fall and temperature data of the study sections are given in Figure 3.2 and 3.3. The overall terrain type of the project has summarized as mainly mountainous which constitutes 15.54 % rolling (mostly in town), 42.12% Mountainous, 39.34% escarpment and 3.00 % flat. First the road has been constructed us unpaved gravel road from the year 1994 to 1999 G.C as B52 link road from Jimma - Chida - Soddo. The road has upgraded from gravel to DS4 road class/ERA/'s geometric design manual 2002. The upgraded road has a cross section width of 7 m in rural section with 0.5 m shoulder on each side and 19 m width (including 3.5 m parking lane and 2.5 m pedestrian walkway) with in town sections. It has 1m to 2.5 m median in district towns and Zone town Tarcha. The road has the cross fall of 2.5% to both sides in tangent section and with 8% supper elevation in curve section with appropriate transition.

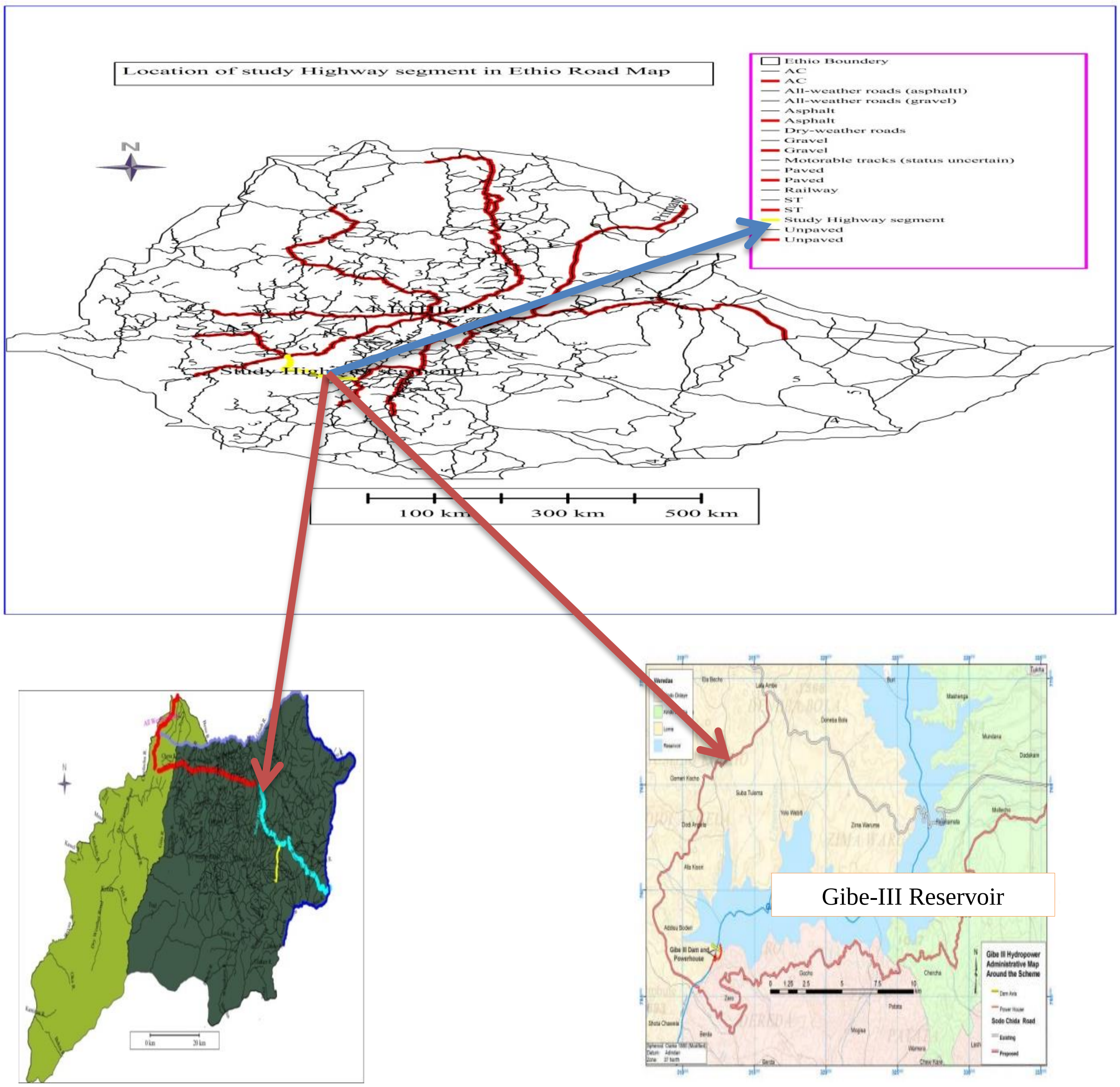

Figure 3.1 Location of selected Highway for Study: source *(Ethio Roads shape file, Global Mapper)*

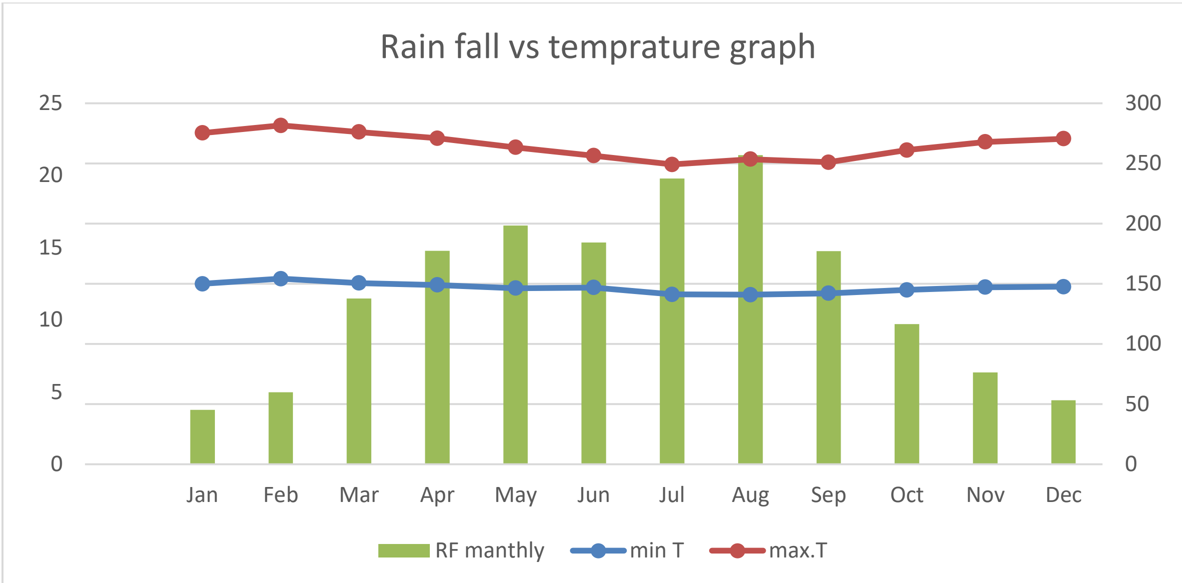

Figure 3. 2 Mean monthly minimum and maximum temperatures (°C) and mean monthly total rainfall (mm) of the first of section study area recorded for the year from 1999-2010 Source: *(National Meteorological Agency; Tarcha District).*

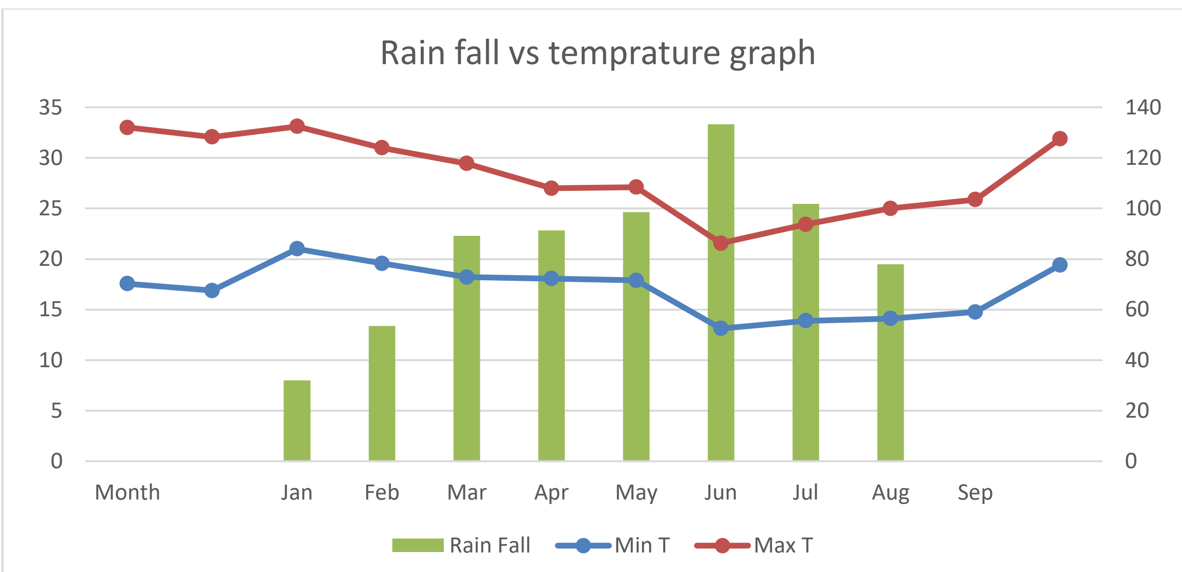

Figure 3. 3 Mean monthly minimum and maximum temperatures (°C) and mean monthly rainfall (mm) of the second section of study area recorded for 2016-2020 (*Source CRSG and ECDSWC, TDSWS)*

3.2 .Research Design

To achieve the objectives of the study, it was designed that laboratory examination and field observation have conducted. The research was undertaken by using both descriptive and analytical methods. Which mean that the methodology used in the research is laboratory analysis of samples extracted from the selected highway segment were base course, sub base and the subgrade material and evaluated/tested in laboratory, and the data could be used to evaluate the impact of environmental factors on the performance of selected highway segment, and the effectiveness of drainage inn removing excess water from the road in site observation.

