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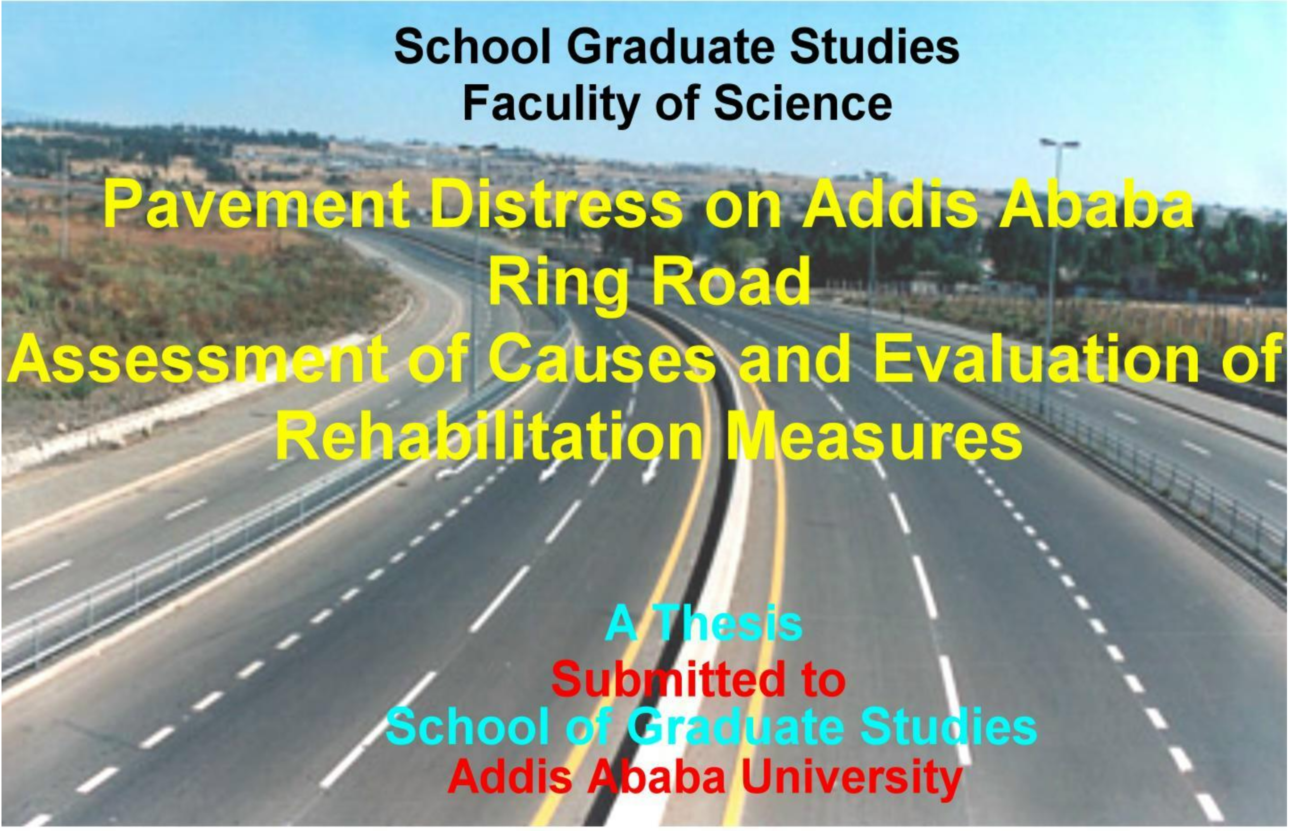

Pavement Distress on Addis Ababa Ring Road Assessment of Causes and Evaluation of Rehabilitation Measures

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Submitted to
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In Partial Fulfillment of the Requirement for the Degree of Masteres of Science in
Engineering Geology

By

ZELEKE TADESSE

July 2013

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMRNT OF EARTH SCIENCE

PAVEMENT DISTRESS ON ADDIS ABABA RING ROAD – ASSESSMENT OF CAUSES AND EVALUATION OF REHABILITATION MEASURES

By
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DECLARATION

I hereby declare that the thesis entitled "PAVEMENT DISTRESS ON ADDIS ABABA RING ROAD –ASSESSMENT OF CAUSES AND EVALUATION OF REHABILITATION MEASURES" has been carried out by me under the supervision of Dr. Tarun Kumar Raghuvanshi and Dr. Trufat Hailemariam Gugsa, School of Earth sciences, Addis Ababa University during the year 2013 as part of Master of Science Program in Engineering Geology. I further declare that this work has not been submitted to any other University or institution for the award of any degree or diploma and all sources of materials used for the thesis have duly acknowledged.

