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ANALYSIS OF PAVEMENT DRAINAGE SYSTEM: A CASE STUDY ALONG BURE TO INJIBARA TOWN ROAD SECTION IN AMAHRA REGION

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Abstract—Moisture has significantly influenced the performance of flexible pavements. Effective drainage systems are essential for maintaining pavement integrity by rapidly removing moisture from the subgrade. This study investigates the drainage system of the Bure to Injibara road in Ethiopia's Amhara region, focusing on identifying the root causes of drainage issues and evaluating the quality of the pavement layers. Data were collected from both primary and secondary sources, including site visits and field studies. Descriptive and experimental research methodologies were employed to assess the current drainage conditions and understand the underlying issues. The descriptive analysis centered on the existing pavement drainage system and factors contributing to drainage inefficiencies. Laboratory tests were conducted on selected sections to evaluate the properties of pavement material layers. The Drainage Requirements in Pavement (DRIP) Software was used to assess drainage quality, and the direct runoff for specific rainfall events was estimated using the soil conservation service (SCS) curve number method. The key finding indicates that the cross-slope time-to-drain is rated as good, while the uniform slope time-to-drain is fair. Visual inspections, material sampling, and laboratory investigations identified critical issues, including climatic conditions, inadequate pavement material properties, the absence of inlets, improper disposal of solid waste into the drain, poor construction quality, environmental impacts, topographical challenges, and suboptimal drainage characteristics. Specific drainage problems included low drain capacity, soil accumulation, lack of inlets, improper waste disposal, and malfunctioning crossing culverts. The study recommends adherence to design manuals, regular maintenance schedules, cleaning, and systematic cleaning to enhance drainage performance. Additionally, the redesign and reconstruction of drainage facilities are proposed to mitigate issues related to poor workmanship. The results show that flexible pavements without drainage layers lead to fully saturated subgrades, compromising their performance. Incorporating drainage layers and edge drains significantly reduces subgrade moisture content, thereby enhancing pavement durability and performance.

Keywords: Adequate drainage, drainage system, pavement damage, poor drainage effect, pavement performance

1.0 INTRODUCTION

Moisture significantly impacts the performance of the flexible pavement. To prevent moisture from penetrating pavement subgrade, it is essential to remove water from these pavements as quickly as possible. Water can easily infiltrate pavement structures, and factors like heavy traffic and freezing temperatures can further compromise their integrity. A well-designed, constructed, and maintained subsurface drainage system is crucial for rapidly removing moisture that may enter the pavement structure, thereby reducing distress such as fatigue cracking and rutting. Conversely, poorly designed or maintained drainage systems can trap moisture, accelerating pavement deterioration beyond what would occur without any drainage system. The primary function of highway pavement is to transmit vehicle loads to the subgrade, utilizing multiple layers of processed materials above a natural soil subgrade. Effective highway drainage is a crucial component of road design and construction, as it collects and disposes of excess water. The main sources of road drainage include surface runoff from surrounding areas, rainfall, and groundwater rising through capillary action [1]. The efficiency of a nation's road transportation system significantly influences its economic and social development. The substantial investment in road infrastructure underscores the importance of well-constructed roads, which are vital for enhancing the socioeconomic condition of a country [2]. Standing water on any pavement type is a major contributor to deterioration issues, as it obstructs traffic and reduces the effective driving width. A well-planned and maintained road drainage system effectively mitigates the environmental impact of runoff on nearby water bodies, enhances road safety, and extends the lifespan of the road surface and associated infrastructure. However, urban development often leads to increased improved surfaces, drainage patterns, and accelerated overland flow, resulting in flooding and soil degradation [3]. In urban settings, inadequate integration of road and stormwater drainage networks poses a significant challenge. Runoff generated within urban areas cannot be safely discharged into the final receiving system, leading to environmental issues such as overtopping, erosion, pollution, and traffic disruption [4]. Moisture from poorly designed drainage systems can degrade the performance of flexible pavements over time, leading to deformation, fatigue cracking, instability, and overall deterioration which ultimately reduce the serviceability and durability [5].

The Bure to Injibara road section is a crucial part of Ethiopia's primary asphalt road network, linking the towns of Bure and Injibara in the Amhara Region. This road primarily accommodates mixed traffic, including passenger vehicles, heavy trucks, and public transport buses. Due to its significant role in regional connectivity, it experiences moderate to high volumes of commercial and agricultural transport. The Average Daily Traffic (ADT) is estimated to be medium compared to other major highways in Ethiopia, with traffic counts typically ranging from 1,000 to 3,000 vehicles per day. Specific data can be obtained from regional transport offices or through surveys. The road features asphalt concrete (AC) pavement, designed to withstand regional traffic demands and weather conditions. However, it has a history of drainage problems, including, Clogging of Side Drains, Inadequate Cross Drainage Structures, and Improper Slope and Camber. The types of drainage are typically trapezoidal or V-shaped, these are designed to manage runoff but often become clogged with sediment and debris. The study identified that inadequate drainage design, poor maintenance practices, low-quality materials, and lack of local practice norms contribute to the issues. Addressing these factors during planning and implementation, alongside enhancing pavement structures, is vital to ensuring their longevity throughout the intended design life [6]. Understanding the physics of water flow on roads is essential, as increased water content in granular materials accelerates road deterioration, reducing shear strength, causing differential swelling in expansive subgrade soils, and leading to various forms of pavement layer damage such as base and subbase layers. To mitigate these effects, it is generally preferred to keep the water content low on the road. Case studies help to better understand the various impacts of water on roadways. Failures that happen quickly and catastrophically cause harm, fatalities, and property damage destruction [7].

In Ethiopia, both urban and rural areas face challenges with insufficient capacity and poor longitudinal slopes in side drains, resulting in poor drainage conditions. These inadequacies compounded by insufficient regulatory policies and public awareness, contribute to increased moisture content, and various forms of pavement deterioration, including mud pumping, corrugation, and edge cutting [8]. This study aims to investigate the effects of inadequate pavement drainage systems on road surface performance, particularly in the Bure to Injibara highway corridor, where pavement deterioration is prevalent. Given the frequent premature failure of flexible pavements, often occurring before their design life, this study is crucial. Inadequate drainage capacity significantly contributes to both functional and structural failures. The study provides highlights into the impact of poor drainage on pavement performance and addresses critical issues related to road maintenance. Ethiopia experiences significant rainfall, and the integration of the water drainage and transportation networks is often lacking. The Bure to Injibara road suffers from widespread pavement deterioration due to various undefined factors. Providing and maintaining effective drainage systems is challenging in many Ethiopian cities and towns. The current drainage system has poor slope conditions affecting pavement and shoulder performance, which compromises efficiency and safety, leading to increased vehicle operating costs, accidents, pollution, and hindrances to mobility. Previous studies have not specifically addressed the pavement drainage system in this area, indicating a need for further research into such as pavement material characteristics, drainage quality using software like Drainage Requirement in Pavement (DRIP), and other relevant tests. This study aims to fill these gaps and assess drainage quality to inform sustainable pavement design and operation.

The general objective is to analyze the pavement drainage system of the Bure to Injibara asphalt road section and propose remedial measures. The specific objectives include evaluating the existing hydrological conditions affecting asphalt pavement layers, analyzing the drainage system to pavement properties using DRIP software, and suggesting possible remedial measures to address drainage issues. The finding will be valuable for future pavement drainage projects in the area, examining existing systems and suggesting improvements to prevent ineffective functioning. This research will benefit academics and researchers focusing on pavement drainage systems, urban drainage, and stormwater management. Ultimately, the study seeks to recommend enhancements to ensure the long-term viability of the Bure to Injibara asphalt road by identifying drainage issues, poor-quality materials, and inadequate workmanship. Understanding the root causes of these failures is essential for effective pavement maintenance and improving construction techniques. This study focuses on examining the drainage problems within the case study of the Bure to Injibara asphalt road segment.