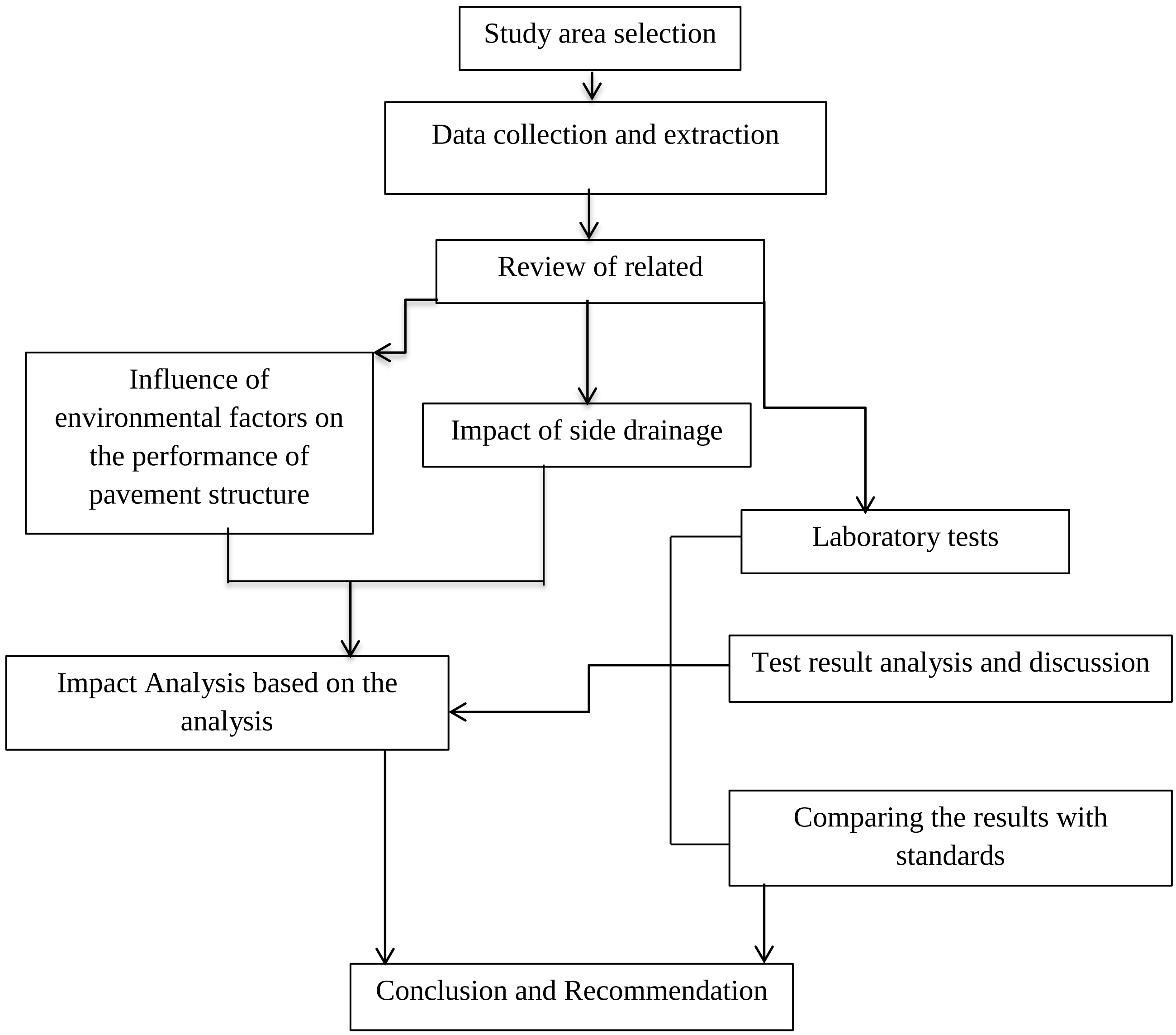

Figure 3.4 Flow chart of methods

3.3. Study Procedures

The procedure followed throughout the conduction of this study were: Review of related literatures on impacts of environmental factors on flexible pavement structures, impacts of temperature, moisture, drainage related impacts, cause of moisture variation with in flexible pavement layers, effects of moisture variation on resilient modulus of bounded and unbounded materials of flexible pavement layers, methods of determination of Mr from CBR, standard measurement of quality of drainage system in removing excess water, moisture sensitive properties of sub grade soil, characteristics of materials for flexible pavement from journal articles, reference books, previous researches and standards ERA and AASHTO. Necessary data collection, laboratory test, organization, comparison, and analysis were obtained, and then subsequently compared the results with preexisting literature and standard specifications. Conclusion and recommendation drew based on the observations and results.

3.4 Material and tools

3.4.1. Tools

- CBR Machine, a set of sieve, sieve shaker, Balance, Molds, Moisture can, Dry oven, Gloves, porcelain dish, spatula, spoon, vacuum pump, Funnel, liquid limit device, grooving tool, hand GPS and other essential tools have used.

3.4.2. Materials

Different materials from different source have been used for this study. Materials used for this study are given in Table 3.1

Table 3. 1 Lists of Materials used for study

No	Material to be used	Description	purpose	Remark
1	Design and specification document	All the design and material specifications used for the project	To compare the study result with its design and specifications	From ECDSW, and CRSG
2	Samples from the site	Sample of base course, sub base and sub grade materials from the selected points of study highway segment.	To conduct laboratory tests	From selected Highway segment(Tarcha-Omo River)
3	Laboratory reports	All essential previous laboratory reports of the selected segment of highway.	To compare the result with my funding and come in conclusion.	From ECDSW, and CRSG

3.4.3. Data collection

3.4.3.1.Primary Data

The primary data was collected through field visit on the selected highway segment in order to identify the deteriorated places and condition of drainage system; hence the data is used to evaluate the role of environmental factors on deterioration and the general performance of the road segment. Road condition survey has carried out to determine the present state and condition of the selected study road sections. The necessary primary data collected for this study was:

- ❖ Locations of the deteriorated section , such as;
  - ✓ Longitudinal and transverse cracking
  - ✓ pumping

- ✓ block cracking
- ✓ edge cracking
- ✓ raveling
- ✓ potholes
- ✓ rutting

- ❖ Width of lane, and shoulder, condition of shoulder and drainage system was observed and recorded.
- ❖ Sample of sub grade, sub base, base course materials for testing.

3.4.3.2.Secondary data

Collection of all the required input secondary data from the concerning bodies has conducted to accomplish this study. Those data's are:

- ✓ The full design of the road and its class from China railway seventh group co..ltd (CRSG) , contractor of the construction works Omo River- Tarcha road upgrading project
- ✓ Standard and specification, Ethiopian Roads Authority, Omo River –Tarcha road upgrading project.
- ✓ weather data records from the contractor and Metrology Agency

3.4.3.3.Data collection Method

3.4.3.3.1. Field observation

The data regarding the effectiveness of drainage in removing excess water was found through field observation on the selected highway segment. In addition to drainage the pavement condition was also observed. The condition of the drainage was captured by camera for same representative places.

Figure 3.5 Field observation and data collection *(By: Mengistu Bayu, 21th April, 2021)*

3.4.3.3.2. Laboratory test of the Engineering property of sampled materials

The objective of the laboratory test design was to ensure that suitable data were collected. A purposive approach was followed, and the data could be used to evaluate the impact of environmental factors on the performance of flexible pavement structure of the study segment. The material properties tested include; particle size distribution, Atterberg limits comprising of liquid limit and plastic limit tests, compaction tests and California bearing ratio (CBR). The Mr was predicted from the CBR result value of sampled materials. These tests were conducted to test likely the occurrence of failure due to the changing properties of pavement base course, sub base and sub grade material along selected highway segment due to environmental factors. Finally, the results were analyzed to determine the engineering properties of Materials in detail, which leading to the comparison with the standard specifications *(ERA, AASHTO)*. The results of laboratory were recorded and compared with existing laboratory result of selected highway segment in order to analyze the impact of environmental factors on the pavement structure to assure the result with national and international standards *(ERA, AASHTO)*.

Figure 3.6 Some of laboratory experiments *(By: Mengistu Bayu; 6th May, 2021)*

3.4.4. Sample size and sampling method

Purposive sampling was used for this study. During the site visits, the conditions of the pavement on the selected roads were visually assessed and pictures of the pavement were taken. In addition, the conditions of the drainages of selected highway were also assessed. The samples were collected from three different selected sampling stations of selected highway segment. Nine representative samples were collected from three stations, three samples from each station, three base courses, three sub bases and three sub grades. The samples were collected at a depth based on their respective layer thickness. For sampled materials laboratory test conducted for material property tests and finally compared with standards to check the quality of materials. The output of the test results were used to compare the material properties used with the standard specification of the project. The effectiveness of drainages and the visual observation of pavement through the selected segment were recorded and pictured.

Figure 3. 7 Sample Extraction and collection *(By: Mengistu Bayu 28th April, 2021)*

3.4.5. Data processing

Data processing has conducted through different laboratory tests to determine the variation in stiffness due to the environmental factors in order to compare with the material property during construction and also adequacy of underlain material to serve as;

- ✓ Subgrade
- ✓ Sub base and
- ✓ Base course material based on project specification and Ethiopian Roads Authority (ERA) standard specifications.

The laboratory tests on representative samples extracted from the site were conducted to characterize materials in relation with environmental factors to compare the test results with the standard specification and the material property during construction as well as with the existing condition of the pavement. Mean time laboratory test was conducted to determine the Mr values of the materials of representative sample. Hence the Mr value has high relation with the environmental factor (moisture).

3.5. Study Variables

3.5.1. Independent variable

They are related to specific objectives and to be measured, manipulated to determine its relationships to observed phenomenon. They are:

- ✓ Temperature
- ✓ Moisture
- ✓ Side drainage condition

3.5.2. Dependent variables

The out puts and factors observed in the study and measured to determine the effects of independent variable.

Performance of pavement structure

3.6. Data Analysis

After collection of all core information through site observation and laboratory the results are analyzed by using excel spread sheet and Microsoft word in the forms of table, graphs and equations. The laboratory tests conducted were Natural Moisture content (NMC), Atterberg limit, proctor, gradation and CBR. NMC is conducted to determine the Natural water content of the material through which the amount of water for the CBR is determined. Liquid limit and plastic limit were conducted to determine the index properties of sampled materials from each station. That is, important to determine the moisture sensitivity of materials. The modified proctor test which is used in the laboratory to show the relationship of moisture content and density of materials (compacted mass of materials in a unit volume through a range of moisture contents) was conducted for each sample from different stations. The gradation test was conducted to determine the degree of inhabitance of different size of materials. The current laboratory test result of CBR values have done and took the mean values of each tables. Samples collected from deteriorated place the CBR tests were carried out and comparisons were made between the CBR value of existing document and current CBR values. CBR values changed to resilient modulus by using *Equation 3.3 and 3.4* and the modulus of asphalt layer was determined by using *Equation 2.2.*

The data collected from repetitive observation, and secondary document analysis was analyzed to meet the specific objectives. Statistical Microsoft Excel 2007 software was employed to analyze the data. The analyzed data were presented using tables, graphs and charts. Using laboratory results the engineering properties of soil materials were determined as per specifications, and then classified as AASHTO Classifications. Defects on the pavement due to environmental factors were analyzed from the results measured in the field and careful observation taken at different section of the road section during different time. The side drainage effectiveness in removing excess water from the road was analyzed from visual observation. Based on field observation made, the adequacy of the drainage was analyzed.

3.7. Laboratory tests

To determine the engineering properties of materials and the relation of results with environmental factors, base course, sub base and sub grade were sampled from three representative stations and different tests have conducted. The basic test such as sieve analysis, Atterberg limit, natural moisture content, compaction, Atterberg limit, and CBR of materials are investigated separately to know the properties of materials as per the relevant code of standard and examine the result in relation with environmental factor (moisture).

3.7.1. Natural moisture content (NMC) (Method: AASHTO T-256)

The oven-drying method was used to determine the moisture contents of the samples. In the oven-drying method, small, representative specimens obtained from large bulk samples were weighed as sampled, then oven-dried at 105°C for 24 hours. The samples were then reweighted, and the difference in weight is assumed to be the weight of the water driven off during drying. The difference in weight is dividing by the weight of the dry soil, giving the water content on a dry weight basis. Hence the natural water content of each sampled materials from their respective station have conducted in this study after oven drying and the *equation 3.1* used to determine it.

$$NMC = \frac{Mass\ of\ Wet\ soil - Mass\ of\ Oven\ dry\ soil}{Mass\ of\ oven\ dry\ soil} * 100 \qquad 3.1$$

3.7.2. Atterbergs limits (Method: AASHTO - T89)

This lab test is performed to determine the plastic and liquid limits of a fine-grained material and then determine the value of plasticity of the material and which are based on the moisture content of the material. The water contents corresponding to the transition from one state to another are termed as Atterberg's Limits are recorded. The three Atterberg's limits, which are liquid limit, plastic limit, and shrinkage limits are the boundary between each of the two consecutive states of the soil-water phases. The liquid limit and plastic limit test are performed only on that portion of sampled materials, which passes the 425 mm (No. 40) Sieve.

A. Liquid Limit (AASHTO T89):

The liquid limit (LL) is the water content, expressed in %, at which the soil changes from a liquid state to a plastic state and water content at which the soil part cut using standard groove closes for about a distance of 13 cm (1/2 in) at 25 blows of the liquid limit machine (Casagrande Apparatus). The liquid limit of a soil highly depends upon the clay mineral present. The conventional liquid limit test is carried out in accordance of test procedures of AASHTO T 89. Hence the representative samples of each Material subjected to Atterberg limits testing to determine the consistency of the soils. An

Atterberg limits device was used to determine the liquid limit of each soil using the material passing through a 475 µm (No. 40) sieve. The liquid limit of each material was determined by using the Casagrande apparatus. The trails conducted for this study were 4 for each type of sampled material.

B. Plastic Limit (AASHTO T90):

The plastic limit (PL) is the water content, expressed in percentage, below which the soil stops behaving as a plastic material and it begin to crumble when rolled into a thread of soil of 3.0 mm diameter. The conventional plastic limit test is carried out as per the procedure of AASHTO T- 90.Two trails were conducted and the average of them recorded for this study.

C. Plasticity Index: -

Is the numerical difference between the liquid and plastic limit. Thus, it indicates the range of moisture content over which the soil remains deformable (in plastic state). Mathematical formula used to determine the plasticity Index of Material is shown in *Equation 3.2.*

$$pI = LL - PL \qquad 3.2$$

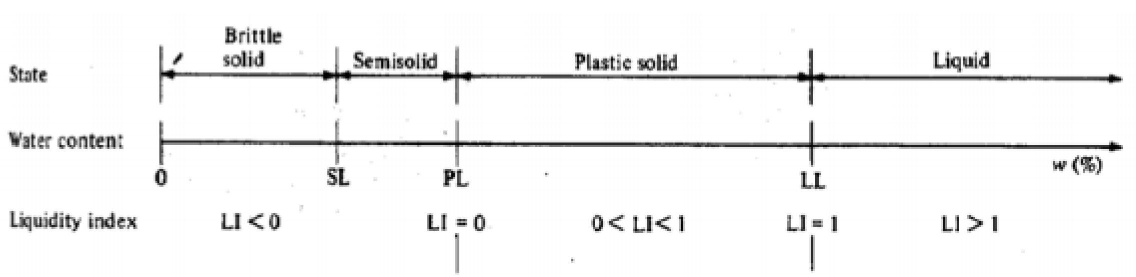

Figure 3. 8 The state of material with varies water content *(Dawson, 2008)*

Generally, soils having high values of liquid limit and plasticity index are poor as sub grades/engineering materials. Soils that cannot be rolled to a thread at any water content are termed as Non-Plastic (NP). "Limit of consistency" of fine grained soils was defined by Albert Attereberg.