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Place and date of submission: School of Graduate Studies, Addis Ababa University
July 2013

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LIST OF ABBREVIATIONS

AACRA	Addis Ababa City Roads Authority
AARRP	Addis Ababa Ring Road Project
AASHTO	American Association State Highway Transport Officials
BH	Borehole
CBR	California Bearing Ratio
CC	Crocodile Crack
DDM	Distress Density Method
DEL	Delamination
DEM	Digital Elevation Model
DEP	Depression
DMI	Distress Manifestation Index
ERA	Ethiopian Roads Authority
GW	Groundwater
LC	Longitudinal crack
PCI	Pavement Condition Index
PH	Pothole
PMS	Pavement Management System
RAV	Raveling
RUT	Rutting
SHOV	Shoving

Abstract

The present study area which forms a part of the ‘Ring road’ in Addis Ababa is located nearly round the city except in the northern portion of the city. The Addis Ababa city is located on the western margin of the Main Ethiopian Rift and is a part of western highland of Ethiopian. The total length of the road is 33.2 Km and the design life of the ring road was for about 20 years. However; it shows manifestation of distress just within 9 years, well before its actual design period. The present research study was conceived with an objective to define the degree of pavement distress and to define and categorize the causes of pavement distress. In order to meet out the objectives of the present study systematic methodology was followed. Firstly, the various kind of distress were identified and located and secondly based on the degree of distress the pavement was sub-divided into five homogeneous zones such as; very poor, poor, fair, good and excellent. It is believed that the distress or deterioration of pavement in the study area might have resulted due to combined effect of various inherent and external factors. For the present study mainly the engineering geological factors were considered. These factors are; Rock and soil types, Geology, Drainage (Rivers, Surface flow direction, GW table and GW flow direction), Elevation (Altitude), Slope terrain, Curvature, Slope aspect and Structural set up (Fault line) of the area. As a part of methodology field visual survey using distress density method was developed and applied. Besides, a standard method of distress manifestation index was also used to produce visual survey maps. In order to assess the relative influence of engineering geological factors on pavement distress, analysis was made in GIS environment. For this purpose overlay analysis was performed using various tools in ArcGIS. To know the relative contribution of each of the causative factors on pavement distress, Raster Calculator - a tool in Arc GIS, was used. Further, analysis was made to know the relative contribution of each of the parameter on pavement condition (DMI). Finally, based on the present study the possible rehabilitation alternatives were worked out.

*****

Chapter 1 INTRODUCTION

1.0 Problem Background

Road network is considered to be very vital for the sustainable economic growth of any nation, especially in the developing countries, like Ethiopia. Despite the need of having long serving road networks, there are lots of economical, technical and management challenges in constructing as well as maintaining these roads. On the other hand, constructed roads need regular pavement condition inspection to implement a comprehensive pavement management system. Such system involves dividing the pavement network into logical segments, recording descriptive segment inventory data and collecting pavement performance, pavement distress conditions and information relating these segments. (Deighton and Sztraka, 1995).

A pavement distress that occurs at the surface can have a number of different causes which must be properly identified before the actual corrective action is taken. The visible manifestation of the problem at the surface may be the same; however, the solution for each cause may be different. Therefore, if the remedial action is to be effective, the cause of the problem must be properly identified and suitably corrected (Fikir Alebachew., 2005).

Plate 1.1 Pavement distress in the study area around Bole Brass and on way Kality to Hana Mariham, respectively

Some of the damages which characterize the structural condition of the pavement are deformation, rutting (fatigue) and cracking. The others are generally unrelated to the pavement structural capacity. This type of damage may be caused either by defective placement, or by deficient materials quality, or by some special local condition, aggravated by traffic. These include longitudinal joints cracking, transverse thermal shrinkage cracking, potholes and raveling, etc (ERA, 2002(b)).

During the preliminary design stage, the pavement evaluation study establishes the nature, severity and extent of the road deterioration, the cause of the deterioration and the strength of the existing road pavement. This information, together with the material test results, is used to identify alternative maintenance or rehabilitation strategies (ORN 18, 1999).

One of the earliest pavement condition indices was the Present Serviceability Rating (PSR) developed at the AASHO Road Test. The PSR was developed at the AASHO Road Test by having raters riding in an automobile assign a pavement condition value that indicated the level of service the pavement provided. However, researchers wanted to measure this index objectively. Therefore, a relationship was developed between the mean PSR assigned by the panel, and some objective measurements such as roughness, rutting and cracking (Deighton and Sztraka, 1995).

Addis Ababa, being Ethiopia's largest metropolis, an official diplomatic capital of Africa, and the fourth largest diplomatic center in the world, has a major ring road highway. The ring road was constructed by the China Road and Bridge Corporation (CRBC) Company from 1998 to 2004. The contract price to complete the Ring Road project was US$ 86.02 million, US$ 67.25 million in the main contract for the road construction and US$ 18.77 million in a supplemental contract. The road included the construction and upgrading of 33.2 km of highway, which included the upgrading of 14.2km of bituminous asphalt concrete surfacing and the construction of 19.2 km of new road, 41 new structures, 6 flyover bridges, 23 pedestrian bridges, and 12 culverts (Peng et al., 2008). However, in spite of its magnificent features and huge economic importance, its serviceability and pavement conditions are not regularly investigated for a proper maintenance strategy or even for future road evaluation/ planning.

The serviceability of roads and its evolution through time is a concept widely accepted by pavement engineers to evaluate road quality and conditions.

As a result, the present study was aimed to assess in detail the condition of the pavement distress and sub-divided the road into homogenous sections according to the degree of distress. The causes which are associated to the distressed features are also evaluated and finally possible rehabilitation alternatives have been evolved.

1.1 History of Road Construction and Rehabilitation in Addis Ababa

A road construction work, just like any other social endeavor or undertaking, has vast and wonderful history of its own, since it is evolved with the social development of mankind. Movement on roads in ancient Ethiopia was done in trails and foot paths. In addition to the traditional shoulder porter age, animals like mule, donkey and horses and camels were used as a means of transportation.