2.0 MATERIALS AND METHODS

This chapter of the research work presents the overall materials, methods, procedures, and techniques used to conduct the research problem. Disturbed samples were taken manually using hand tools such as shovels and digging bars. The depth, at which sampling was made, was predicted from the thickness recommended by Parkman consultant's design recommendation. Excavated pavement layer materials, such as subgrade, subbase, and base course, were employed in the field, along with equipment such as cylinders, scarpers with handles, metal containers, and balances. In laboratory testing, disturbed subgrade, subbase, and base course material from four stations was employed, as well as distilled water for compaction, the Atterberg limit, and sieve analysis tests. The Drainage Requirements in Pavements (DRIP) software is a computational tool designed to evaluate and optimize drainage systems within pavement structures. It analyzes water flow through various pavement layers and calculates the time needed for water to exit the system, which is crucial for maintaining structural integrity and longevity. DRIP simulates infiltration and flow, estimating drainage times to calculate the drainage coefficient and assess the pavement's resistance to water-induced damage. However, the software has several limitations includes DRIP software assumes that pavement layers are homogeneous and isotropic, which may not accurately reflect real-world conditions where materials vary in composition and permeability, The software may oversimplify the interactions between multiple pavement layers and external factors, such as groundwater pressure and The reliability of DRIP results dependence on input accuracy hinges on the quality of input data; inaccurate data entry can lead to misleading conclusions.

2.1 Study Area

The study was carried out on the 47-kilometer Bure to Injibara Asphalt Pavement Road, which is situated in the Amhara regional state of western Ethiopia's highlands. Figure 1 illustrates this route. This region consists of a large mountainous mass that slopes gently from east to west. Bure is located between latitude $10^{0}17'$ and $10^{0}49'$ north, and longitude $37^{0}00'$ and $37^{0}11'$ east. Injibara, the administrative center of Awi Zone, is located at 10°57' North and 36°56' East, at an elevation of 2560 meters above sea level. Injibara has an average annual temperature of 22 °C and receives approximately 600 mm of rainfall annually.

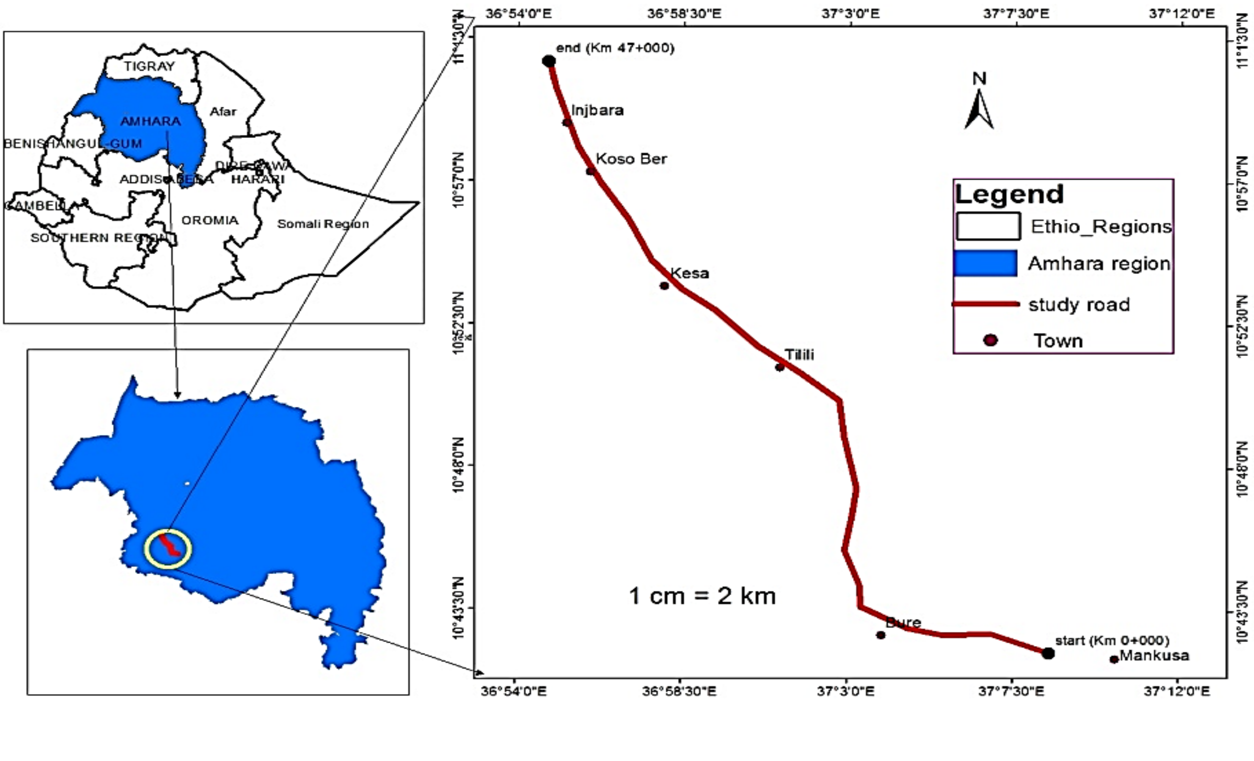

Figure 1 Map of the study area

2.2 Research Method

The field inspection assesses road conditions, including several failed road stations, road drainage, and topographic characteristics. The investigation began with a visual evaluation of the entire route, followed by the selection and marking of representative stations for key failed road places. The analysis results provide a comprehensive understanding of the current drainage system along the Bure to Injibara road corridor and suggest alternatives for designing suitable drainage solutions. After that, manual sampling was used to take representative samples from each of the pavement layers of the identified failed stations and send them to the Debre Markos Road Maintenance District laboratory office of the Ethiopian Road Authority.

2.3 Research Design

An experimental study design was employed to achieve the research's ultimate purpose. Data was collected and analyzed for pavement drainage systems to quantify pavement performance. The two activities that make up an experimental research design are fieldwork and laboratory tests. To identify potential causes of pavement drainage system failure, fieldwork includes close observation of the road environment and sampling from multiple sites. The engineering characteristics of base course, subbase, and subgrade materials about road surface conditions are also tested in laboratories.

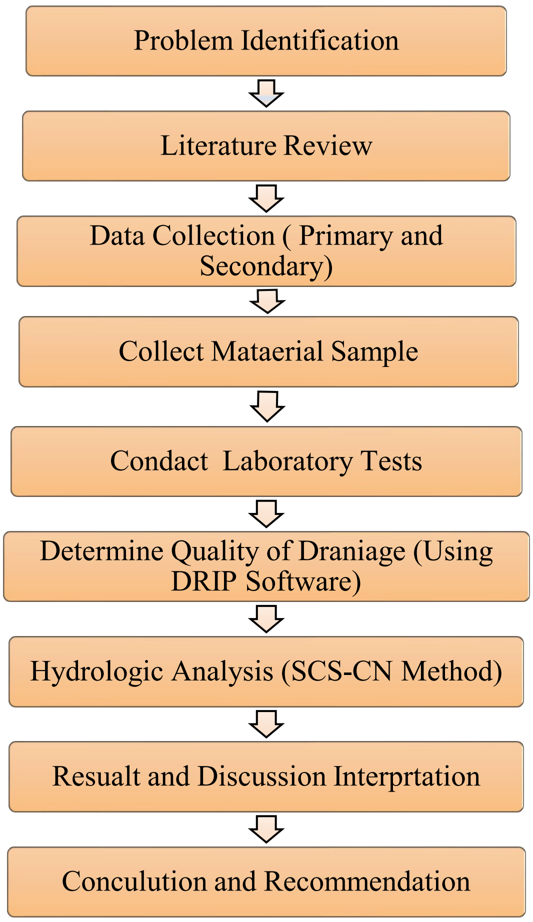

Figure 1 Flow chart for research design

2.4 Sampling Size and Techniques

In research studies, sampling refers to selecting representative study units. The research sites include 47 km of asphalt roads, featuring both paved and unpaved ditches. For this analysis, a randomly selected sample was chosen from a failing section of the study road corridor to minimize sampling errors. To adequately address the research questions, it was essential for the researcher to gather information from all relevant cases. Random sampling techniques were employed to collect samples for subsequent analysis. In a simple random sample, every member of the population has an equal and independent chance of being selected, achieved through a randomization process.

The selection of sampling locations for the study was based on specific criteria to ensure a representative and thorough assessment by identification of critical areas of drainage failure, such as water pooling, rutting, or cracking, were prioritized for sampling, as they provide valuable insights into deficiencies in the drainage system, variation in terrain and hydrology sites represent diverse terrain conditions, including flat, sloped, and undulating areas, as well as regions near water bodies or low-lying areas prone to flooding and coordination with stakeholders: input from local authorities and project managers helped identify road sections likely to experience drainage-related challenges based on past observations.

2.5 Description of Study Variable

The study encompasses two types of variables: dependent and independent. The dependent variable, which was observed and measured to assess the impact of the independent variable, is the performance of asphalt pavement. The independent variables include factors such as the dimension of the drainage structure, clogging of the drainage system, inadequate maintenance, and the engineering properties of the soil.