3.7.3. Particle size distribution (Method**: AASHTO T- 27)**

Soil in nature exists in different sizes, shapes and appearance. Depending on these attributes, the soil at a site can be packed either densely or loosely. Hence, it is important to determine the percentage of various sized soil particles in a soil mass. This test is performed to determine the percentage of different grain sizes contained within a soil. The grain size analysis or gradation is measured in the laboratory using test: a mechanical sieve analysis for the sand and coarser fraction (soil particles larger than 0.075 (0.063) mm, Grain size Analysis was carried out to determine the grain size distribution of base course, sub-base and sub-grade materials and used in the classification of the soils can be obtained from the particle size distribution curve. The mechanical analysis consists of determination of the amount and portion of coarse material by the use of sieve. This test is performed to determine the percentage of different grain sizes contained within a soil or aggregate and it is used to determine the textural classification of soils (i.e., gravel, sand, silty clay, etc.) which in turn is useful in evaluating the engineering characteristics such as permeability, strength, and swelling potential in relation to environmental factor (moisture). Therefore, a mechanical sieve analysis was carried out in accordance of test procedures of AASHTOT-27 for materials.

3.7.4. Compaction test (Method: AASHTO -180)

This test is to obtain relationship between compacted dry density and soil moisture content, using manual compaction effect. The test is used to provide a guide for specification on field compaction. A modified version of the test was developed to allow the application of greater compaction effort (and achieve greater density), compacting the soil of the same height in five approximately equal layers using a 4.5kg hammer falling through 457mm height (modified or heavy compaction test). Material or soil compaction tests were performed using disturbed soil sample. The tests were done in the laboratory according to AASHTO T-180 (Modified Proctor Test) is used for base course, sub-base and subgrade materials. The sample was first air dried and sieved (usually through the 4.75-mm (No.4) sieve or 19 mm sieve), mixed thoroughly with water and then compacted in 5 layers. The mass of the compacted sample is measured (W), and a small sample taken to measure the corresponding moisture content (w). More water ware then added to the soil, and the procedure repeated until the dry density obtained decreases. The experiment was conducted to examine the moisture sensitivity of materials due to variation in moisture content because of environmental factor (moisture) in addition to obtaining compacted dry density and moisture content relation to achieve the maximum dry density at which the materials gains its high strength at certain compaction efforts.

At Natural moisture content higher than the OMC, the air and water in the soil mass tend to keep particles apart and prevent compaction. The dry density at higher moisture contents than OMC, decreases and the total voids decrease.

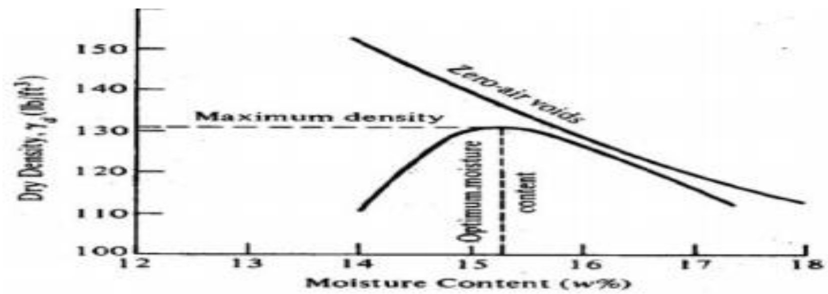

Figure 3.9 Density Moisture Relationship of pavement material *(AASHO, 1993)*

3.7.5. California Bearing ratio test (CBR):-

The strength of subgrade, sub-base and base course materials are expressed in terms of their California bearing ratio (CBR) values. The CBR value is a requirement is design for pavement materials of natural gravel or crushed rock the purpose of pavement construction. The CBR is a measure of shearing resistance of the material under controlled density and moisture conditions the test consists of causing a cylindrical plunger of 50 mm diameter to penetrate pavement component materials at 1.25 mm/minute. The Loads for 2.54 mm and 5.08 mm are recorded .This load is express as percentage of standard load value at respective deformation level to obtain CBR value. The test procedure is based on, American society for testing and materials, AASHTO T193. The CBR Value for a pavement material depends upon its density, molding moisture content and moisture content after soaking. The points CBR was conducted for base course, sub base and subgrade soil in the laboratory and design CBR value considered at 95% of MDD. The California bearing ratio (CBR) was used to evaluating the suitability of materials used base course, sub base and subgrade layers. Three point CBR test is made for all of the samples of different layers base course, sub-base and subgrade materials. Materials strength is classified according to the CBR values which determine the suitability of each type of materials for its respective layer with attention to environmental factors. The 4 days (96hr) soaked CBR tests were performed on the material samples to determine the sampled material shear strengths and predict the Mr values which determines the stiffness of material. The CBR number is obtained as the ratio of the unit load (in KN/m^2) required to effect a certain depth of penetration of the penetration piston in to a compacted specimen of material at some water content and density to the standard unit load. The results from the laboratory tests combined with the relevant pavement condition survey provide an evaluation of pavement performance in relation to environmental factors. Hence the Value of Mr is estimated from the calculation by using the formula described as (AASHO, 1993)

$$Mr(Mpa) = 1.7(CBR)^{1.2} \quad 3.3$$

for base course and sub base granular materials and

$$Mr(Mpa) = 10.342(CBR) \quad 3.4$$

for sub grade soil respectively.

And the amount of water to be added for the CBR in order to get the maximum shear strength is given in Equation 3.5

$$\text{Water to be Added} = \frac{\text{OMC} - \text{NMC}}{\text{NMC} + 100} * 6000 \quad 3.5$$

3.8. Determining the temperature of AC layer

It has been widely accepted that temperature mainly impacts the asphalt layer, where increase in temperature can reduce the stiffness of asphalt materials, which in turn limit the stress strain response of the pavement and reduce the ability of pavement structures to distribute loads from moving traffic *(AASHTO, 2009)*.The common empirical formula developed by AASHTO (1993) which was described in *Equation 2.2* was used to determine the Modulus of asphalt layer with respective to representative temperature value. The values determined by using formula

$E1(t) = 15000 - 7900 \times \log(t)$ given in *Equation 2.2*. The Mr value of asphalt layer with respective ambient temperature of months in year was represented in the form of graphs.

CHAPTER FOUR
RESULTS AND DISCUSSION

From both the field observation and the laboratory-based studies to achieve the objectives of the study, it was observed that the environmental factors (Temperature and moisture) have an impact on the performance of pavement structure.

4.1. Impact of temperature on the performance of pavement structures of selected highway segment

The impact of temperature variation on flexible pavement abundantly occurs on the asphalt layer and its impact is indirect to the rest of pavement structures *(Ksaibati, 2011 , Taha et al., 2013, AASHO, 1993).* A relationship between temperature and the elastic modulus of the asphalt mixtures of the motorways calculated using *Equation 2.2*, after determination of asphalt temperature by using *Equation 2.1* and the results of the respective modulus of resilient of asphalt with its respective temperature in accordance to variation in temperature with in season for sections has illustrated in Figure 4.1 and 4.2. And Tables 4.1 and 4.2 shows the Elastic modulus of AC with respective asphalt temperature for study section one and two respectively. The figures show the relationship between the pavement temperature and elastic modulus (E) for both sections of roads. It was observed that along the selected highway segment (50 km) there is different temperature from place to place. The maximum temperature ranges for first section of road is 20.76 to 23.46°C .The temperature near to Omo River (Gibe –III Dam), second section   is 21.56 to 33.12 °C and decrease approach to Waka town. And from the result it shows that, the less temperature in the first section, the highest is the modulus of elasticity of the asphalt and the higher is temperature in the second section, the less is modulus of elasticity of asphalt layer as given in Figure 4.2. This implies temperature has impact on AC layer of flexible pavement, which can also affect the stress resistance of beneath layers.

Table 4. 1 Elastic modulus of AC with respective asphalt temperature for section one

Month	Minimum Temperature (°C)	Maximum temperature (°C)	Monthly rainfall (mm)	T_{asp} (°C)	E (MPa)
January	12.49	22.94	45.12	12.04	6.46
February	12.84	23.46	59.69	12.48	6.34
March	12.54	23.01	137.61	12.10	6.44
April	12.41	22.58	177.27	11.94	6.50
May	12.19	21.94	198.44	11.67	6.57
June	12.23	21.37	184.18	11.72	6.56
July	11.76	20.76	237.48	11.13	6.73
August	11.74	21.12	256.96	11.10	6.74
September	11.83	20.91	177.01	11.22	6.51
October	12.07	21.76	116.52	11.52	6.62
November	12.26	22.32	76.22	11.76	6.55
December	12.29	22.54	53.08	11.80	6.54

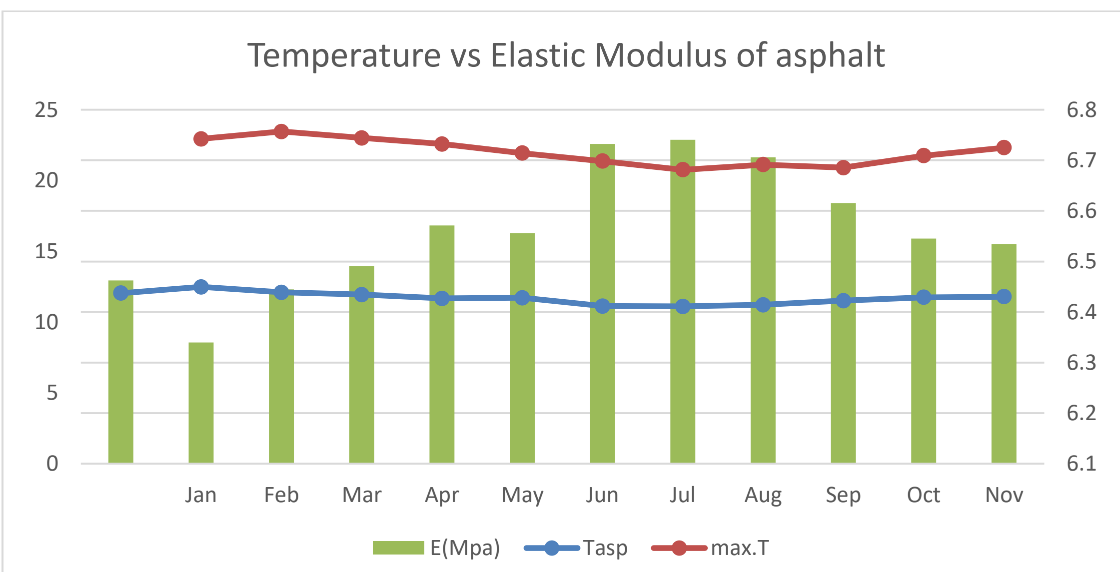

Figure 4. 1 Temperature vs Elastic Modulus of asphalt in section one study road

Table 4. 2 Elastic modulus of AC with respective asphalt temperature for section two

Month	Minimum Temperature (°C)	Maximum temperature (°C)	Monthly rainfall (mm)	T_{asp} (°C)	E (MPa)
January	17.56	33.00	0.00	37.68	2.55
February	16.88	32.07	0.00	36.52	2.66
March	21.00	33.12	32.00	37.83	2.54
April	19.56	31.00	53.56	35.18	2.78
May	18.21	29.45	89.11	33.24	3.00
June	18.06	27.00	91.33	30.18	3.32
July	17.89	27.11	98.53	30.32	3.30
August	13.13	21.56	133.32	23.38	4.20
September	13.89	23.43	101.76	25.72	3.86
October	14.11	25.00	77.89	27.68	3.61
November	14.76	25.87	0.00	28.77	3.50
December	19.41	31.89	0.00	36.30	2.68