Addis Ababa city was founded by Minellik II and Empress Taitu in 1887. The history of the city's road development also begins from the inception of the city. Minellik II constructed the first ever two roads in the city as well as in the country that stretch from Addis Ababa to Addis Alem and from his palace to England Embassy in 1902. In 1904 the first roller was imported by the emperor and was being pulled by many people for its operation.

Emperor Minellik was also believed to be the first in importing two cars in Addis Ababa and introduced the car technology in the city for the first time in 1907. The country's modern road construction is highly interlinked with Emperor Haile Sellase's ruling period. During the regime of Haile Sellase-I number of contractors were organized to carry out road construction. The first one to be established by the Government to construct roads was Public Works Department. It was established to construct roads in Addis Ababa and in its surroundings. After few years this department was raised to a minister level and Addis Ababa also got the chance to establish its road development organizational structure. When it was decided for Addis Ababa to have a mayor and a council in 1942, the city roads construction and maintenance was organized under the municipality. To fulfill the road construction activities together with building works the "Road and Building works" department was established. This department stayed till the replacement of the Haile Sellase regime by the Derge regime performing its duties. However, no fundamental organizational change of the department was observed in the Derge regime.

In 1993 the existing Government (EPRDF) has established regional governments and gave them power to administer their regions with autonomy. During this time Addis Ababa was also established as one of the regions. The Addis Ababa administration during this period established the "bureau of works and urban development" and the bureau organized a department under it to carry out the road construction and maintenance works. The newly established road department constructed and maintained the city roads till the establishment of the Addis Ababa City Roads Authority (AACRA) in March 15, 1998 by regulation No.

7/1998 to be administrated by board of directors to construct, maintain and administer the road works in Addis Ababa by the city Administration. The total length of road constructed in the city till the establishment of the authority in March 1998 was 1300 km of which 900 km was gravel road and the remaining 400 km was Asphalt surfaced road.

The Addis Ababa City Roads Authority has done remarkable progress in the city roads expansion and upgrading in the last 11 years since its establishment. To date the City Roads length reached 2814 km of which 1534km is gravel surfaced and 1280km is Asphalt surfaced and the road net work coverage has reached 10.34% compared with the developed area of the city **(** http://www.aacra.gov.et).

Plate 1.2 Ring Road Kaliti Interchange

Plate1.3 Gotera Interchange

1.2 Road network in Addis Ababa

Addis Ababa City should have efficient and reliable transport services so that it could sustain being political city of Africa and centre of International organizations and to be a model to other cities with both management and service delivery capabilities.

Road network coverage of the city:

- Total width of the city is 54,000 hectare.
- Built up area of the city 169.02 Km^2.
- Constructed Asphalt Road in 7 m width 1280 Km.
- Constructed Gravel road in 7 m width 1534 Km.
- Total road network of the city in 7 m width 2814 Km till 7 July, 2009.
- The coverage of the road compared with the built up area is 10.34%

Addis Ababa City Ring Road , the study area main asphalt Road Projects constructed by contractors and AACRA’s Own force during the last 10 years. (http://www.aacra.gov.et)