2.6 Data Sources and Methods of Collection

This study utilized both primary and secondary data collection techniques. Primary data collection began with identifying drainage issues affecting the pavement to determine their causes on a specific road. Site observations were conducted to evaluate the current conditions and deficiencies of the drainage system in the study area. A field survey was performed, using a tap measure to assess the existing pavement drainage system along the Bure to Injibara Road. Secondary data sources included various written documents, topographical maps, published and unpublished papers, the internet, journals, books, and information from the Ethiopian Road Authority's Debre Markos road network management. Data collection methods included field visual inspections, pavement condition assessments, and sampling representative pavement materials from the study area. Selected paving materials also underwent laboratory testing and field assessments.

3.0 RESULTS AND DISCUSSIONS

In this study, a detailed review of similar research previously conducted in the study area was first assessed, with the primary aim of identifying the root cause of the problem. Additionally, the road climate, topography, and drainage characteristics were reviewed and interrelated with how these factors are interrelated with the road design recommendations stipulated in the design manual and the actual road construction. Several tests were conducted to describe the characteristics of the paving material layers. The geotechnical properties of the embankment, subgrade, subbase, and base course materials were determined. Based on the results, the classification of these materials was assessed according to the design and construction requirements specified in the ERA design manual. Results were then evaluated as per [9] design recommendations for the respective area climate, drainage, and topography, if any. Previous findings also correlate with these study findings. In according to the evaluation of materials, i.e., best or poor, in correlation with climate, drainage, and topographic conditions, their quality recommendations in [9], and the relation with previous findings, methods of improvement suggest a conclusion. Using the AASHTO standard process, the soils' suitability for use as base course, subbase, and subgrade was assessed in the lab according to the requirements for road construction. These tests are essential for identifying and categorizing materials as well as determining their caliber in terms of specifications and design methodologies [10].

To determine the causes of pavement failure, collected materials were subjected to various laboratory tests. These tests were performed on the pavement layers to identify the underlying sources of damage related to the subgrade soil. To gain insights into the behavior of the materials in the failure area, tests such as Atterberg limits (including liquid limit, plastic limit, and plasticity index), sieve analysis, and compaction tests were performed. The tests followed the guidelines established by the Ethiopia Road Authority design document, lab manual, and specifications established by the American Association of State Highway and Transportation Officials [9]. Several laboratory tests were used in this study, including sieve analysis, compaction, and Atterberg limits which are briefly described below.

3.1 Sieve Analysis Test Results

In the study, the sieve analysis involves a set of laboratory procedures used to assess the drainable pavement layers. The material was shaken on a stack of sieves with diameters ranging from 37.5 to 0.075 mm. The laboratory results for each material are provided in the table and figure below.

3.1.1 Base Course Materials

All base course materials must have a suitable particle size distribution to provide excellent mechanical stability. They must also contain enough fines (material passing the 0.425 mm sieve) to compact densely. In the study region, sieve analysis test results were found to be within the upper and lower bound specifications.

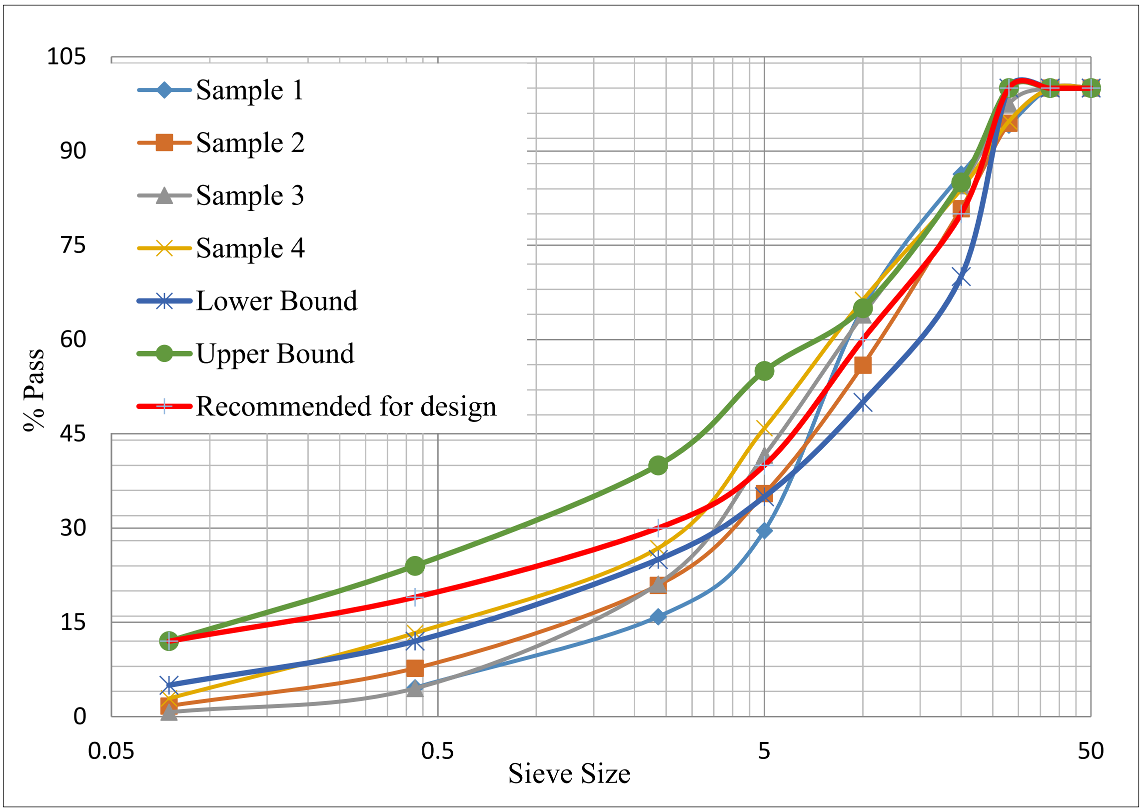

Figure 3 Sieve analysis test result for base course material

3.1.2 Sub-Base Material

The subbase material is a critical component of the pavement structure, as it distributes loads and serves as a working platform for the construction of the upper pavement layers. In this instance, the quality of the subbase material was affected by moisture content and traffic loading, which caused excessive deformation. The sieve analysis test results for subbase material taken from the study area were found to be below the lower bound specifications.

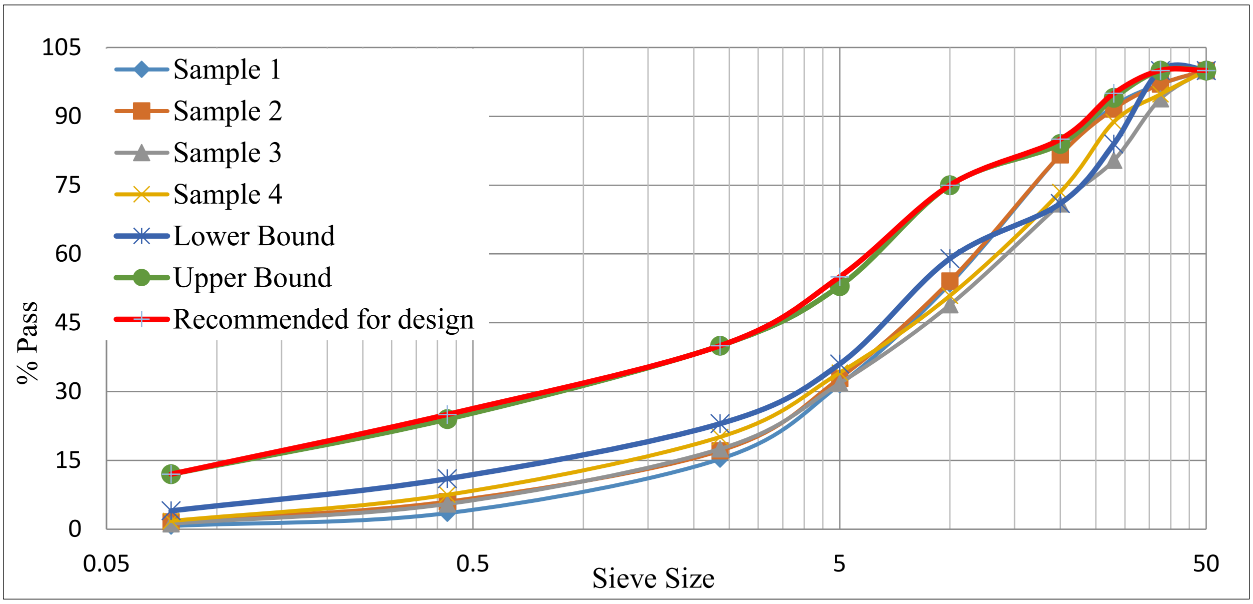

Figure 4 Sieve analysis test result for subbase material

3.1.3 Subgrade Material

When tire loads are applied to a subgrade that is too weak, the pavement will bend excessively and ultimately fail. This means that the materials will not interlock and bond properly to create a stable layer. Additionally, seepage increases moisture levels in pavement structures and embankments.