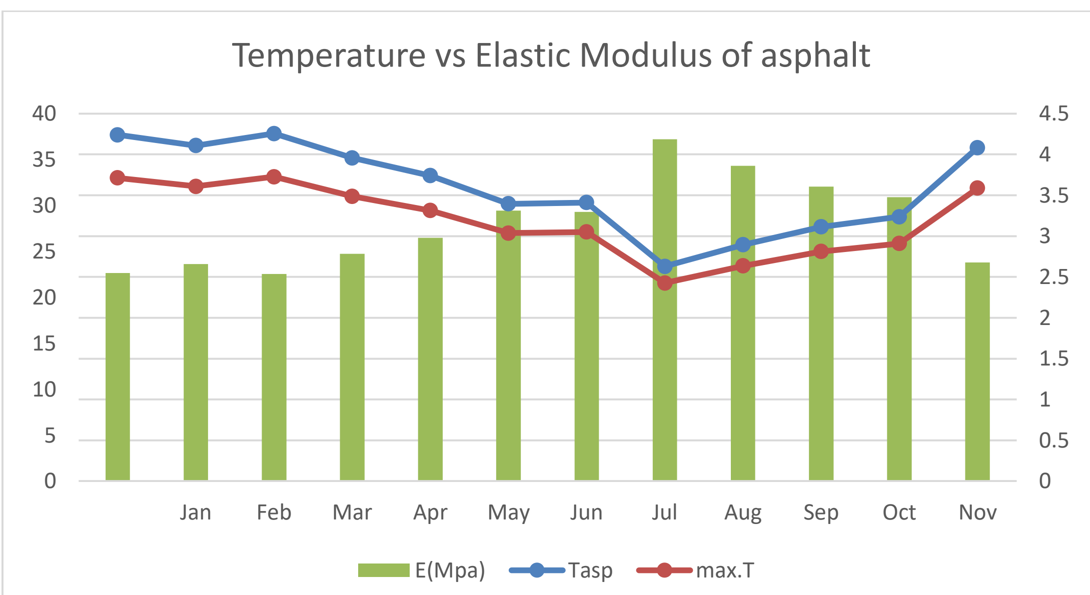

Figure 4. 2 Temperature vs Elastic Modulus of asphalt in section two study road

From the results described on Figure 4.1 and 4.2, at low temperatures the elastic modulus values increase and at high temperatures the elastic modulus values decrease. This finding is consistent with the rheological properties and viscosity, whereby the asphalt mixture is easily influenced by changes in temperature. Figure 4.3 shows the relationship between the pavement temperature and elastic modulus (E) for both sections.

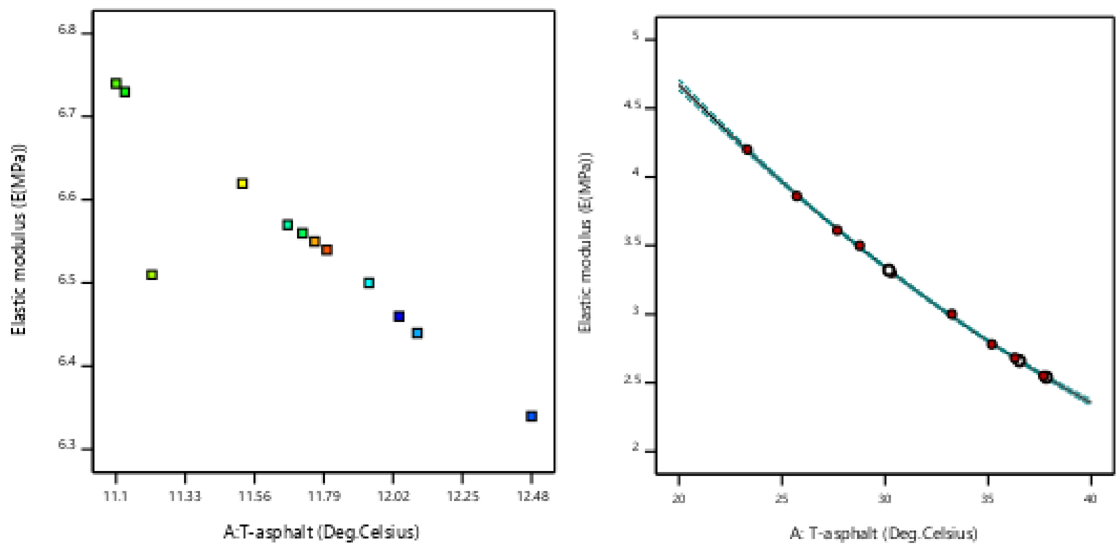

Figure 4. 3 Moduli versus temperature for section one and section two of study road using AASHTO (1993): Graph by Design Expert 11 software

a) section one b) section two

Based on the empirical equation of AASHTO (1993), and the relation conducted by using design Expert, Figure 4.3, both parameters show a good agreement, where R^2 is 0.9999 for second section and 0.9995 for the first one, equal to one (ideal conditions). At low temperatures the elastic modulus values increase and at high temperatures the elastic modulus values decrease. This implies that change in the pavement temperature directly affects the stiffness of the asphalt-bound layers, which alters the stress state throughout the pavement. This change in stress state can, in turn, affect the stiffness of the underlying unbound layers since they usually exhibit stress dependence. The structural capacity of the entire pavement system is thus affected by changes in pavement temperature and can cause early distress to flexible pavement structure as it was observed on the selected study area, Figure 4.4.

4.2. Impacts of Moisture Variation on performance of pavement

4.2.1. Material characterization

4.2.1.1.Natural Moisture Content (NMC)

For the samples collected from three representative stations NMC was determined. This NMC value determines the amount of water to be added to determine the CBR Value at which the material can attain its strength. It also indicates that during the time of field compaction, how much water could be showered or ripped to release its moisture in order to attain its maximum dry density. In a sense the value of NMC should be less than OMC.

The NMC and corresponding amount of water to be added and comparison of existing OMC and NMC for three samples are summarized in Table 4.3. The NMC is greater than OMC, this resulted with the amount of water to add for Compaction in order to get the maximum dry density as well as the strength of material that is expressed in terms of CBR Value is not needed or needed in small amount. This implies that the amount of moisture in the area is high and due to the entrance of water to the pavement structure, and the source of this water could be, high rainfall in the area, infiltration from the surrounding s through poor side ditch construction, poor disposal of ground water near the pavement structure and lack of treatment. This excessive moisture content in the pavement base, sub base, and subgrade soils can cause early distress and lead to a structural or functional failure of pavement *(salour, 2015b)*. Hence moisture related damage could caused reduction of base course, sub base and subgrade strength and stiffness. Due to these, base course and sub base materials, increased in moisture content could reduce the inter-particle friction and contact forces due to water lubrication effects between the contact areas of the particles and in subgrade soils, moisture variation could additionally affected the state of stress of the material through pore suction and pore pressure effects further it could reduce the Mr which is the measure of stiffness of materials *(Salour, 2015a)* Furthermore, a relatively rapid decrease in the level of serviceability could occur, because the pavement ability to transmit dynamic loads imposed by the traffic would be greatly weakened, therefore these caused early distress on the pavement base course, sub base and sub grade of selected study highway segment.

Hence, due to this factor in combination heavy axle loads could caused the deterioration on selected highway segment. These are: - rutting, longitudinal and traverse cracking, potholes, reveling, edge cracking, block cracking and pumping. In addition to these, there is also pavement surface deflection in some place. The percentage of distress on the selected highway segment within 50 km are analyzed and summarized in Figure 4.4. It implies in such climatic areas, the contractor, during construction and maintenance time, shall consider the condition of compaction under which the OMC that results with maximum dry density, the amount of water because the area is moist and the pavement structure gains its moisture from the natural environment at post construction and also it is essential to provide well designed and paved shoulder, excellent surface and sub-surface drainage system to control the entry of excess water from the surroundings to pavement structure and remove the excess water from pavement structure. Providing adequate drainage to a pavement system has been considered as an important design consideration to ensure satisfactory performance of the pavement, particularly from the perspective of life cycle cost and serviceability *(Rabab'ah, 2007).*

Table 4. 3 NMC and OMC of sampled Materials

Station	Material	OMC (%)	NMC (%)	Water to be added (ml)	Existing OMC (%)	Existing NMC (%)
89+320	BC	8.50	13.67	-273.00	10.95	3.39
	SB	18.38	23.50	-248.75	8.20	2.93
	SG	16.13	19.70	-178.95	20.50	5.59
104+540	BC	9.00	5.12	223.00	8.20	2.90
	SB	10.70	17.10	-327.93	14.00	7.60
	SG	12.51	30.06	-809.63	19.75	6.13
124+000	BC	5.83	5.45	21.54	9.33	3.42
	SB	8.40	14.40	-314.68	12.50	4.70
	SG	11.92	18.22	-319.75	21.82	5.34

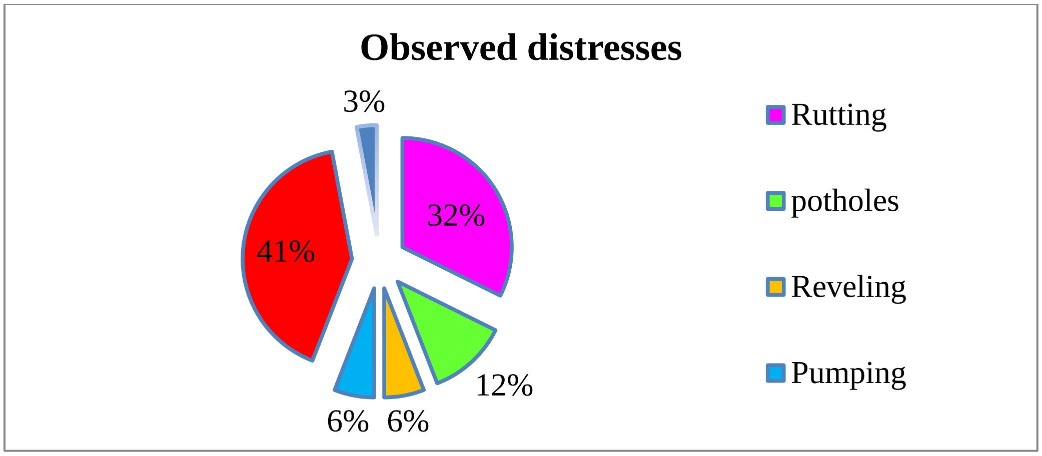

Figure 4. 4 Distresses observed on the selected highway segment

4.2.1.2. CBR and Mr

The 4 days (96hr) soaked CBR tests were performed on samples to determine the materials shear strengths. The CBR number is obtained as the ratio of the unit load (in KN/m2) required to effect a certain depth of penetration of the penetration piston in to a compacted specimen of material at some water content and density to the standard unit load. Meanwhile the Value of Mr which determines the stiffness of material is estimated from the calculation by using the formula described in *Equation 3.3* and *3.4* as per *(AASHO, 1993)* for base course and sub base granular materials and sub grade respectively.

From the result, at OMC, the samples were attained both MDD and CBR respectively. CBR values were increased gradually prior to its maximum level at OMC. Samples with highest NMC above the OMC level showed a dramatic decline of CBR value and resulted with decreased Mr.

The values of OMC, NMC, MDD, and CBR of sampled materials from each station are illustrated in Table 4.4. The NMC value exception to base course materials from station 104+540 and 124+000, are greater than OMC and could caused decline in CBR values. This implies the increased value of moisture could resulted in declined value of CBR as well as Mr, and the source of variation of moisture content could be , high rainfall in the area, infiltration from the surrounding through poor side ditch construction, poor disposal of ground water near the pavement structure.

Table 4. 4 OMC, NMC, MDD and CBR of sampled materials

Station	Material	OMC (%)	NMC (%)	MDD (%)	CBR (%)					
					2.00 mm			5.08 mm		
					No of blows			No of blows		
					10	30	65	10	30	65
89+320	BC	8.50	13.67	2.28	47.10	51.90	62.80	46.70	53.90	99.60
	SB	18.38	23.50	1.69	6.40	11.10	16.10	6.40	11.70	13.80
	SG	16.13	19.70	1.82	4.80	9.70	13.00	5.40	10.80	12.90
104+540	BC	9.00	5.12	2.34	34.60	56.60	128.8	39.40	70.50	126.00
	SB	10.9	17.1	2.09	15.90	23.80	22.50	19.10	24.50	23.40
	SG	12.51	30.06	1.71	4.80	6.50	4.90	6.50	6.50	5.40
124+000	BC	5.83	5.45	2.39	36.10	51.90	103.70	37.30	61.20	101.60
	SB	8.4	14.4	2.09	19.10	27.00	41.80	29.00	41.50	59.60
	SG	11.92	18.22	2.04	11.20	13.00	9.70	11.80	12.90	8.60

Hence for the comparison of existing (construction time) and post construction value of CBR and Mr are discussed as the following for each of specimens collected from the site.