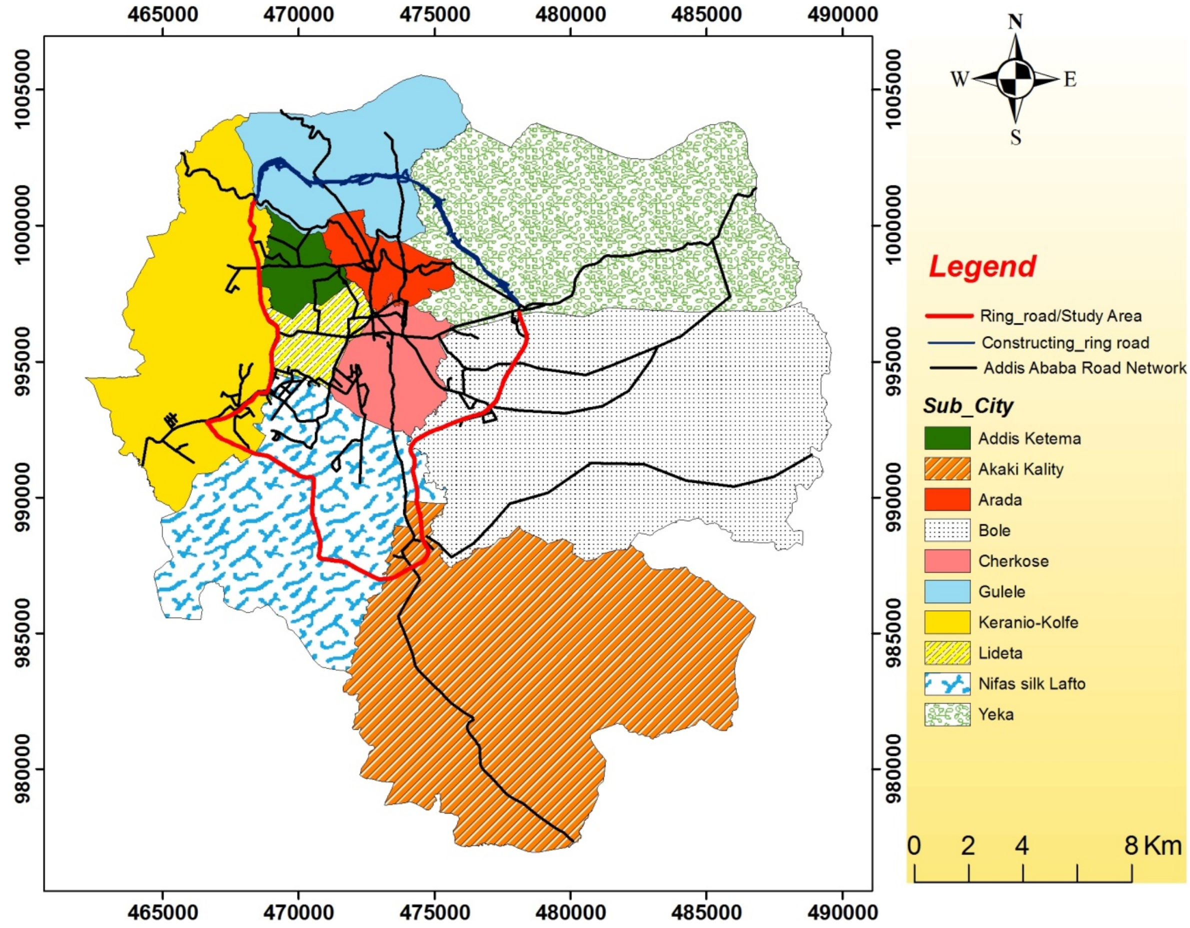

Fig 1.1 Road Network of Addis Ababa *(Source: Google earth)*

According to Addis Ababa City Roads Authority (AACRA), by the end of 2013 the road coverage will be 15%. In order to complete the above road construction there is a budgetary need of more than 15 billion Ethiopian Birr or USD 1 billion. This will be a very good opportunity for investors on the infrastructure sector (http://www.aacra.gov.et).

1.3 Objective of the Research

For the present study, following general and specific objectives were formulated;

1.3.1 General Objectives

(i) To define the degree of pavement distress conditions.

(ii) To recognize the causes of pavement distress.

(iii) To suggest appropriate rehabilitation measure.

1.3.2 Specific Objectives

Since the road is characterized by different deformation features, the main objective is to identify the degree of damages with possible causes and to evolve possible rehabilitation measures.
Thus, the specific objective of the present study includes;

(i) To collect data defining the controlling parameters along the ring road
(ii) To study, analyze and define the cause/s of pavement distress and associated failures
(iii) To identify the nature of pavement distress in the ring road
(iv) To categorize the causes of pavement distress
(v) To define and rate the effects of individual and combined parameters
(vi) To develop pavement distress and distress manifestation index
(vii) To evaluate the overall pavement conditions
(viii) To draw the lesson learned from the failures of the ring road
(ix) To advice some precautions for future similar scale road constructions in the city.

1.4 Methodology

In order to achieve the above objectives the following systematic methodology has been followed;

- Literature review on pavement deterioration problems, possible causes, rehabilitation measures, hydrogeology, geology, etc of the study area.
- Collection of Secondary data from different organization for the fulfillment of the study.
- Field works to overview the land use land cover, physiographic and geologic setup of the study area in order to see the overall changes in the study area.
- Visual inspection of pavement distress failures such as potholes, rutting, shoving, depression, crocodile cracks, delamination, raveling, longitudinal cracking, corrugation etc. Extent and severity level are also recorded.
- Evaluation of drainage conditions through their flow direction with respect to the ring road.
- Examination and interpretation of existing related maps, satellite imagery data (DEM 30 meter spatial resolution) and documents.
- Construction of a working database in GIS environment based on the collected maps, images and related spatial data.
- Undertaking detailed analysis on the existing results and procedures.
- Performing parameter mapping.

- Undertaking filed mapping and proper measurements.
- Updating the existing maps from the new field investigations.
- Assessments of existing laboratory testing to understand the existing pavement condition.
- Conducting detailed analysis and interpretation of the overall data through systematic parameter evaluation techniques using selected descriptive indices.
- To know the relative contribution of each of the causative factors of engineering geology parameters on the pavement distress, Raster Calculator and overlay analysis are performed using various tools in ArcGIS.
- Data processing, presenting and preparation of maps and graphs are done with the help of the following soft-wares, Global Mapper-11, ArcGIS-9.3, Surfer-8, Microsoft Excel and MSWord.
- Finally, organized presentation of the results and proper reporting in defined thesis writing practice.

1.5 Scope of the Present Research Study

Many standardize roads have been constructed in Addis Ababa in the past 12 years. Majority of the roads are giving their services to the required standards. However, some of the roads deteriorate before achieving their design periods. These in turn create a negative impact to the country's economy. Many problems are assigned for the deterioration of paved roads. Identifying the appropriate causes for the problem is the crucial step for the road construction sector. As the network of the road is increases, there is a gradual shift from construction of new pavement to maintenance and rehabilitations. Identifying the appropriate rehabilitation measures can have great effect on the total cost of the road construction.

From the reconnaissance visit and evaluation of the ring road, it is observed that most of the spans of the road and squares have been distressed. The nature of observed pavement distress includes potholes, shoving, rutting, crocodile cracks, depression, delamination, raveling and longitudinal cracking, potholes. Basically the above mentioned pavement distresses can be grouped into two classes. A structural distress incorporates those damaged parts of a pavement to sustain a load imposed to its surface, while a functional distress are those where pavements may not perform its intended function without causing discomfort to the users. A functional distress may or may not cause progressive change in to structural distress.