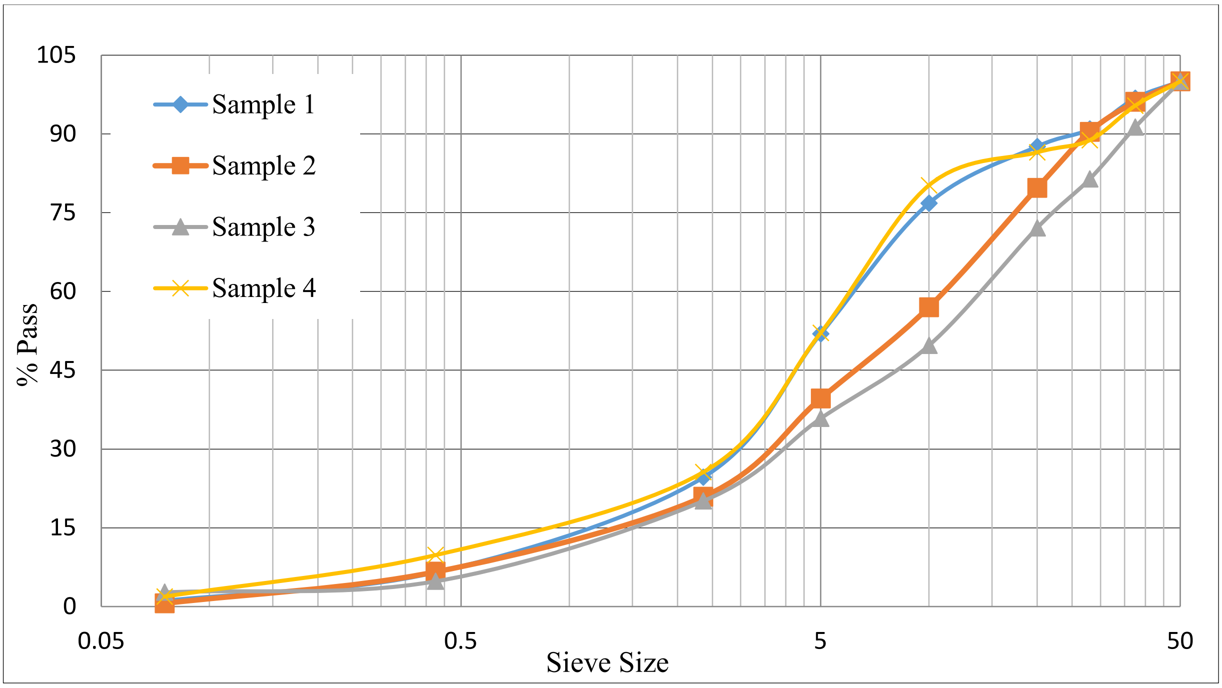

Figure 5 Sieve analysis test result for subgrade materials

Many pavement damages and surface deterioration can be traced back to inadequate subgrade drainage, particularly over clay subgrade or shallow rock formations. Utilizing an open-graded subbase, along with draining fabric that directs water to roadside ditches, can significantly reduce the negative impact of stagnant water beneath the pavement [11].

3.2 Compaction Test Result (AASHTO T-180)

Compaction improves the soil's shear strength, stability, bearing capacity, and permeability. To conduct this test, a representative sample that passed through 19-mm sieves was weighted and thoroughly mixed with water in a determined quantity. With 56 blows in five layers of approximately equal height, the mixed specimen was crushed in the mold. This procedure was continued with more samples until the weight of the material compacted in a mound was reduced.

Table 1 Compaction test result for pavement material (AASHTO T-180)

Material	Station (km)	Base course		Subbase		Subgrade	
		OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)
Sample 1	109+000	6.21	1.789	7.69	1.764	25.00	1.717
Sample 2	116+500	7.15	1.906	9.44	1.750	12.71	1.580
Sample 3	125+000	6.91	1.733	8.12	1.809	19.89	1.340
Sample 4	143+700	6.27	1.740	7.17	1.780	24.08	1.660

The compaction test results indicate that the average maximum dry density (MDD) and optimal moisture content (OMC) for the base course are 1.79 g/cm^3 and 6.64%, respectively. These values do not meet the required criteria, which specify (MDD) greater than 2 g/cm^3. For subbase material, the optimal moisture content ranges from 7.17% to 9.44%, and the maximum dry density ranges from 1.75 g/cm^3 to 1.809 g/cm^3, respectively. All sub-base maximum dry density values are below the specified threshold value of maximum dry density greater than 2 g/cm^3. In the case of subgrade material, the optimal moisture content varies from 12.71% to 25%, and the maximum dry density ranges from 1.34 g/cm^3 to 1.72 g/cm^3. All subgrades' maximum dry density values fall short of the required minimum of 1.76 g/cm^3.

3.2.1 Density Test Results and Percentage of Compaction

Compaction lowers short-term deformations under cyclic loading, compressibility, and the possibility of excessive long-term settlement, instability, and decreased erosion resistance. Compaction also increases the soil's elastic stiffness, strength, and bearing capacity. In this study modified compaction test was conducted as AASHTO T-180 standard methods of testing and the results are shown in Table 2 including their respective filed density results.

Table 2 Density and percentage of compaction test (AASHTO T-180) method

Sample	Location	Dry Density g/cm^3	Max.Dry Density (g/cm^3)	% of Compaction	Specification (Minimum)
Base course	9+000	1.710	1.789	95.58	98%
Sub-base		1.680	1.764	95.24	95%
Sub Grade		1.620	1.717	94.35	93%
Base course	16+500	1.840	1.906	96.54	98%
Sub-base		1.630	1.750	93.14	95%
Sub Grade		1.510	1.580	92.40	93%
Base course	25+000	1.690	1.733	97.52	98%
Sub-base		1.730	1.809	95.63	95%
Sub Grade		1.270	1.340	94.78	93%
Base course	43+700	1.690	1.740	97.12	98%
Sub-base		1.720	1.780	96.62	95%
Sub Grade		1.530	1.660	92.16	93%

By the method of compaction, the Ethiopia Road Authority manual recommends a minimum practicable maximum dry density of 93 percent for subgrade, 95 percent for subbase, and 98 percent for base course [9]. From the result, one can realize that the road subgrade material at stations 16+500 and 43+700 is less dense than specified. Subbase material at stations 16+500 is less than specified, and the material of the base course at stations 9+00, 16+500, 25+000, and 43+700 does not satisfy density criteria. Lower density means may flex high under the application of traffic loading.

3.2.2 Moisture Density Relation from Compaction Test

The depth of the water table becomes a critical factor influenced by the type of soil, especially when it rises during the rainy season and affects the moisture content. Moisture in the soil acts as a lubricant, facilitating the movement of particles. Excess moisture can lead to water-filled cavities, which reduces the material's load-bearing capacity. To achieve the maximum density, the soil must have the correct amount of moisture. It is essential to know the maximum dry density standard for future use. To assess this, plot the data points on the appropriate moisture density relation curve, using the material's dry density and percent moisture content.