4.2.1.2.1. Base course

Table 4.5, 4.6 and 4.7 shows the Californian bearing ratio values and the estimated Mr values of base course collected from three different places and took the average values of each .The sample was collected in range of existing laboratory result from previous result to compare with current test result with the specification under ERA for the project and variation could be due to variation of moisture in the project area. The comparison was taken after determination of resilient modulus from the conducted CBR laboratory result. From the results, the CBR and Mr Values of the materials dramatically decreased. The results show the specimens having high values of NMC than OMC has less value of CBR and Mr. This implies that, as the amount of moisture in base course of material increases the material in response could has decreased value of shear strength and stiffness which is expressed in terms of Mr to resist the load from heavy traffic. Hence the pavement has exposed to distresses described on Figure 4.4. Therefore approaches could be employed to control or reduce moisture problems are: Prevent moisture from entering the pavement system, use materials that are insensitive to the effects of moisture, incorporate design features to minimize moisture damage, quickly remove moisture that enters the pavement system and use of open graded materials as in order to remove excess moisture from pavement structure. The CBR and Mr values of base course material from sampled station are given in Tables 4.5 4.6, and 4.7 whereas the important data are given under *Appendix-B*

Table 4. 5 CBR values and the estimated Mr values of base course from station 89+320

Station 89+320						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	6.22	9.33	47.10	46.7	46.9	172.13
30	6.84	10.78	51.9	53.9	52.9	198.82
65	8.30	19.91	62.8	99.6	81.2	332.6
				Average	60.3	234.52

Table 4. 6 CBR values and the estimated Mr values of base course from station 104+540

Station 104+540						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	4.56	7.88	34.6	39.4	37.0	129.45
30	7.47	14.10	56.6	70.5	63.5	247.81
65	17.01	25.20	128.8	126.0	127.4	571.12
				Average	76.0	316.12

Table 4. 7 CBR values and the estimated Mr values of base course from station 124+000

Station 124+000						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	4.77	7.47	36.1	37.3	36.7	128.4
30	6.84	12.24	51.9	61.2	56.5	215.31
65	13.69	20.33	103.7	101.6	102.7	440.71
				Average	65.3	261.47

The existing CBR values and predicted Mr Values of the material are given in Table 4.6, 4.7 and 4.8 respectively.

Table 4. 8 The existing CBR values and Mr Values of base course, station 89+320

Station 89+320						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	7.22	11.61	48.2	46.7	47.45	174.56
30	9.96	19.29	75.4	96.4	85.9	355.83
65	816.59	23.64	125.7	118.2	121.95	541.84
				Average	85.1	357.41

Table 4. 9 The existing CBR values and Mr Values of base course, station 104+540

Station 104+540						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	6.33	12.45	39.56	46.7	43.13	155.66
30	8.6	20.42	68.77	96.4	82.56	339.41
65	18.23	26.77	133.56	1244.66	129.11	580.23
				Average	84.95	358.44

Table 4. 10 The existing CBR values and Mr Values of base course, station 124+000

Station 124+000						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	5.33	8.12	43.55	45.67	44.61	162.10
30	7.2	13.45	58.76	76.54	67.65	267.16
65	12.66	21.65	111.53	108.21	109.87	478.10
				Average	74.05	302.45

Comparing the results and the existing Value shows that, the Mr value of the material could decreased due to the moisture variation (*Mehrotra, 2014b*).

4.2.1.2.2. Sub base

Tables 4.11,4.12 and 4.13 shows the Californian bearing ratio values of sub base materials which was collected from three different places. From the laboratory results of CBR and predicted Mr Value of sampled materials and their existing values respectively, the Mr value decreased. *Appendix-B*

Table 4. 11 CBR values and the estimated Mr values of Sub base, station 89+320

Station 89+320						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	0.85	1.27	6.4	6.4	6.4	15.67
30	1.48	2.33	11.10	11.7	11..4	31.56
65	2.12	2.76	16.10	13.8	14.9	43.64
				Average	10.9	30.29

Table 4. 12 CBR values and the estimated Mr values of sub base, station 104+540

Station 104+540						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	2.12	3.82	15.90	19.10	17.50	52.78
30	3.18	4.88	23.80	24.50	24.10	77.60
65	2.97	4.66	22.50	23.40	22.90	73.00
				Average	21.50	67.80

Table 4. 13 CBR values and the estimated Mr values of Sub base from station 124+000

Station 124+000						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	2.54	5.94	19.10	29.80	24.40	78.66
30	3.60	8.27	27.00	41.50	34.20	118.00
65	5.51	11.87	41.80	60.00	50.70	188.83
				Average	36.40	128.50

The existing laboratory result of the sub base material is described in Table 4.14, 4.15 and 4.16.

Table 4. 14 The existing CBR values and Mr Values of Sub base, station 89+320

Station 89+320						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	2.54	5.94	19.10	29.80	24.45	78.77
30	3.60	8.27	27.00	41.50	34.25	118.04
65	5.51	11.87	59.60	41.80	50.7	189
				Average	36.47	128.61

Table 4. 15 The existing CBR values and Mr Values of Sub base, station 104+540

Station 104+540						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	2.43	3.64	18.35	28.54	223.45	74.91
30	3.58	5.65	38.78	26.91	32.85	112.26
65	3.35	6.32	47.86	39.64	43.75	158.35
				Average	33.35	115.17

Table 4. 16 The existing CBR values and Mr Values of Sub base, station 124+000

Station 124+000						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	2.84	6.14	20.10	31.20	25.65	83.44
30	4.66	8.64	32.00	39.55	35.78	124.38
65	5.62	12.34	61.87	49.54	49.54	183.82
				Average	37.00	130.56

4.2.1.2.3. Sub grade

In comparing the results with existing values of Mr which was determined from CBR, shows the Mr value of the sub grade soil is decreasing in each sampled station in comparison with the existing result. This is due to the Mr value of fine-grained subgrade is highly dependent on the moisture content *(AASHO, 1993, Dawson, 2008, Golchin et al., 2021)*. The moisture content usually varies throughout the service life of a pavement due to seasonal variation *(Qiao et al., 2013)*. Therefore increase in the moisture content, past the optimum conditions can be detrimental to fine-grained subgrade soils. If the pavement design fails to account for changes in the Mr value due to moisture fluctuations, it could lead to a decrease in the service life of a pavement. Hence the selected highway section for this study could be exposed to different distress as illustrated in Figure 4.4. The variation in moisture content in the sub grade soil of study highway segment could be high rainfall in the area, infiltration from the surroundings through poor side ditch construction, poor disposal of ground water near the pavement structure. And the considerable measurements shall be taken for proper maintenance and reconstruction of the pavement by blocking or reducing the entrances of water which causes the excess moisture to the sub grade soil which in turn reduces the stiffness of sub grade materials, such as use materials that are insensitive to the effects of moisture means of preventing moisture-accelerated damage is to use moisture insensitive or non-erodible and non-expansive materials that are less affected by the detrimental effects of moisture, Incorporate design features to minimize moisture damage an effective means for minimizing surface infiltration is to provide adequate cross-slopes and longitudinal slopes to drain water from the pavement surface quickly, provision of paved shoulder with appropriate slopes, well designed and effective side ditch. In general, the less time the water is allowed to stay on the pavement surface, shoulder or side ditch, the less moisture can infiltrate through joints and cracks *(Rabab'ah, 2007).* Tables 4.17, 4.18 and 4.19, show the CBR values of sub grade from the sample stations and other data are given under *Appendix-B.*

Table 4. 17 The CBR values and estimated Mr Values of Sub grade, station 89+320

Station 89+320						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	0.64	1.07	4.80	5.40	5.10	52.71
30	1.29	2.14	9.70	10.8	10.20	106.00
65	1.71	2.57	13.00	12.90	12.90	133.90
				Average	9.40	97.54

Table 4. 18 The CBR values and estimated Mr Values of Sub grade, station 104+540

Station 104+540						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	0.64	1.29	4.80	6.50	5.60	58.27
30	0.86	1.29	6.50	6.50	6.50	66.95
65	0.64	1.07	4.90	5.40	5.10	53.00
				Average	5.70	59.40

Table 4. 19 The CBR values and estimated Mr Values of Sub grade, station 124+000

Station 124+000						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.50	2.36	11.20	11.80	11.50	119.28
30	1.71	2.57	13.00	12.90	12.90	133.90
65	1.29	1.71	9.74	8.60	9.20	94.87
				Average	11.20	116.02

Table 4.20, 4.21 and 4.22 shows the existing laboratory result of CBR and the predicted Mr value

Table 4. 20 The existing CBR values and Mr Values of Sub grade, station 89+320

Station 89+320						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.71	3.64	12.80	18.30	15.55	160.82
30	2.57	4.93	19.50	24.70	22.10	228.56
65	3.64	5.57	28.00	27.60	27.80	287.51
				Average	21.82	225.63

Table 4. 21 The existing CBR values and Mr Values of Sub grade, station 104+540

Station 104+540						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	0.87	1.43	9.54	18.30	13.92	143.96
30	1.20	1.76	12.98	24.70	18.84	194.84
65	1.43	2.05	24.55	19.67	22.11	228.66
				Average	18.29	189.20

Table 4. 22 The existing CBR values and Mr Values of Sub grade, station124+000

Station 124+000						
	Load(KN)		CBR (%)		Ave. CBR (%)	Mr(Mpa)
Blows	2.54	5.08	2.54	5.08		
10	1.62	2.88	12.8	13.43	13.12	135.64
30	1.88	2.76	14.65	15.67	15.16	156.78
65	1.39	1.86	17.65	11.665	14.65	151.51
				Average	14.31	147.98

4.2.1.3.Moisture Density Relationship

4.2.1.3.1. Base course

In the first two stations, the result of MDD and OMC is attained at second trial, 4%. And in the last station it is at 2%. Hence from the result, the increase in moisture content results, decrease in dry density. This implies the high impact of moisture variation on the compaction properties of material during construction and after it. Because once the construction is completed, the material gains the moisture from the surrounding in different way from different source depending on the location of the project is appeared *(Ksaibati, 2011)*. These sources could be high rainfall in the area, infiltration from the surroundings through poor side ditch construction, poor disposal of ground water near the pavement structure. This property is also the same for sub base and subgrade materials sampled from the selected highway segment from the study area and all the results of laboratory are described in their respective graphs. And could caused the distress displayed in Figure 4.4. From graphs we can see that the moisture content is negative function of dry density. All the data are given under *Appendix- A*