It is observed that almost *68.11 %* squares and 37.34 % of spans of road which is between two consecutive squares of ring road have distressed. Out of *68.11%* about 59.75% of squares have severely distressed. Similarly, out of 37.34 % spans of road almost 18.24 % have also severely distressed. Accordingly, the payment distress categorized based on their pavement conditions as excellent, good, fair, poor and very poor pavement status. However, further detailed categorizations and defining the cause of these different pavement distresses, needs a proper systematic mapping and geological-geotechnical evaluations in establishing its serviceability/pavement distress indices. Therefore, the present research may be helpful in adding value to the engineers who are participating in road construction and supervision works in identifying the different types of distress features, causes and rehabilitation alternative in Ethiopian context.

1.6 Application of the Results and Limitations of the Research

Till 2004, the road maintenance works in the roads of Addis Ababa were not organized with proper human power, equipment and material resources. Such inadequate resources coupled with organizational shortcomings within the municipality such as lack of formal policy and standards for road maintenance has resulted in sub-standard maintenance services which directly or indirectly has affected the pavement performance.

Addis Ababa City Roads Authority (AACRA, 2004) had annual expenditure of around 300 million Birr for road construction and maintenance, out of which more than 30 million Birr was expended for routine maintenances. Such expenditure for maintenance of the Addis Ababa roads is obviously too big and require special attention. Besides, AACRA do not have proper strategy until recently for the identification of distresses or for the selection of treatment options.

The Authority's position is now improving with the development of pavement management system (PMS), which, if properly implemented, can assist them to identify and quantify pavement distresses; hence, this research will have some input in upgrading the Authority’s maintenance management by indicating causes of pavement distress and to develop a database that support pavement management system . It is also a first attempt in the ring road, the data produced in this research could initiate and/or support further related research on the ring road or to adopt for other main roads in the city. Moreover, the present study may also be important for AACRA to manipulate road maintenance with proper cost and appropriate methods. As there is no previous research conducted on the Addis Ababa ring road there is a limitation on data. There is also shortage of secondary data; especially laboratory test and other important information about the road during construction.

1.7 Scheme of Presentation

The present study comprises the following chapters and is presented schematically as follows:

Chapter I covers the introduction of pavement distress types, causes and rehabilitation measures in general. Additionally, it covers about the history of the road construction, rehabilitation and road network in Ethiopia, objectives, methodologies, application of the result and limitations of the research and finally, the scheme of presentation.

Chapter II presents literature reviews on pavement condition assessment and failure criterion, pavement distress types, survey methods and possible causes, different maintenance and rehabilitation methods, previous pavement distress study in Addis Ababa and finally genesis of the present research study

Chapter III describes the study area through sub topics discussing about the road section, location, topography and geomorphology, drainage pattern and hydrogeology, regional geology, land use and land cover of the area, climate and seismicity of the area.

Chapter IV describe existing pavement condition assessment through sub topic assessment of existing pavement condition, existing ground condition (sub-grade) and preparation for pavement construction, existing pavement design assessment, assessment of existing pavement condition using visual inspection survey and finally ,comparing between Distress Density Method (DDM) and Distress manifestation index (DMI).

Chapter V discussed the assessment of possible causes of pavement distress through impact assessment of Engineering Geological parameters on road status condition (DMI), pavement distress suseptability analysis and finaly discussing about overall pavement distress condition and possible causative factors.

Chapter VI describe the alternative rehabilitation option through sub topics rehabilitation option and methods of maintenance and/or rehabilitation

Chapter VII deals with conclusion and recommendations that includes scientific and logical recommendations.

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Chapter 2 LITERATURE REVIEW

2.0 Preamble

During the present study a systematic and detailed literature review of the research problem has been carried out in order to establish a conceptual framework about pavement distress types, their associated causes and alternative rehabilitation option.

Pavement distress varies depending on factors such as; the type of construction material such as; sub base, base course and surfacing, the type of sub grade, drainage system, climate and traffic levels. These problems range from very minor to very serious and to a complex one. Moreover, they can be localized or affect major part of pavement layers of the road.

In order to carry out design for pavement rehabilitation, the existing pavement condition must be evaluated. Such an evaluation usually involves the assessment of the existing pavement structural adequacy, surface distress, roughness, rutting, and to lesser extent, skid resistance. The design of final stage pavement may only involve the assessment of pavement structural adequacy because the first stage of pavement is usually not old enough to exhibit distresses related to traffic loading and the environment (ATU, 1997).

In the present chapter various flexible pavement distresses are discussed. Further, discussion on each distress includes pictures, description of the distress, what problems are associated with distress type and typical causes that might be responsible for the distress.

There are methods by which the pavement distresses can be identified and rated. These include assessment of the road through visual condition survey, deflection survey, roughness survey, DCP tests and sub-grade and pavement layers investigations (AASHTO, 1993).

The methods by which the pavement distresses can be identified and rated are discussed in this chapter.

After conducting the investigation to differentiate the possible causes for the problem at hand, the suitable maintenance and rehabilitation methods were worked out. While evolving these remedial measures theoretical and practical aspects were considered. This has been discussed in the chapter six of this thesis.