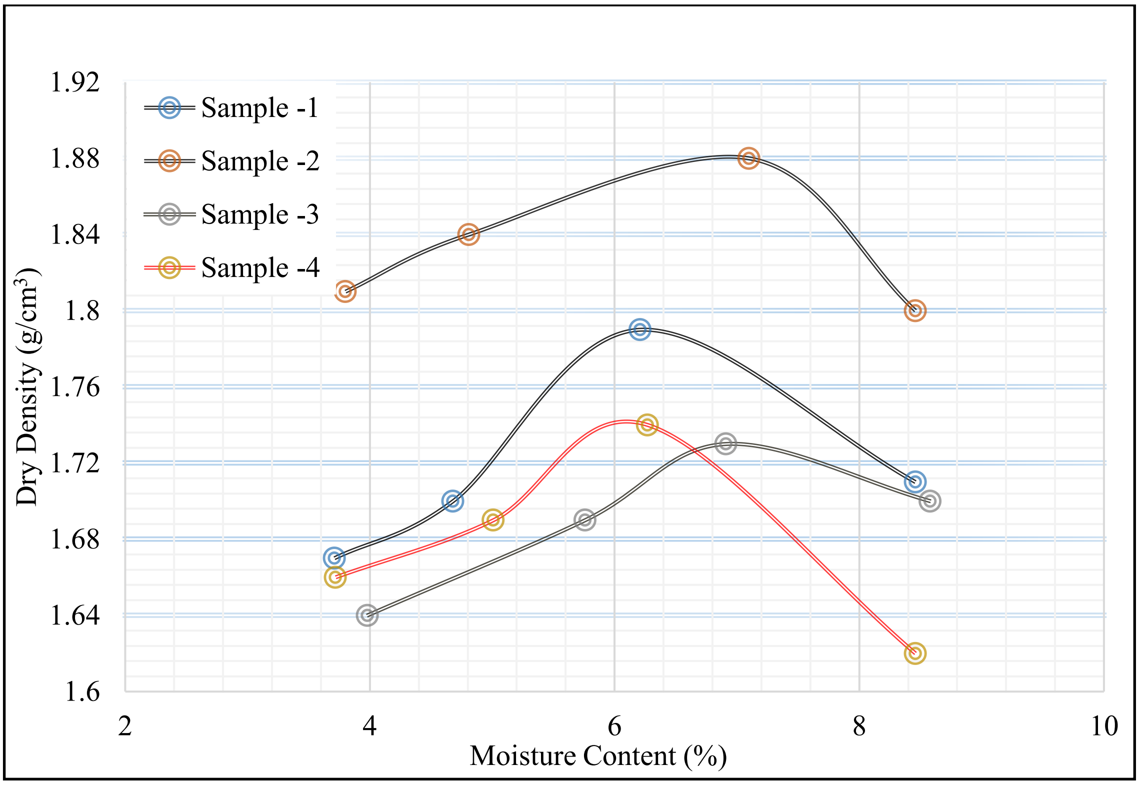

Figure 6 Moisture density relation for base course material

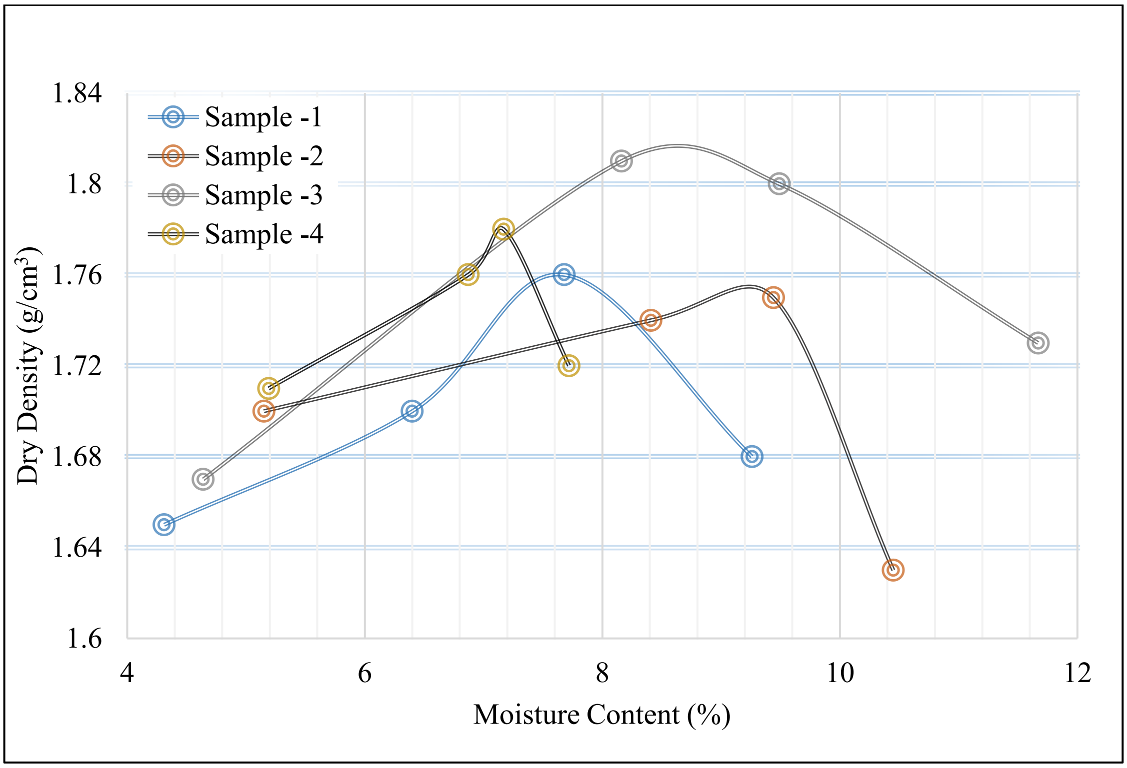

Figure 7 Moisture density relation for sub-base material

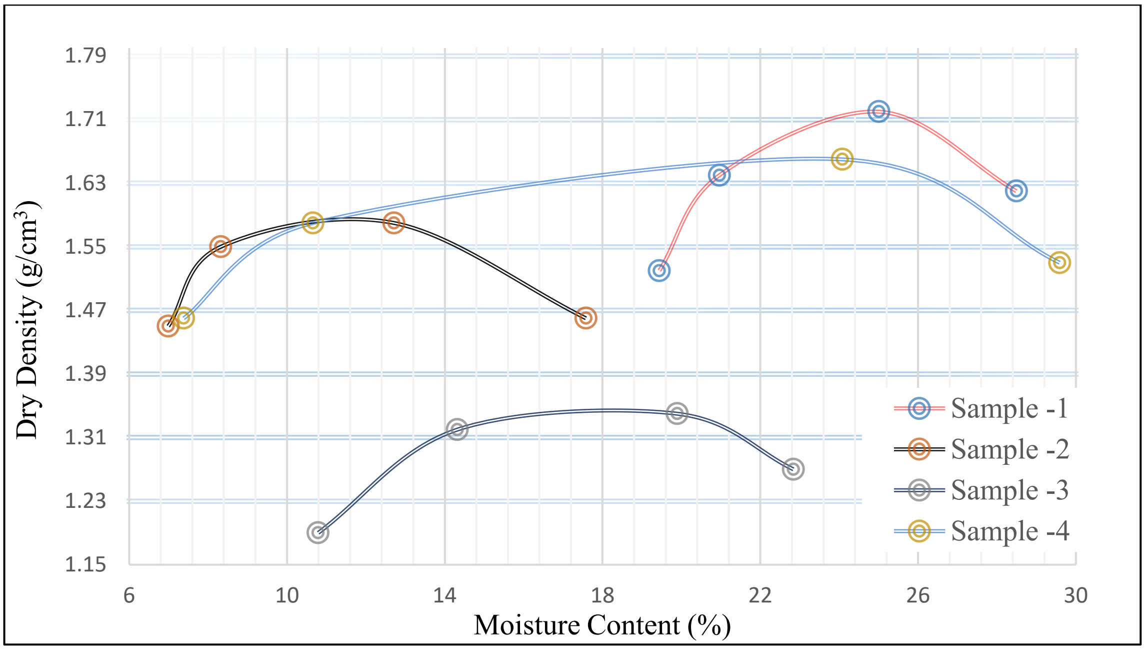

Figure 8 Moisture density relation for sub-grade material

3.3 Atterberg Limits Test Result

3.3.1 Liquid Limit Test (AASHTO T-89)

A soil sample that passed through the No. 40 sieve was weighed and blended with distilled water to form a homogeneous paste. This paste required 15-40 blows to close the groove in the Casagrande cup and was then soaked for 24 hours. After soaking, the past was smoothed and the Casagrande cup was grooved to a maximum depth of 12.7 mm. The number of blows required to close the gap over a distance of approximately 13 mm was recorded by operating the apparatus at a rate of two revolutions per second.

Table 3 Liquid limit test result

Sample Station	Base course	Subbase	Subgrade
Sample 1	25.15	36.62	52.94
Sample 2	31.55	40.63	47.70
Sample 3	29.20	32.62	52.32
Sample 4	28.12	43.07	35.38
Specification	Less than 45	Less than 45	Less than 90

Note: According to Table 3, the samples are safe in the location of the Ethiopia Road Authority design standard, and as a result, the samples are unaffected by this criterion [9].

3.3.2 Plastic Limit (AASHTO T-90)

When the soil sample is shaped into a 3 mm-diameter thread and rolled on a glass plate with the palm, it begins to disintegrate. The moisture content of the crushed thread is used to determine the soil's moisture content. The plastic limit is defined as the water content at which the soil thread breaks when rolled to a diameter of 3 mm. This plastic limit is calculated as the average moisture content at which this breaking occurs. The results of plastic limit are similar to the study of detail geotechnical and stability considerations of Debre markos-merawi asphalt road project, case in failed sections of Amanuel-bure road studied by Simachew Zewdu [11].