Station 89+320

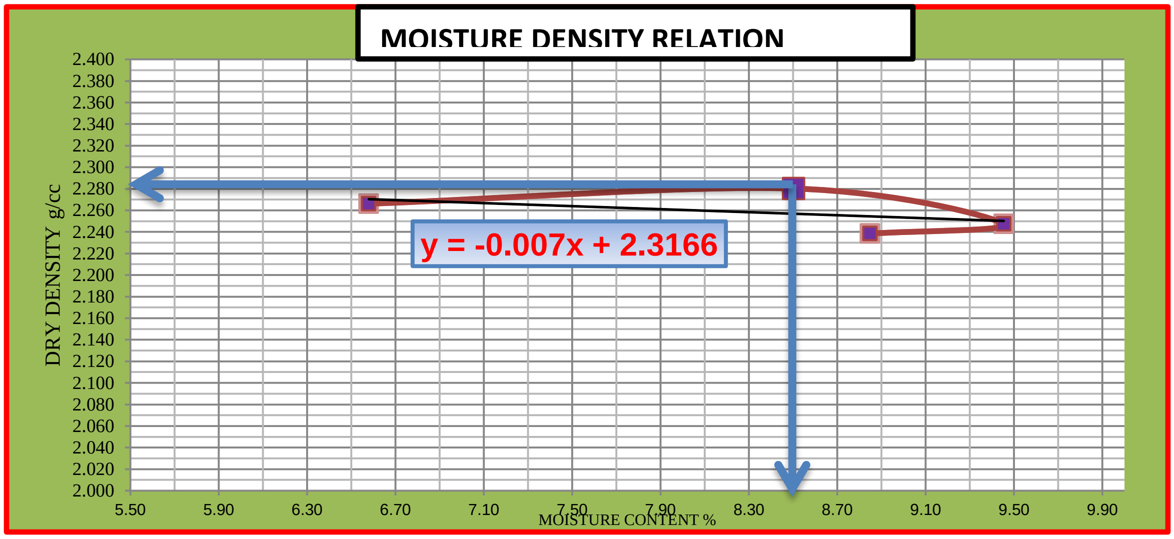

Figure 4. 5 Moisture density relationship of base course material from 89+320

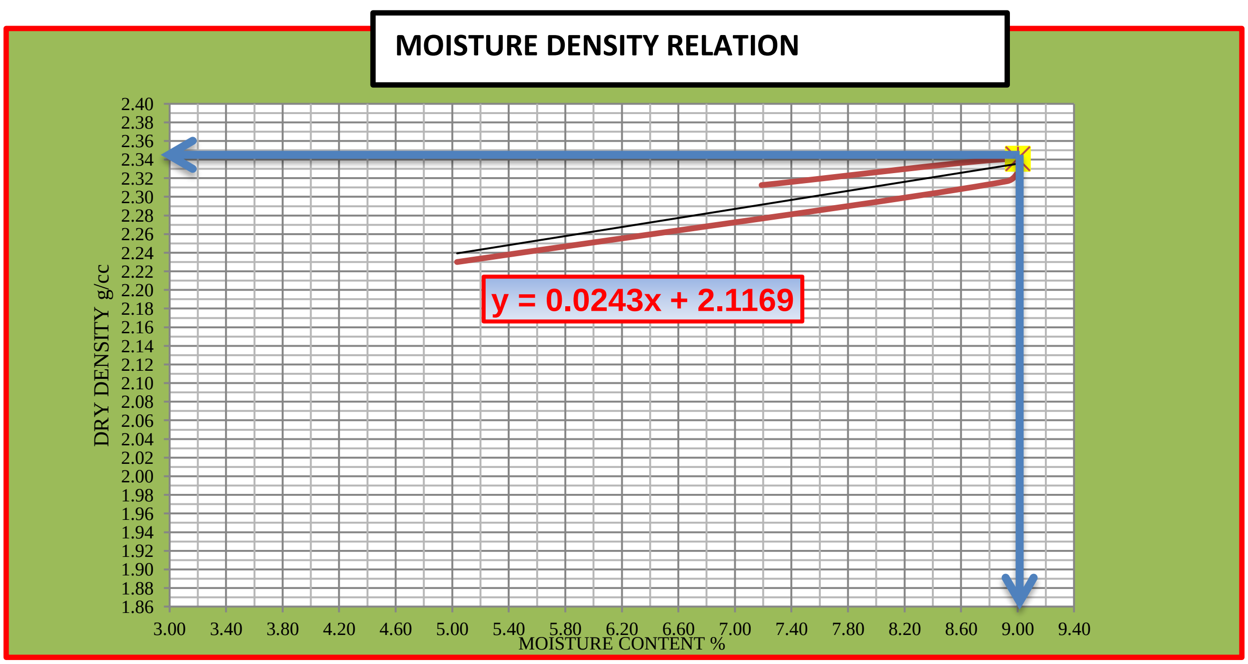

Figure 4. 6 Moisture density relationship of base course material from 104+540

Station 124+000

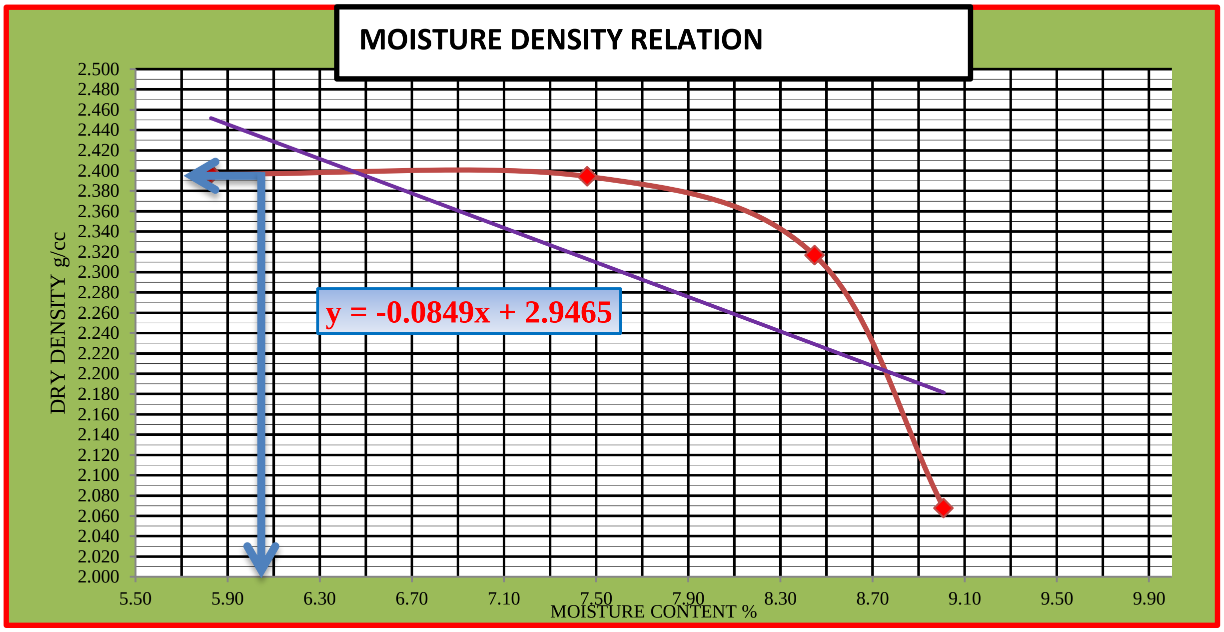

Figure 4. 7 Moisture density relationship of base course material from 124+000

4.2.1.3.2. Sub base

From the result, the moisture density relationship of sub base sampled material is described in the Figure 4.8, 4.9 and 4.10 with respect to its sample station. The result shows that the dry density is inversely proportional to the moisture content of the material. For the first two stations, i.e. stations 89+320 and 104+540 the maximum dry density is achieved at 4% that is first trial. And for the next trial the result is declining with increase moisture content 5% to 7%. For station 124+000 the maximum dry density is achieved at 5%, and the function is the same to first two stations. The data for experiment is given under *Appendix- A* and Figure 4.8,4.9 and 4.10 show the final result for each representative sample station.

Station 89+320

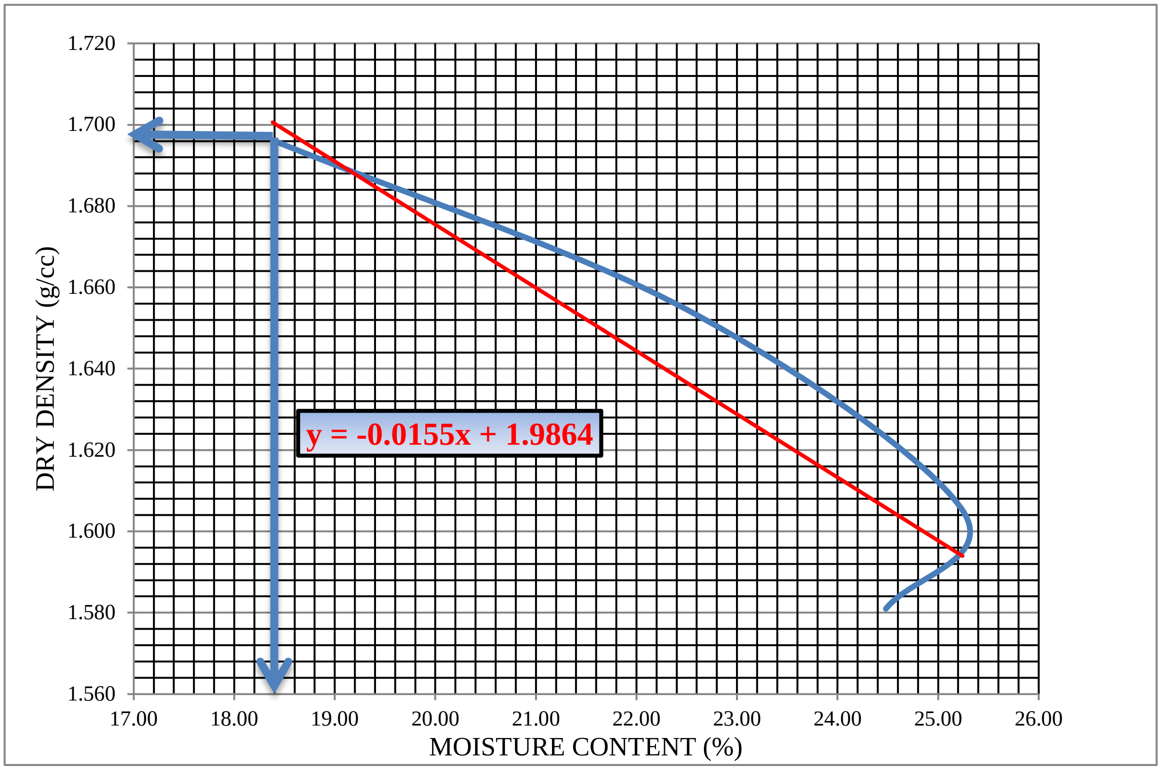

Figure 4. 8 Moisture density relationship of sub base material from 89+320

Station 104+540

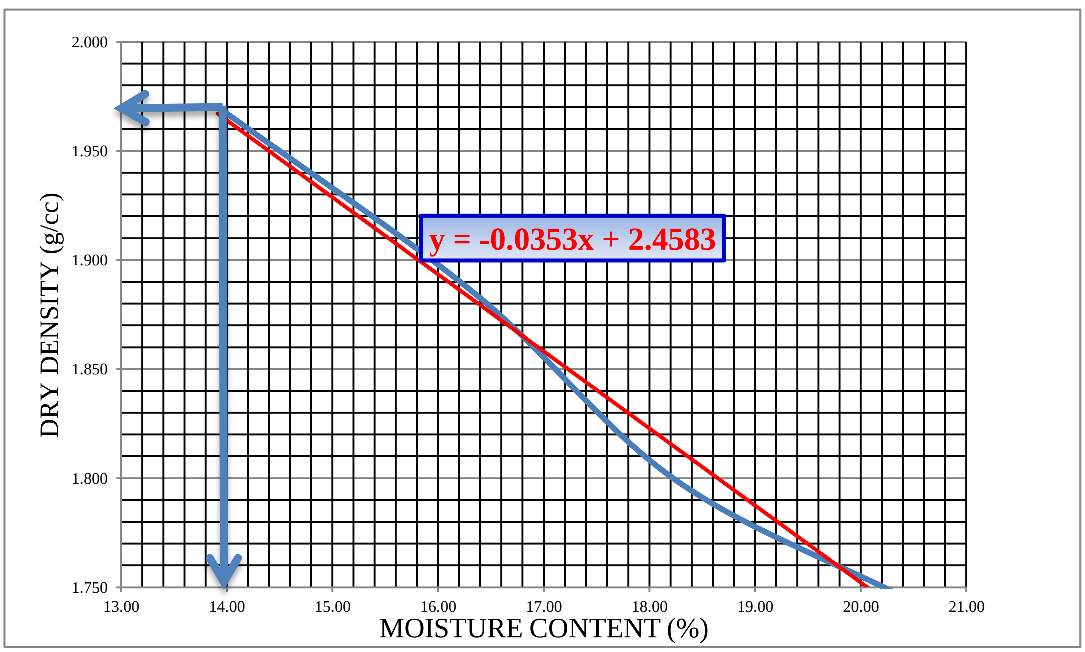

Figure 4. 9 Moisture density relationship of sub base material from 104+540

Station 124+000

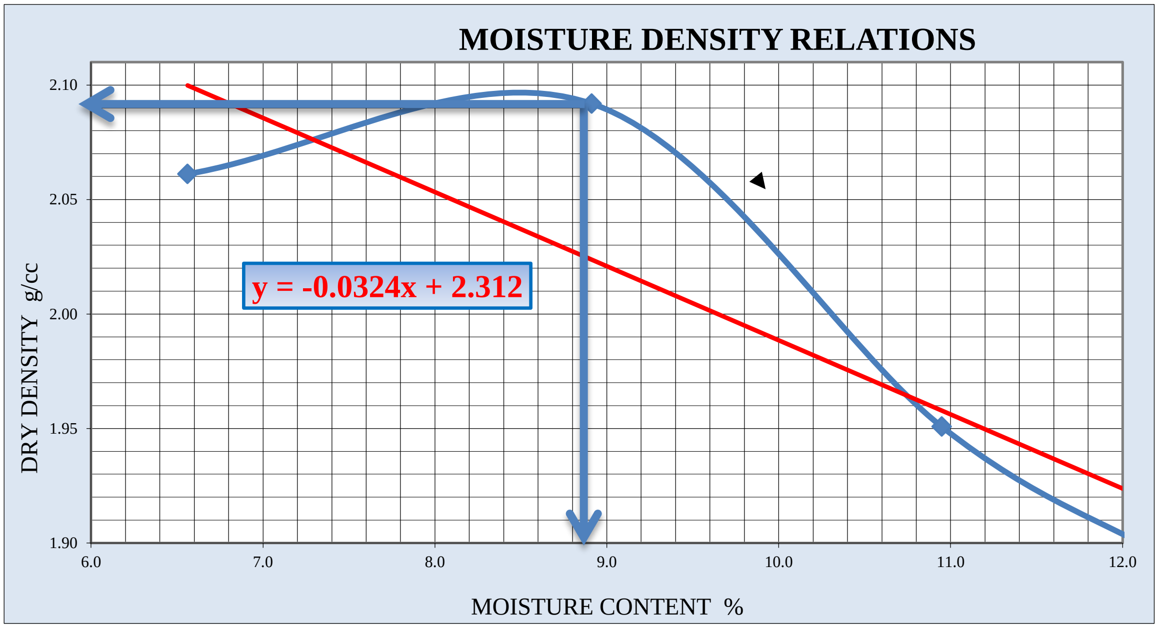

Figure 4. 10 Moisture density relationship of sub base material from 124+000

4.2.1.3.3. Sub grade

The moisture density relationship of representative sub grade sample from each sampling station is shown in the Figure 4.11, 4.12 and 4.13 and all the data are given under *Appendix A*. From the Figures, the dry density is inversely proportional to moisture content. As the moisture content increases, the dry density tends to lowest for each representative sample. This implies that, the variation in moisture content due to environmental condition could have impact on sub grade moisture density relationship, since the dry density of materials governs the compaction properties of materials through which the maximum strength is achieved. As result the material gets weak to resist the stress from upcoming load due to traffic. The stiffness of materials with respective MDD and OMC, and CBR value was determined by using the formula described in *Equation 3.4* and presented in section 4.2.1.2.Therefore the selected segment of highway could be exposed to the distress in combination with heavy traffic load.