2.2 Performance and Failure Criterion of Pavement

Pavement performance evaluation is an important activity in the maintenance and rehabilitation works. It includes evaluation of existing distresses, road roughness, structural adequacy, traffic analysis, material testing and study of drainage condition. This section deals with types of bituminous surfaces, types and causes of distresses (Fiker Alebachew, 2005).

Generally, concepts of pavement performance include some consideration of structural performance, functional performance, and safety. The structural performance of a pavement relates to its physical condition, i.e. occurrence of cracking, faulting, raveling or other condition which would adversely affect the load carrying capacity of the pavement structures or would require maintenance. The functional performance of a pavement concerns how well the pavement serves the user. In this context the riding quality or riding comfort is the dominant characteristics (AASHTO, 1993).

Pavements form the basic supporting structure in highway transportation. Each layer of pavement has a multitude of functions to perform which has to be duly considered during the design process. Different types of pavements can be adopted depending upon the traffic requirements. Improper design of pavements leads to early failure of pavements affecting the riding quality also (Mathew and Rao, 2006).

Flexible pavements generally consist of a prepared road bed underlying layers of sub base, base course and surface courses. In some cases the sub-base and/or base course will be stabilized to maximize the use of local materials.

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade (Fig. 2.1).

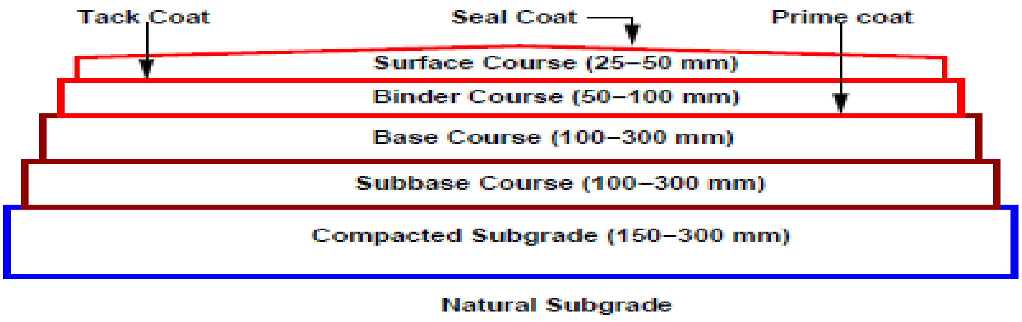

Fig 2.1 Typical cross section of a flexible pavement

Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layers of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat: Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course: Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are:

- ✓ It provides characteristics such as; friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade.
- ✓ It must be tough to resist the distortion under traffic and provide a smooth and skid-resistant riding surface.
- ✓ It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course: This layer provides the bulk of the asphalt concrete structure. Its chief purpose is to distribute load to the base course. The binder course generally consists of aggregates having less asphalt course by the binder course results in more economical design.

Base course: The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials

Sub-Base course: The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage and reduce the intrusion of fines from the sub-grade in the pavement structure. If the base course is open graded, then the sub-base course with more fines can serve as filler between sub-grade and the base course. A sub-base course is not always needed or used. For example; a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

Sub-grade: The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content (Mathew and Rao, 2006).

2.2.1 Types of Asphalt Pavement Distress

It is necessary to have a clear understanding of type of pavements distress before discussing the different methods of evaluation, identification of causes and selection of appropriate treatment. The major causes of these distresses can be categorized into three groups. These are;

(i) ***Load associate distress*** which are caused by over loading, high repletion and high tire pressure. The types of distresses categorized in this group are alligator cracking, corrugation, edge cracking, potholes, rutting and slippage crack.

(ii) ***Climate/ Moisture associate distresses*** which are caused by environmental condition and structural weakness in the pavement. The types of distresses categorized in this group are bleeding , block cracking, joint reflection, line cracking (longitudinal/ transversal) patching of climate/during swell cause distress, weathering, raveling and shoving

(iii) ***Drainage /Moisture associate distress*** which are caused by paving material due to method of construction and quality construction material and also lack of maintenance will further aggravate distress. The types of distresses categorized in this group are land and shoulder drop off, depression and swell (AASHTO, 1993).

Some of the pavement distresses are discussed thoroughly in the following paragraphs. During the detailed surface condition survey the nature, extent, severity and position of some of the following defects were recorded.

Alligator (fatigue) Cracking

Alligator cracks are interconnected cracks forming a series of small blocks resembling an alligator skin (Plate 2.1). The length of the cracked pieces is usually less than 15 cm on the longest side. In some cases, alligator cracking is caused by excessive deflection of the surface over unstable sub-grade or lower courses of the structure. The unstable support is usually the result of saturation of the bases or sub-grade. Although the affected areas in most of the cases are not large, occurring principally in traffic lanes, occasionally, will cover entire sections of pavements (AASHTO, 1993).

Block Cracking

Block cracking is an interconnected series of cracks that divide the pavement into approximately rectangular pieces. Block cracking is differentiated from alligator cracking by size and by not being load related. The blocks usually range from 30 by 30 cm to 300 by 300 cm (Plate 2.2). The cracking is caused mainly by daily temperature cycling and by shrinkage of the asphalt concrete. This distress is not load related however is usually associated with the asphalt aging and hardening (Fikir Alebachew, 2005).