Table 4 Plastic limit result of all samples

Sample Station	Base course	Sub-base	Subgrade
Sample 1	19.98	25.59	36.95
Sample 2	22.72	28.63	32.32
Sample 3	23.58	21.56	33.57
Sample-4	20.36	32.11	35.38

3.3.3 Plasticity Index

High plasticity index values in subgrade materials imply susceptibility to swelling and shrinkage, leading to pavement deformation. High plastic soil can retain a significant amount of total moisture in the diffuse double layer, particularly through absorption, and is typically susceptible to high compressibility, permeability, and hydraulic conductivity, all of which can cause water logging and flooding, both of which can lead to road failure. The plasticity of the recommended material is defined in the Ethiopia Road Authority design manual. For fill material placed over expansive soils, impermeable soils with a plasticity index greater than 15% are advised, while embankment materials should not exceed a plastic index of 45%. Similarly, a plastic index of 6% to 12% is recommended for sub-base materials with a maximum of 6% for the plasticity index in other applications [9].

Table 5 Plasticity index for materials in the road

Station	Sample	Base course	Sub-base	Subgrade
9+000	Sample 1	5.16	11.02	15.99
16+500	Sample 2	8.82	12.00	15.38
25+000	Sample 3	5.62	11.05	18.74
43+700	Sample 4	7.61	10.95	16.01
Recommended Specification		Less than 6	6-12	Less than 45

According to the result from Table 5, only base course samples at 9+000 and 25+000 satisfy plasticity. Similarly, the PI value of subbase sample material at 16+500 and 43+700 is higher than Ethiopia Road Authority design manual specification [9]. The results of this study also similar to the study of detail geotechnical and stability considerations of Debre markos-merawi asphalt road project, case in failed sections of Amanuel-bure road [11].

3.4 Soil Classification

To classify soil, apply test data using the process of elimination Table 6 and the test data satisfy the correct classification according to the AASHTO soil classification manual [10]. Table 6 below presents the soil classification system according to the AASHTO Soil Classification for subgrade, subbase, and base course samples. These classifications are based on the particle-size distribution, liquid limit, and plasticity index properties of the clay material samples.

Table 6 AASHTO classification of subgrade, subbase, and base course

Sample	Sieve size			LL	PI	Group	**Common types of key constituent materials**
	2.36	0.425	0.075				
Sample 1,2	15.9	4.6	1.2	25.15	5.16	A-2-4	Silty or clayey gravel sand
Sample 1,3	15.3	3.5	0.7	36.62	11.02	A-2-6	Silty or clayey gravel sand
Sample 1,4	24.6	6.5	1.1	52.94	15.99	A-2-7	Silty or clayey gravel sand
Sample 2,2	20.9	7.7	1.7	31.55	8.82	A-2-4	Silty or clayey gravel sand
Sample 2,3	17.1	6.0	1.6	40.63	12.00	A-2-7	Silty or clayey gravel sand
Sample 2,4	20.9	6.6	0.6	47.70	15.38	A-2-7	Silty or clayey gravel sand
Sample 3,2	21.1	4.5	0.7	29.20	5.62	A-1	Stone fragments gravel and sand
Sample 3,3	17.5	5.5	1.2	32.62	11.05	A-2-6	Silty or clayey gravel sand
Sample 3,4	20.1	4.8	2.7	52.32	18.74	A-7-5	Clayey soils
Sample 4,2	26.8	13.3	2.9	28.12	7.61	A-2-4	Silty or clayey gravel sand
Sample 4,3	20.1	7.5	1.8	43.07	10.95	A-2-7	Silty or clayey gravel sand
Sample 4,4	25.6	9.8	1.9	35.38	16.01	A-7-5	Clayey soils

Materials in groups A-1 and A-2-4 can be used satisfactorily as subgrade and embankment materials if they are adequately drained and compacted beneath a base or surface course of modest thickness that is appropriate for the traffic they will be carrying. Studies have indicated that they can also be made satisfactory by adding modest amounts of artificial or natural binders [10]. Moreover, the quality of the samples used as embankments and/or subgrade materials varies within the clay granular groups A-2-6 and A-2-7 as well as the silt-clay groups A-4, A-5, A-6, and A-7. These range from fair and bad subgrades, which could need a layer of subbase material or thicker base materials to offer enough support for traffic loads, to roughly equivalent good A-2-4 and A-2-5 subgrades [10]. In general, groupings A-2-4, A-2-6, and A-2-7 in the classification of the soil used in our research denote gravel and sand, including silt-clay with excellent to good qualities. On the other hand, the clayey soils (A-7-5) will have material qualities that range from fair to poor. Poor sub-grades require a layer of sub-base material or an increased thickness or base coarse to furnish adequate support for traffic loads [10]. This study's goal was to assess the Bure to Injibara asphalt road section's pavement drainage system and suggest corrective action. The results of this study are similar to the study of detail geotechnical and stability considerations of Debre markos-merawi asphalt road project, case in failed sections of Amanuel-bure road [11].

3.5 Hydrological Analysis Result

A hydrologic analysis is crucial for identifying flood-hazard areas and determining locations where construction and maintenance may be unusually expensive or hazardous. Given that various levels of government plan, design, and construct highway and water resource projects that may impact one another, interagency coordination is both desirable and often necessary. Improving drainage facilities through maintenance, redesign, and reconstruction is vital for mitigating the effects of poor workmanship in drainage and road construction. Proper connections or integrations between the road network and drainage systems are always required during road construction. The goal of hydrologic analysis is to determine the maximum reliable discharge for a given waterway during a specific design period. Key factors that significantly impact the maximum discharge include the catchment area, slope, soil type, vegetation, amount of rainfall, and storm duration. Hydrological calculations for evaluating drainage system performance typically involve several assumptions. The intensity-duration-frequency (IDF) curves utilized are derived from historical rainfall data, reflecting average conditions throughout the design period. The catchment area that feeds into the drainage system is clearly defined and remains constant. A specific return period, such as 10 and 25 years, is selected to design the system, striking a balance between cost and risk.

3.5.1 Adequacy of Existing Drainage System

The drainage capacity of the current system was assessed based on hydraulic calculation results. The main causes and effects of inadequate drainage systems on the asphalt pavement layer are insufficient capacity, a lack of input structures, improper maintenance, and the disposal of solid waste into drainage structures. In our case, the drainage structure is a rectangular open ditch. The existing condition of the drainage channel was evaluated using Manning's formula with the measured values.

$$V = \frac{1}{n} * (R)^{2/3} * (S)^{1/2} \tag{1}$$

$$Q_c = A * V \tag{2}$$

Where:
Qc = discharge capacity (m^3/s)
V = Velocity (m/s)
A =Area (m^2)
R = Radius (m)

Table 7 Current condition of the hydraulic performance of the existing drainage system

Town	Depth (m)	width (m)	slope (m/m)	Area (m^2)	coefficient	perimeter (m)	Radius (m)	Velocity (m/s)	Discharge (m^3/s)
Bure	0.7	1.2	0.02	0.84	0.015	2.60	0.32	4.23	3.55
Tillie	0.6	1.2	0.02	0.72	0.015	2.40	0.30	4.21	3.04
Injibara	0.8	1.2	0.02	0.96	0.015	2.80	0.34	4.58	4.39

3.5.2 Hydrological Analysis for Injibara and Bure Town Drainage System

The hydrological analysis results for Bure and Injibara towns are shown in Table 8 below. The calculations were done using the Soil Conservation Service Curve Number (SCS-CN) method. The average runoff coefficient (C) is 0.15. The unit discharge was calculated using the intensity-duration-frequency curve for rainfall region A2, considering the time of concentration and intensity return periods of 10 and 25 years.