Station 89+320

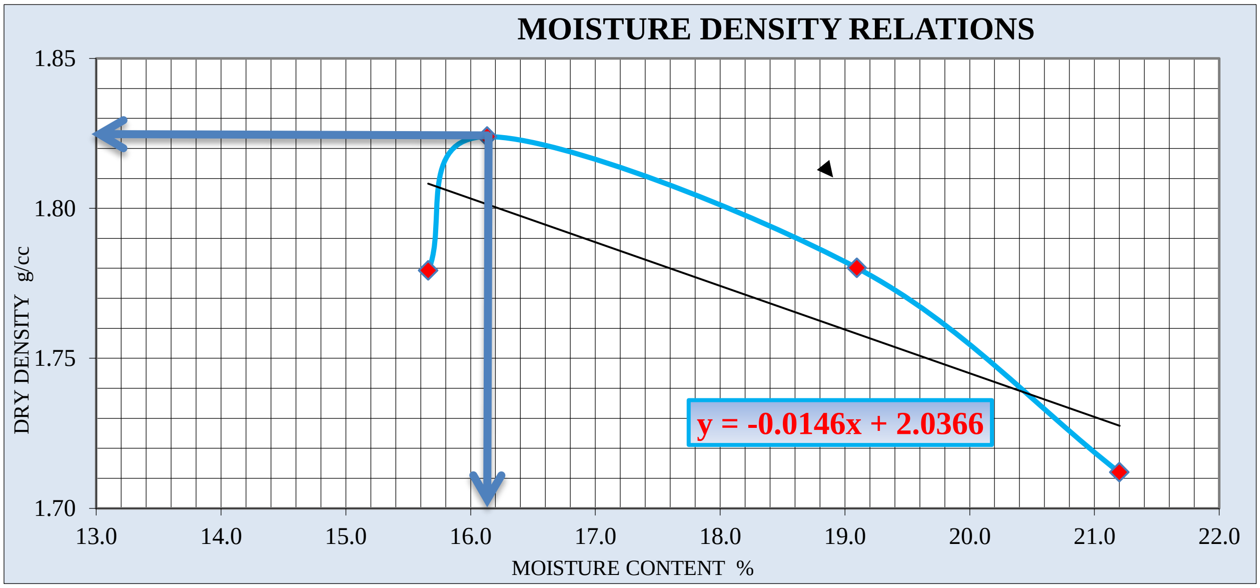

Figure 4. 11 Moisture density relationship of sub grade material from 89+320

Station 104+540

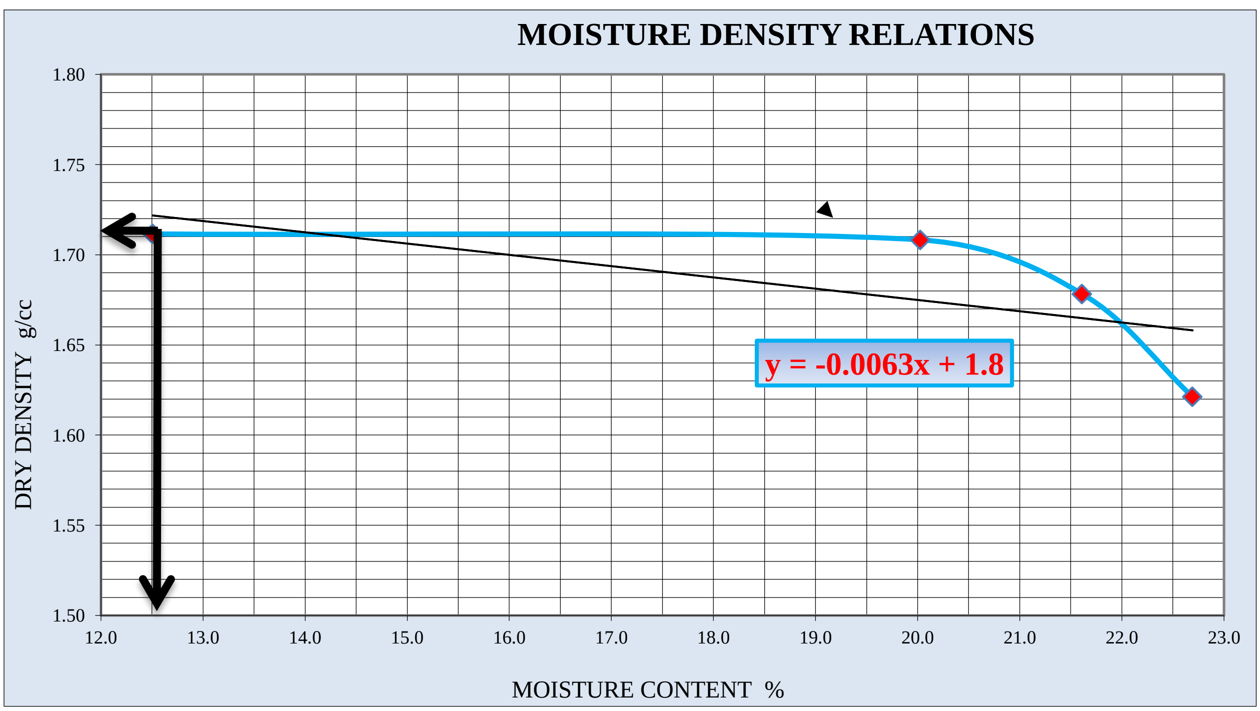

Figure 4. 12 Moisture density relationship of sub grade material from 104+540

Station 124+000

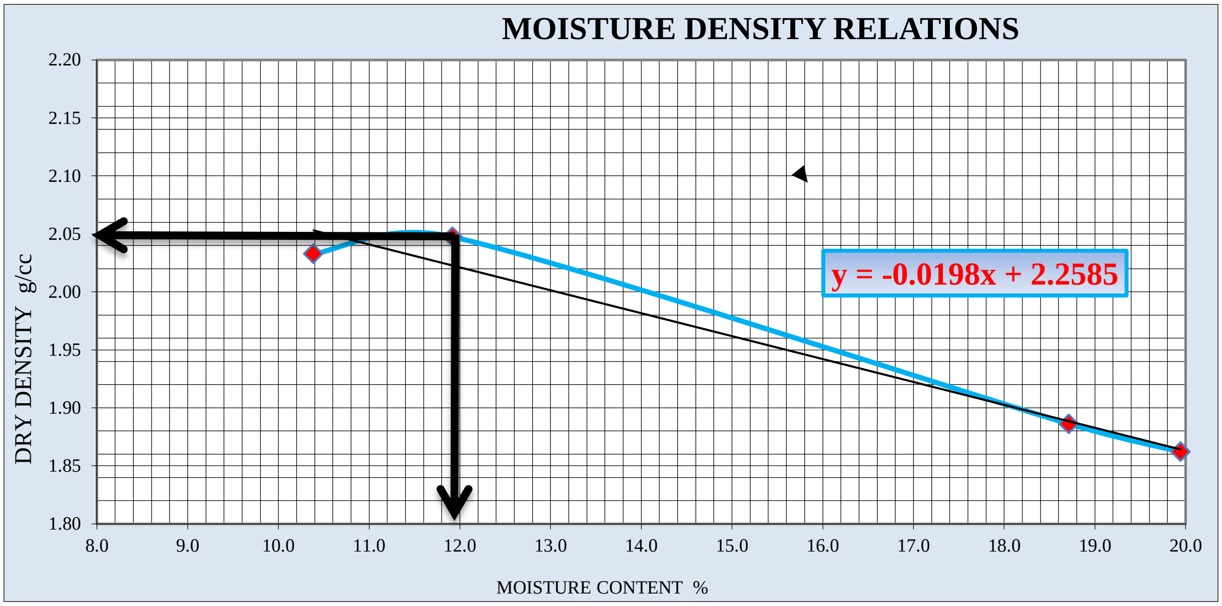

Figure 4. 13 Moisture density relationship of sub grade material from 124+000

4.2.1.4. Particle size Distribution

4.2.1.4.1. Base course and sub base

The grain size Analysis result for the first sample station analysis result is given in Table 4.23. From the table, the values of percent passing for lower and upper limit do not satisfy the specification of the material given for the project as per ERA specification. It shall be considered the influence of the porosity of materials posed by granular materials on the deformational behavior of the entire pavement structure. The study conducted by *(Tamrakar and Nazarian, 2016)* using aggregates with similar particle size distributions and fines content showed that the resilient modulus increased with in increasing the materials having maximum particle size (boulder), so that an increase in particle size (the boulder the material is) decreased the particle -to- particle contact resulting in a lower total deformation and consequently a higher deflection. Therefore it can be concluded that increase in finer materials, there could be increased moisture content because the finer materials block the space between the courser materials that allows the removal of excess water entering the pavement base/ sub base layers. As result there could be increased amount of moisture in pavement base/sub base, the result could be the decreased stiffness of materials and the observed distresses could be occurred on selected highway section for this study. This test result for both the rest of sample stations remains the same, but it satisfies the specification *(ERA, 2013).* The test results and table values are summarized for the rest of sample station are summarized in the form of table and chart in *Appendix -D.*

Table 4.23 Particle size distribution laboratory result for base course from station 89+320

Sieve size (mm)	Weight retained (g)	% retained	% passing	Specification (ERA, 2013)	
				Lower limit	Upper Limit
50	0.00	0.00	100.00	100.00	100.00
37.5	0.00	0.00	100.00	95.00	100.00
20	895.00	7.30	92.70	60.00	80.00
10	3860.00	31.60	61.00	40.00	60.00
5	1380.00	11.50	49.70	25.00	40.00
2.36	1160.00	9.50	40.20	15.00	30.00
0.425	1710.00	14.00	26.20	7.00	19.00
0.075	455.00	3.70	22.40	5.00	12.00
Pan	60.00	0.50			

The particle size distribution of sub base from station 89+320 is given in Table 4.24, the percentage passing No.200 sieve is 6.4% which is under the specification, hence the specification (ERA) is the % passing the No.200 sieve is less than 10 %. The upper and lower limit of the specification given to the sub base material is given in Table 4.24.

The particle size distribution of sub base for station 89+320 is described in *Appendix-D* in chart with respect to the upper and lower limit of the specification given to the sub base material

Table 4.24 Particle size distribution laboratory result for sub base from station 89+320

PARTICLE SIZE DISTRIBUTION (AASHTO T-27)							
Sieve size(mm)	Weight Retained(g)	% Retained	Cumm.Retained %	% Pass	Specification Limit (ERA) Grading		
63	0	0.0	0.0	100	100	100	
50	0	0.0	0.0	100	90	100	
25	2615	23.7	23.7	76.3	51	80	
4.75	4116	37.3	61.0	39.0	35	70	
0.075	3594	32.6	93.6	6.4	5	15	
Pan	701	6.4	100	0.0			
Total	11026	100					

4.2.1.4.2. Sub grade

The result of particle size distribution of sub grade soil is given in *Appendix -C* and the classification of soil based on the result found from particle size distribution and Atterberg's limit is given in the Table 4.25.