Longitudinal Cracking

Longitudinal cracks basically run parallel to the centerline of the roadway (Plate 2.3). They most often occur at the joint between adjacent lanes of asphalt mixture or at the edges of the wheel paths in a rutted pavement. These cracks allow water to penetrate into the underlying layers; possible softening of stabilized layers and accelerating the development of fatigue cracks radiating outward from the longitudinal crack (AASHTO, 1993).

Transverse Cracking

They are Cracks perpendicular to the pavement's centerline direction (Plate 2.4). These cracks allow moisture to percolate down to the lower portion of the pavement layers and sub-grade soil to cause further disintegrations of road pavement. Moreover, the cracks make the pavement rough for the good ride of traffic. Thermal shrinkage of Hot Mix Asphalt (HMA) surface due to low temperature or asphalt binder hardening is one of the causes for the development of these cracks. These cracks may also be reflexive cracks due to failure beneath the surface of HMA layer (AASHTO, 1993 and ORN 18, 1999).

Bleeding and Fatting-up

Bleeding is a film of bituminous material on the pavement surface that creates a shiny, reflective surface. Bleeding is caused by excess asphalt cement in the mix and/or low air void content. During hot weather the asphalt fills the voids of the mix and then expands out onto the surface of the pavement. The process is not reversible during cold weather, thus asphalt binder will accumulate on the surface (NCDT, 2010).

Plate 2.1 Alligator Cracking

Plate 2.2 Block Cracking

Plate 2.3 Longitudinal Cracking

Plate 2.4 Transverse Cracking

Bleeding is usually observed first in the wheel paths and is the result of bitumen being forced to the road surface by the action of traffic (Plate 2.5). Here aggregates are totally covered by continuous film of binder.

Fatting-up of the surface is a less extreme form of bleeding where the surface becomes very smooth but there is insufficient binder to form a continuous film on the surface (Plate 2.6). In this case aggregates are visible even if they have smooth and shiny appearance (ORN 18, 1999).

Fretting and Stripping

Fretting is the progressive loss of fine aggregate from the road surface and occurs when the small movements of individual particles, under the action of traffic, exceeds the breaking strain of the bitumen (Plate 2.7). It tends to occur later in the life of the surfacing after the bitumen itself deteriorates with age and usually begins in areas of high traffic stress such as sharp bends.

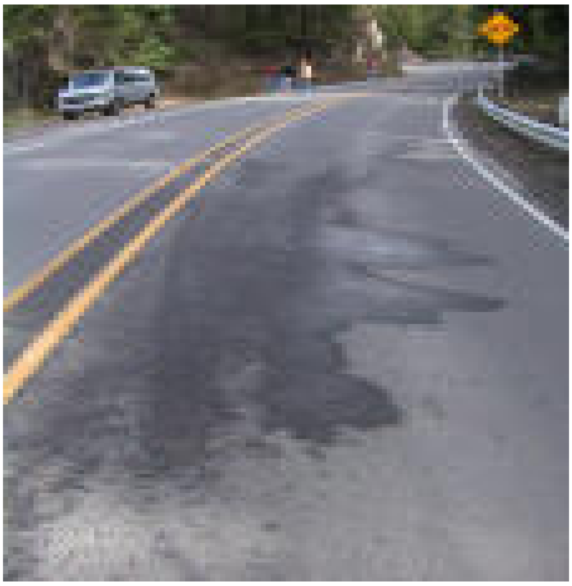

Plate 2.5 Bleeding on the road surface

Plate 2.6 Fatting-up of the road surface

Plate 2.7 Fretting of aggregates

Plate 2.8 Stripping in Asphalt

The loss of fine aggregate at the surface results into lack of mechanical interlock which can eventually lead to the loss of coarse aggregate and the formation of potholes. Stripping in asphalt surfacing is the result of the displacement of binder from the surface of the aggregate caused by the combined action of water and traffic (Plate 2.8). In most of the cases there is a migration of the binder towards the surface of the road resulting into localized bleeding at the surface and unstable poorly coated aggregate beneath. Although the mechanisms of failure differ, the result of both fretting and stripping types of deterioration will be a shallow pothole or a series of potholes (ORN 18, 1999).

Aggregate Polishing

The micro texture of the surfacing, as measured by the resistance to polishing of the aggregate, is the dominant factor in wet skidding resistance at lower speeds (Plate 2.9). The assessment of polishing is more difficult than that of the surface texture, but will be unnecessary if surfacing aggregates having a satisfactory minimum Polished Stone Value were used during construction (Department of Transport, 1994a; as cited in ORN 18, 1999).

Rutting

Rutting is load associated deformation and will appear as longitudinal depression in the wheel paths. It is the result of an accumulation of non-recoverable vertical strains in the pavement layers and in the sub-grade (Plate 2.10). This type of rutting is not associated with any shoving in the upper layers of the pavement unless it becomes very severe. The width of the running surface and the traffic flow govern the number of observable wheel paths on paved roads. Rut depths should be recorded in the wheel path showing the most rutting. On most roads this is usually the verge side wheel path because here the road pavement is generally weaker as a result of higher moisture contents and less lateral support (ORN 18, 1999).

Depressions

Depressions which are localized, caused by settlement of the pavement layers, construction faults and differential movement at structures, particularly culverts, should be recorded. These are easy to see after periods of rain as they take longer to dry than the rest of the road. When the road is dry, they can also be identified by the oil stains that occur where vehicles cross the depression (Plate 2.11). The depth should be measured using the 2 meter straight-edge and calibrated wedge (ORN 18, 1999).