Table 8 Summary of The Watershed Properties Calculations in Injibara and Bure Town

	Injibara town	Bure town
Curve number (CN)	91 wet	96 wet
Precipitation(p) of 10 years	74.45 mm	74.45 mm
Precipitation(p) of 25 years	85.70 mm	85.70 mm
Initial abstraction(Ia)	5.0 mm	2.0 mm
Potential maximum retention (s)	25 mm.	10 mm.
Direct runoff 10 year (Q10)	51 mm	64 mm
Direct runoff 25 year (Q25)	62 mm	75 mm
The slope of the watershed	0.02	0.02

Table 9 Summary of the peak discharge estimation (Qp) in Injibara and Bure town

	Injibara Town	Bure Town
Unit conversion factor (α)	0.000431	0.000431
Time of concentration (Tc)	1.59hr	1.88hr
Runoff Coefficient (C)	0.15	0.15
Intensity (I) for a return period of 10 years	22 mm/hr	22 mm/hr
Intensity (I) for a return period of 25 years	28 mm/hr	28 mm/hr
Depth of runoff, mm (Q10)	51 mm	64 mm
Depth of runoff, mm (Q25)	62 mm	75 mm
Drainage area (A), km^2	12 km^2	8 km^2
Rainfall Type II regression Coefficients (ERA DDM, 2013)	C0=2.55323	C0=2.55323
	C1=-0.6151	C1=-0.6151
	C2=-0.1640	C2=-0.1640
qu= $\alpha*10^{co+c1logtc+c2(logtc)2}$	0.01141 $m^3/s/km^2/mm$	0.01126 $m^3/s/km^2/mm$
qu10 =0.00278*C*I10*A	0.1101 $m^3/s/km^2/mm$	0.0734 $m^3/s/km^2/mm$
qu25 =0.00278*C*I25*A	0.1401 $m^3/s/km^2/mm$	0.0934 $m^3/s/km^2/mm$
Qp10 = qu*Q10*A	6.98 m^3/s	5.765 m^3/s
Qp25 = qu*Q25*A	8.48 m^3/s	6.756 m^3/s

Note: To compare this discharge to the town's current discharge, which was determined by measuring the width and depth of the drainage channel for each sub-catchment, the study's main findings were that the town's drainage system coverage is inadequate, that proper stakeholder integration is lacking, that community participation is limited, and that there is no drainage network design in place.

3.6 DRIP Result in Time to Drain 50% Drainage

The time-to-drain method evaluates the duration required for excess water to exit the pavement structure, which is crucial for preventing water-related issues such as rutting, cracking, and asphalt layer stripping. This method highlights the importance of drainage layers in maintaining a dry and stable base, directly influencing pavement durability. Its straightforward approach, based on measurable parameters, allows for easier interpretation and application in real-world conditions compared to more complex hydrological models. DRIP (Drainage Requirements in Pavements) is specifically tailored for time-to-drain calculations, utilizing established equations and guidelines from AASHTO and other standards. This method emphasizes the efficiency of subsurface drainage layers, which are often neglected in favor of surface drainage assessments. By focusing on how effectively water is removed from the base and subbase layers, the time-to-drain method addresses the issue of prolonged water retention, which can accelerate damage mechanisms, such as subgrade softening and increased stresses on pavement layers. Prioritizing rapid drainage is essential for enhancing the structural integrity and extending the service life of the pavement. Additionally, the time-to-drain method offers flexibility to assess performance across varying hydrological conditions, particularly relevant to the Bure to Injibara asphalt road section.

Considering the variance in hydraulic conductivity for the drainage layer and the size of the pavement section, the Drainage Requirement in Pavement (DRIP) software assesses water flow within the pavement using the time-to-drain method. Drainage Requirement in Pavement (DRIP) software analyzes pavement subsurface drainage to assess the efficacy of drainage during the pavement design phase. The tool is beneficial for quickly determining the drainage quality of a stretch of pavement that will consistently be saturated, aiding in the prediction of sections of wet pavement that will constantly remain below the groundwater table. The software evaluates moisture movement within a pavement, estimating time-to-drain and providing a drainage rating based on input parameters, such as permeability and effective porosity of the drainable base material. During the design of the road, it was expected the pavement structure would be in good to excellent drained condition which means the drainage was removed from the pavement structure within two hours to one-day time. However, in the field inspection, it is seen that the pavement structure is staying along with water. Thus the roadbed strength may be reduced due to this effect [12]. The results from the Drainage Requirement in Pavement (DRIP) software for roadway geometry (A) and (B) by time-to-drain approach are as follows:

Table 10 DRIP software result for geometry A pavement material

Base course	C_u	C_c	Porosity (n)	Effective Porosity (Ne)	Permeability (k_{base})
	7.68	2.32	0.275	0.16	38.072 m/day (0.441 mm/sec)
Subgrade	C_u	C_c	Porosity (n)	Effective Porosity (N_e)	Permeability ($k_{subgrade}$)
	9.17	1.56	0.385	0.227	228.507 m/day (2.645 mm/sec)
Subbase	C_u	C_c	Porosity (n)	Effective Porosity (N_e)	Permeability($k_{seperator}$)
	8.96	2.10	0.323	0.194	127.171 m/day (1.472 mm/sec)
Permeable Base: Time to Drain Method					
			Effective porosity (Ne)		0.159
			Percent saturation (S)		71.091 %
Quality of drainage (Time to drain *50%*) drainage-hours					**6.46hr - Good Less than 1 day**

Table 11 DRIP software result for Geometry B pavement material

Base course	C_u	C_c	Porosity (n)	Effective Porosity (N_e)	Permeability (k_{base})
	16.89	2.02	0.275	0.151	13.276 m/day (0.154 mm/sec)
Subgrade	C_u	C_c	Porosity (n)	Effective Porosity (N_e)	Permeability ($k_{subgrade}$)
	16.49	1.54	0.385	0.241	337.669 m/day (3.908 mm/sec)
Sub-base	C_u	C_c	Porosity (n)	Effective Porosity (N_e)	Permeability($k_{seperator}$)
	8.14	1.81	0.323	0.198	196.277 m/day (2.272 mm/sec)
Permeable Base: Time to Drain Method					
			Effective porosity (Ne)		0.151
			Percent saturation (S)		72.545%
Quality of drainage (Time to drain *50%*) drainage-hours					**76.57hr-Fair Less than 1 week**

When assessing drainage quality based on the time it takes for 50% of moisture in the pavement to drain, it is evident that materials with higher saturated hydraulic conductivity (Ksat) provide superior drainage performance. According to the DRIP software's time-to-drain analysis, drainage effectiveness varies from good to fair, depending on the materials used. Key factors that influence drainage time include effective porosity, drainage channel length, layer thickness, drainage path slope, and layer permeability. Notably, the sensitivity of time-to-drain to base permeability and thickness is relatively low; beyond a base thickness of 0.3 m and a base permeability (K) of 300 m/day, the time-to-drain remains nearly constant. This indicates that increasing permeability and thickness beyond these thresholds does not significantly enhance the pavement drainage capacity, as the porous base is assumed to be fully saturated before drainage begins, adhering to the principles of saturated flow. Consequently, selecting a material with hydraulic conductivity greater than 300 m/day will not significantly improve the drainage layer's effectiveness. Various highway agencies have established a minimum k value of 300 m/day and recommended a thickness limit of 3–4 inches for permeable layers [13].

If time-to-drain is recognized as a more effective measure of subsurface drainage effectiveness, it is advisable the recommended to utilize permeable bases with higher K values [14]. The finding suggests that for moisture-sensitive materials, the stability of unbounded pavement materials is notably enhanced when their degree of saturation is maintained between 60% and 70%. Therefore, the drainage layer design should aim to reduce saturation levels in the pavement structure as quickly as possible. Open-graded pavement layers' must not only have appropriate K values to enhance drainage but also be robust enough to withstand construction and traffic loads. To prevent the saturation of the drainage layer, research supports the design layers with high K values and suitable thickness, assuming steady flow conditions. Time-to-drain serves as a valuable metric for evaluating drainage systems' effectiveness. Studies indicate that significant pore pressure develops in pavement materials when saturated levels exceed 80%, which influences the selection of base materials and gradation. Any aggregate specification developed for pavement bases and subbases must balance these competing requirements [15].

The primary goal of open-graded aggregate specifications examined in this study is to the rapid drainage of excess moisture from the pavement sublayer, albeit at the cost of other performance. For untreated permeable bases, the coefficient of uniformity (Cu) has long been used as a stability indicator, with a minimum Cu value of 4 generally regarded as acceptable. This threshold indicates that untreated permeable bases are stable and robust enough to support a certain level of construction traffic [13]. The findings from Mayrberger and Hodek were utilized to identify aggregate types that provide optimal stability under the combined impacts of traffic and environmental factors[16]. In this research, however, the permeability of the drainage layer material falls below the minimum requirement of 300 m/day for effective drainage. Despite this, the drainage quality is classified as good, with a draining time of less than one day in road geometry A, while road geometry B exhibits fair drainage quality with a draining time of less than one week.