4.2.1.5.Atterberg's limits

The liquid limit, plastic limit and Plasticity index of sampled materials form each station are summarized in Table 4.25 and other reliable data are given under *Appendix -C*. From the chart, we see that as the moisture content increases, the result is decrease in number of blows. The results of liquid limit (LL), plastic limit (PL) and plastic index (PI) is summarized in Table 4.25 and all the data are presented in *Appendix -C.* The specification for the base course material of the project suggests that the maximum PI value is 6%. Hence, the result is under the specified specification for the first sample station 89+320. The results of remaining sampling station 104+540 and 1124+000 also given in Table 4.25 respectively. Thereby all the important data are given in *Appendix -C*

The specification for the sub base material of the project suggests that the maximum LL and PI value as 35% and12% respectively as maximum value. Based on this, the sub base material for the first and last stations satisfy the required condition however the third station material do not satisfy the condition.

The maximum LL and PI values of sub grade material under specification are 60% and 25% respectively. As the result determined from the laboratory and expressed in Table 4.23, the sub grade material of the first and last station do not satisfy the specification. Their respective LL and PI values are 58.36% and 26.23% for the first station and 58.97% and 25.7% for last station. The values of LL and PI for second station are 55.28% and 24.07% slightly satisfies the given condition under ERA specification. But incase variation in moisture content of materials after construction, the index properties of materials differs, from construction time gradually *(Pajtim Sulejmani, 2020)*. And this is in line with *(ERA, 2013),* After the pavement is constructed, the moisture content of the subgrade will generally change. Table 4.25 shows LL, PL, PI and classification of sampled material whereas the important laboratory data is given in *Appendix -C.*

Table 4. 25 LL, PL, PI and AASHTO classification of sampled Materials

station	Material Type	LL (%)	PL (%)	PI (%)	classification (AASHTO)	Useful type of significant constituent materials
89+320	Base course	27.7	24.5	4	A-2-4	Silty or clayey gravel and sand
	Sub base	26.2	23.9	2.3	A-2-4	Silty or clayey gravel and sand
	Sub grade	58.36	32.13	26.23	A-2-7	Silty or clayey gravel and sand
104+540	Base course	28.8	22.83	5.97	A-2-4	Silty or clayey gravel and sand
	Sub base	40.5	34.9	5.6	A-2-4	Silty or clayey gravel and sand
	Sub grade	55.2	31.21	24.07	A-2-7	Silty or clayey gravel and sand
124+000	Base course	25	28.4	-3.4	A-2-4	Silty or clayey gravel and sand
	Sub base	24.5	20	4.5	A-2-4	Silty or clayey gravel and sand
	Sub grade	60.1	33.27	26.83	A-2-7	Silty or clayey gravel and sand

Generally moisture is primarily important in the performance of pavement sub grade. As it was observed from laboratory experiment the moisture sensitivity of sub grade material are; dry density, LL, PI, CBR and Mr. Based on the result from laboratory during this study, and described in detail for each sampled soil, dry density against moisture content for each sample from three different stations, it is observed that dry density is negative function of moisture content and this has impact on the compaction properties of the sub grade material as moisture content increase the maximum dry density tends to low generally it is known that the moisture content of sub grade is at compaction, the field moisture content after a few year can be completely different *(Yaning Qiao 2020).* The shear strength of soil measured as CBR is very sensitive to change in moisture content through which the Mr value of the sub grade soil is determined from it which is a measure of relative shear strength to be inversely proportional to moisture content from the result. It was found that from the predicted value of Mr from CBR result during the study, the resilient Modulus of sub grade soil which is the measure of stiffness of it dramatically decreased, this could be the variation of moisture content in the sub grade due to environmental factor (moisture) and the moisture sensitive properties of material used as sub grade. Due to the moisture sensitive properties of sub grade soil as result of impacts of environmental factors some of the predominant defects could be occurred and observed were rutting, longitudinal and traverse cracking, potholes, reveling, edge cracking, block cracking and pumping as described in chart as Figure 4.4 .Different study have been conducted by different researchers that as moisture content increased, the resilient modulus decreased and larger sub grade deflections that can cause early pavement failure *(Xiao et al., 2012, Saevarsdottira and Erlingsson, 2013, Zumrawi, 2016, Wayessa and Abuye, 2019)* as it was also observed during the study. Hence subsequent drains in Tarcha-Omo River highways should be constructed, which satisfies standard construction and design for surface drainage, as well as level of ground water from sub grade soil, treatment techniques should be applied to for maintenance and reconstruction of distressed places.

4.3. Efficiency of the drainage system in removing the excess water from the pavement structure

Drainage quality is an important parameter which affects the highway pavement performance. The excessive water content in the pavement base, sub-base, and sub-grade soils can cause early distress and lead to a structural or functional failure of pavement.

From field observation made, along the selected highway segment for this study, there is no effective side drainage constructed. Even though the road has been constructed five years ago, the construction of side drain is not completed. In other hand, the drainage structures constructed are also not effective in removing the excess water from the pavement structure. In addition to this, as observed from field, in some places the constructed drainage structure is not properly managed and the construction procedure is not scientifically followed, see Figure 4.14b: the backfilling work not done, due to this the surface water is directly enter to the pavement structure easily figure 4.14a. For example, after digging and construction of town ditch the selected backfill material is not filled timely. This is abundant in Gessa town after construction of the pavement and U-ditch last three year.

Figure 4. 14 Ponding at sides of U-ditch at Gessa *(By: Mengistu Bayu, 21th April, 2021)*

a) ponding at side of U-ditch b) ponding duet to late backfill in U-ditch

Meantime, it was observed defects on drainage structures on the selected road: obstructions, silting ,ponding in drains and on shoulders, drain lining is damaged, defect at drain outfall, silting or debris blocking on culverts, erosion of culvert bed at outlet, minor headwall damage.

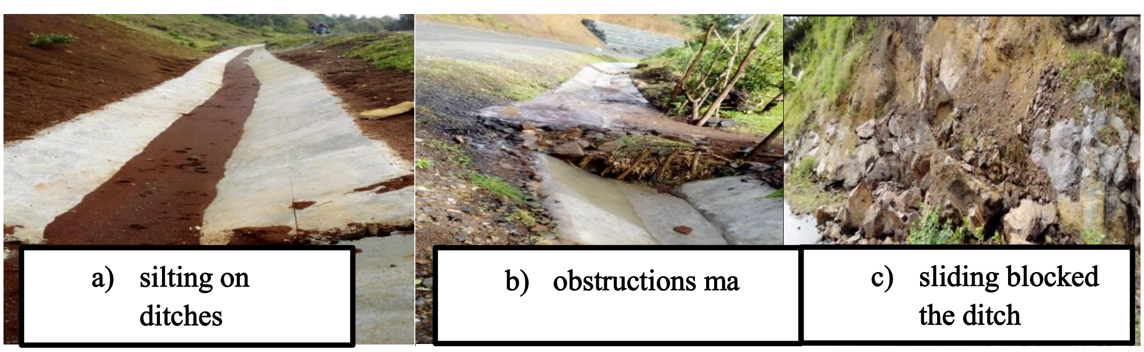

Figure 4. 15 Different Obstructions on side ditch *(By: Mengistu Bayu, 21th April, 2021)*

Generally different types of damages on the selected highway segment have observed during the study could be due to in adequacy of side ditches in removing water from the surface of pavement of from surroundings.

These are deformation, pumping, pothole and washing of the road pavement. The deformation observed was about 10 to 18 cm in all sampled places. Washing of the pavement shoulder also observed due to improper slope provided and this caused the edge break on different stations of the study segment. Figure4.16 shows different damages occurred to roads in the study area as it was observed in the field investigation.

Figure 4.16 Observed problems on shoulder *(By: Mengistu Bayu, 21th April, 2021)*

a) washing of pavement shoulder b) Edge breaking

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Based on the results obtained in the field observation and Laboratory investigation, the following conclusions have been drawn.

- Revelling and Block cracking is the observed distress on selected highway segment where the temperature is high near to Give-III (section two of study highway).
- The NMC of base course, sub base and sub grade materials sampled from station 89+320 is greater than OMC. That is 13.67%, 23.5% and 19.7% for base course, sub base and sub grade respectively whereas OMC from the result are 8.5%, 18.38% and 16.13%.The NMC of materials sampled from station 104+540 are; 5.12%, 17.1% and 30.06% for base course, sub base and sub grade and their respective OMC values are; 9%, 10.70% and 12.51%. The NMC and OMC of Materials from station 124+000 has determined and the values are; 5.45%, 14.40% and 18.22% and 5.83%, 8.40% and 11.92%. Form these, almost the values of OMC<NMC. This implies that the moisture content of pavement materials varies after construction due to fluctuation in moisture in the study area.
- The Mr Values of materials sampled from each station is less than compared with the Mr values of determined from CBR during the construction of the road five years ago. The Mr values various in each layer in each station in decreasing order. Mr Value for base course from each station varies 357.40 Mpa to 234.52 Mpa, 358.44 Mpa to 316.12 Mpa and 302.45 Mpa to 261.47 Mpa for station 89+320, 104+540 and 124+000. For sub base it varies 128.61 Mpa to 30.29Mpa, 115.17 Mpa to 67.80 Mpa and 130.50 Mpa to 128.50 Mpa for station 89+320, 104+540 and 124+000 respectively. The result of Mr for sub grade soil varies 225.63 Mpa to 97.54 Mpa, 189.20 Mpa to 59.40 Mpa and 147.98 Mpa to 116.02 Mpa from station 89+320, 104+540 and 124+000. The decreasing values of Mr values indicates that, the Mr which is the measure of stiffness of base course, sub base and sub grade Material varies with moisture content fluctuations. One of the reasons for reduced resilient modulus with increased moisture content is lubricating effect of water, causing lower inter-particle forces. Hence the environmental factor (moisture) is major constraint in

pavement life after it has been constructed. Therefore decrease in Mr could lead to increased deflection of pavement which results in shortening of the service life of the pavement.

- It was determined 35 distresses in different places as described in Figure 4.4.The observed distresses are Edge Cracking 41%, Rutting 32%, Potholes 12%, Pumping 6%, Revelling 6% and 3% of block cracking. This indicates the majority of extents of the distress were edge breaking. This is due to lack of support of the shoulder/non-sealed shoulder, excessive moisture, hence the shoulder is washed by water from surface.32% of rutting has observed. The type of rutting observed was wide rutting. This indicates failure of sub grade materials. The observed pothole was 12% and it is observed in flat terrain. Revelling was observed station near to Gibe-III or Gebeta Lahager Halala Kela claster where the temperature is high. Pumping is observed more between waka and Gessa Towns where the annual rain fall goes more than 500 ml and extremely high from March-August. This indicates that the rain fall has considerable effect on pavement unbounded and sub grade material. Due to high rain fall in the area, there might be change in ground water level and cause deflection on sub grade layer of soil; this is highly manifested at station 89+320 as shown in Figure 3.5.
- The sub grade soils sampled from three representatives are grouped in A-2-7 as per AASHTO soil classification rating as to good as sub grade material.
- The quality of drainage quality is poor as observed water is logged at side drains. Pavement drainage is most beneficial when excessive moisture can be rapidly removed from the structure, ideally within 2 hours and preferably within 24 hours; however, the benefits derived from a subsurface drainage system will vary depending on pavement type, annual rainfall, subgrade conditions, geometric design, and design of the overall pavement system.
- Dry density, Atterberg’s limit and Mr are sensitive to moisture content of sub grade material at compaction and the field moisture content certain year after construction due to heavy rain fall, poor drainage, and sub-surface water level.

5.2. Recommendation

- For Ethiopian Road Authority (ERA), it is better in the future design and construction of flexible pavement, the pavement layer thickness should be considerably increased or boulder base and sub base with less fine materials should be used in cases of highways in areas where the yearly rain fall >2000 mm and surrounded by agriculture lands to reduce the higher distress caused by variations in water content during the highway service life after construction and the thickness of AC layer should be considered where the temperature is high.
- Provide the subgrade soil with a minimum diameter of grain size with corresponding to 10 % finer (weight) in the distribution to overcome flow of water through them that can cause adverse effects on the strength properties of subgrade soil and boulder materials for effective removal of sub surface water carefully with considerable slope.
- For Consulting Firms and Contractors', attention should be given to construction of side and cross drainage structures after preparation of sub grade layer prior to starting the overlaying pavement layers.
- Excess moisture should be eliminated, and the shoulders rebuilt with good materials.

For Future Researchers

- Further study should be carried out on the other factors that cause variation of moisture or saturation in a subgrade soil.
- Further study should be carried out on the depth of ground water and its fluctuation at different season.
- The Mr value of current study was predicted from CBR test results of materials. The Mr test alone shall conduct in future study. Additional test parameters like unconfined compressive strength; volumetric shrinkage, and mineralogical tests should also be performed to have more accurate test results.

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Appendices