3.6.1 Material Permeability Result

The void content of the mixture affects its permeability, with average values ranging from 300 µm/s at two percent (2%) air voids to 30 µm/s at twelve percent (12%) air voids. Permeability typically increases threefold with each one percent (1%) rise in air void content. To ensure efficient drainage, the material used for the drainage layers must meet a minimum permeability requirement. Generally, a permeability of 300 meters per day (3.4722 millimeters per second) is sufficient for most applications to provide proper drainage [13].

Table 12 Material permeability result using DRIP software

Cross Slope (Geometry A)		
Material type	Permeability	Result
Base course	Permeability (k_{base})	38.072 m/day (0.441 mm/sec)
Subbase	Permeability($k_{seperator}$)	127.171 m/day (1.472 mm/sec)
Subgrade	Permeability ($k_{subgrade}$)	228.507 m/day (2.645 mm/sec)
Uniform Slope (Geometry B)		
Material type	Permeability	Result
Base course	Permeability (k_{base})	13.276 m/day (0.154 mm/sec)
Subbase	Permeability($k_{seperator}$)	196.277 m/day (2.272 mm/sec)
Subgrade	Permeability ($k_{subgrade}$)	337.669 m/day (3.908 mm/sec)

Because of this, the permeability of the drainage layer material in this study is less than what is necessary for effective drainage. Consequently, while the drainage quality is good, with a draining time of less than one day in road geometry A, the permeability of the base course and subbase course materials, except for subgrade materials, is insufficient for the required drainage application. This results in fair drainage quality, with a draining time of less than one week in road geometry B. To address these issues, the pavement drainage analysis suggests increasing the coefficient of permeability or implementing crowned pavements (as in Road Geometry B), where side ditches are used to shorten the flow path. Crowned pavements are especially suitable for multi-lane roadways. For laboratory test results on base course, subbase, and subgrade material, using the upper end of the recommended specification should be considered for further design. In this research, the material permeability results were obtained by using DRIP software. Except for subgrade pavement material on a uniform slope (Road Geometry B), the permeability of the material is below the minimum necessary for drainage application, as shown in the above table.

3.7 Topography and Drainage Conditions on the Study Area

The Bure to Injibara road section is situated in the western part of Ethiopia, where the region's topography significantly impacts drainage design and pavement performance. This area features hilly to moderately mountainous terrain, with elevations ranging from 1,500 to 2,300 meters above sea level. Such elevation variations lead to considerable changes in slope along the road, affecting surface runoff and drainage efficiency. The road section includes both gentle and steep slopes, with an average slope of approximately 3-7%, and reaching up to 12-15% in more mountainous areas. Steeper sections are primarily located near ridges and hilltops, while flatter areas are found in the valleys. This variability in slope affects water flow and the effectiveness of drainage systems.

Consequently, the topography in the Bure to Injibara region necessitates careful drainage design to address potential runoff issues and ensure the long-term durability of the pavement structure.

Insufficient drainage causes early pavement erosion, which causes driving issues and road structural breakdowns. Water can infiltrate the pavement system in three ways: through fractures in the surface layer, through improperly drained side ditches or shoulders, or through capillary action in fine-grained foundation soils that allow water to seep from the underlying groundwater. This moisture weakens and stiffens unbound pavement materials, promotes fine particle migration, and can produce swelling and soil expansion in coarse granular materials [17]. The topography and drainage conditions of the route were observed during a field visit. The results of the field visit, particularly topography, were compared to the instrumental data in Parkman's report. As a result, the road between 9+000 and 16+500 was revealed to have a curved topology. Floods on the road's surface run through the road's face and are eroded by the station's paved side ditches. However, because the paved ditch has deteriorated, moisture will most likely seep in via the crevices. The paved ditches at station 16+500, on the other hand, are in good shape, with more distortion on the opposite side of the previous collapse. At a station, the road edge drops a little, allowing moisture from the unsealed shoulder to seep in. At stations 25+000 and 43+700, the area is flat and swampy. These areas may not be able to drain rapidly if there is a lot of rain. During heavy rains, because the side ditches are closed, surface water may sit for a long time before draining. Despite this, the area's terrain prevents external drainage from crossing the road.

3.8 Drainage and Shoulder Performance

The shoulder of a road is essential for both the structural integrity of the pavement and its drainage efficiency. Designed to provide lateral support, the shoulder aids in runoff management and serves as a safe stopping area for vehicles. Its performance is closely linked to the effectiveness of the local drainage system, as improper drainage can significantly compromise shoulder stability and the overall longevity of the road. The primary role of the drainage system adjacent to the shoulder is to facilitate the rapid removal of water from both the pavement and shoulder areas. Water accumulation in the shoulder can lead to various problems. Key factors influencing shoulder performance include cross slope, shoulder drainage features, and subsurface drainage. To enhance shoulder design and ensure effective drainage without compromising performance, the following design recommendations should be implemented: proper cross slope, integrating shoulder drains, sufficient drainage inlets, appropriate shoulder material selection, and slope and ditch design.

According to the road geometric design manuals, shoulders are essential to a road's structural integrity because they provide lateral support to the pavement layers [9]. They aid in the internal drainage of the pavement and help remove surface water from the road surface. Shoulders are especially crucial when dealing with unbound materials on pavement, with a recommended minimum width of one meter (1 m). Surface water infiltration can reduce the pavement's load-carrying capacity and cause more serious damage to the road body. However, this study found that the shoulder width was less than 0.5 m in several locations. In some areas, particularly rural and urban locations, shoulder construction was completely absent. The study of the pavement condition reveals that drainage issues exacerbate the problem. Generally, the average thickness of the base and sub-base courses is less than the road's design thickness, resulting in an inability to support the traffic load. The findings indicate that most flexible pavement defects occur in the study region, suggesting the roads are in poor condition. Proper highway drainage is essential for removing surface water from the pavement. Surface water can cause problems with ice in the winter, making proper drainage crucial to preventing flooding. Standing water on a road can lead to maintenance issues by softening the earth beneath the surface, which deteriorates the road and may cause accidents, endangering other road users [18].

4.0 CONCLUSION

The performance of roadway pavement is significantly influenced by drainage quality. Excessive water in the base, sub-base, and sub-grade soils can lead to premature discomfort and ultimately result in structural or functional failure of the pavement. Effective drainage is essential for ensuring the pavement operates satisfactorily and sustainably over time. The primary goal of drainage design is to manage the flow of water across and along the road, facilitating its proper conveyance downstream without obstruction. A well-designed pavement drainage system prevents the base, sub-base, and subgrade components from becoming overly wet or saturated. The time to drain was employed to assess the drainage system's effectiveness. Results from the DRIP software indicate that the pavement drainage layer performs adequately, with evaluation ranging from good to fair for base materials. When a drainage layer is present, the subgrade can reach a saturation level of 72 percent; without it, saturation levels remain 100 percent. The analysis of the pavement drainage system suggests Increasing the coefficient of permeability or employing crowned pavements (Road Geometry A), to reduce flow routs using said ditches. Insufficient pavement thickness, cracked ditches, and poor construction quality lead to inadequate drainage, excessive seepage into the lower layers, and compromising supporting components. To mitigate moisture-related issues, three strategies are recommended:

- Preventing moisture from entering the pavement system,
- Utilizing materials resistant materials and design elements
- Removing any moisture that does infiltrate the system.

Overall, the findings highlight that drainage layers effectively lower subgrade moisture content, while flexible pavements without drainage layers tend to reach full saturation. Addressing drainage issues through target design improvements, better maintenance practices, and strict adherence to standards will substantially enhance the pavement drainage system along the Bure to Injibara town road section. Before pinpointing problematic zones and hazardous areas within the pavement drainage system, a compressive evaluation is essential. The main objective of pavement drainage design is to prevent the saturation of foundational, subbase, and subgrade materials, thereby minimizing moisture-related complications. To design an effective pavement drainage system, it is advisable to increase the coefficient of permeability or implement crowned pavements (uniform slope road geometry). Additionally, selecting materials that meet the highest recommended specification based on laboratory tests is crucial. The size, length, alignment, and drainage structures of the road must comply with the minimum requirements set by the Ethiopian Road Authority drainage design manuals. Enhancing the drainage potential of symmetric cross-section pavements can be achieved by installing edge drains on both sides. To ensure efficient moisture control, it is important to improve drainage design parameters by raising the of permeability the drainage layer materials. Regular maintenance schedules for permeable base materials will help preserve their drainage performance. By implementing these recommendations, the pavement drainage system along the Bure to Injibara town road section can be optimized, leading to improved road performance, reduced moisture-related damage, and enhanced safety and durability of the roadway infrastructure in the Amhara region.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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