Pothole

Potholes are usually caused by a localized weakness in the pavement resulting from a combination of such factors as too little asphalt, thin surface thickness, too many fines, too few fines, or poor drainage (Plate 2.12). Unless repaired promptly, their growth will be accelerated by traffic and moisture collected in the pothole.

Plate 2.9 Polished Aggregates

Plate 2.10 Rutting on the Wheel-path

The occurrence of potholes often coincides with a period of heavy rainfall during which water penetrates the asphalt layer through cracks, usually closely spaced alligator cracks, and softens the granular base course. Fine material is pumped through the cracks so that the underlying base support is weakened resulting in removal of the adjacent material by traffic. Once the first piece is dislodged, the pothole grows rapidly since all other pieces are more easily dislodged than the first piece. Potholes can develop along any crack that occurs in a pavement for example; longitude or transverse cracks either can deteriorate (Fikir Alebachew, 2005).

Raveling (very porous asphalt)

Raveling is the on-going separation of aggregate particles in a pavement from the surface downward or from the edges inward (Plate 2.13). Usually, the fine aggregate wears away first and then leaves little "pock marks" on the pavement surface. As the erosion continues, larger and larger particles are broken free and the pavement soon has the rough and jagged appearance typical of surface erosion. There are many reasons why raveling can occur, however one common cause is placing asphalt too late in the season. This is because the mixture usually lacks warm weather traffic which reduces pavement surface voids, further densification, and kneading of the asphalt mat. For this reason raveling is more common in the cold climates (Snow Belt) (http://www.pavemanpro.com/article/identifying_asphalt_ pavement _defects/).

Plate 2.11 Depression

Plate 2.12 Potholes with alligator crack

Plate 2.13 Raveling

Plate 2.14 Slippage crack

Slippage Cracks

Slippage cracks are crescent-shaped cracks or tears in the surface layer(s) of asphalt where the new material has slipped over the underlying course (Plate 2.14). This problem is caused because of lack of bonding between layers. This is often because a tack coat was not used to develop a bond between the asphalt layers or because a prime coat was not used to bond the asphalt to the underlying stone base course. The lack of bond can be also caused by dirt, oil, or other contaminants preventing adhesion between the layers (http://www.pavemanpro.com/article/identifying_asphalt_pavement_defects).

Plate 2.15 Edge Cracks

Plate 2.16 Shoving

Edge Cracks

Edge Cracks travel along the inside edge of a pavement surface within one or two feet. The most common cause for this type of crack is poor drainage conditions and lack of support at the pavement edge (Plate 2.15). As a result underlying base materials settles down and become weakened. Heavy vegetation along the pavement edge and heavy traffic can also be the instigator of edge cracking.

Shoving

Shoving is the formation of ripples across a pavement. This characteristic shape is why this type of distress is sometimes called wash-boarding (Plate 2.16).

Shoving occurs at locations having severe horizontal stresses, such as intersections. It is typically caused by: excess asphalt; too much fine aggregate; rounded aggregate; too soft asphalt; or a weak granular base.

Delamination

Delamination is the localized loss of the entire thickness of an overlay (Plate 2.17). It is caused by the lack of a bond between the overlay and the original pavement. Water again is the culprit when it gets between the two layers of pavement. Delamination is usually confined to the wheel path area and takes several years after the overlay to become a serious problem. Once they occur, they are difficult to properly patch.

Cleaning the old surface and applying a light asphalt emulsion tack coat will go a long way toward alleviating this problem. A tack coat is especially helpful when the overlay thickness is two inches or less. (T. Hall et al, 2002)

Plate 2.17 Delamination

Plate 2.18 Corrugation

Corrugations

Corrugations consist typically of a series of ridges perpendicular to the centre line of the road and usually extend across the whole width of the carriageway (Plate 2.18). Their spacing, or wavelength, is usually in the range of 0.5 -1.0 m but can, in some circumstances, be as much as 10 m. In paved roads they are caused by instability in either the asphalt surfacing or in an unbound road base under a thin seal. There is generally no need to measure the severity of the corrugations as it will not affect the selection of the remedial treatment (ORN 18, 1999).

2.2.2 Major Causes of Distress

Deterioration in flexible pavements with asphalt base is generally associated with traffic loading and/or with environmental factors. The major causes for the above mentioned distresses can be grouped in to three categories. The first is due to overloading that includes excessive gross loads, high repletion of loads and high tire pressure. Second climatic environmental conditions may cause surface irregularities and structural weaknesses on the pavement. For example; volume change of soil due to wetting and drying resulting from improper drainage may be the prime cause of pavement distress. A third causes may be disintegration of the paving materials due to method of construction and quality of construction material. Use of contaminated aggregate and inadequate construction supervisor are also factors that may aggravate pavement distress. Lack of maintenance will further aggravate pavement distress.

The different types of pavement distresses discussed previously above can be associated with material properties through considerations of various mechanisms and manifestation of distress. Failure modes can accordingly be divided into three categories: (i) rupture (ii) distortion, and (iii) disintegration (Fikir Alebachew, 2005).

2.3 Method of Pavement Distress Survey

Distress surveys can be grouped in to two broad categories; non-destructive and destructive surveys**.** The non-destructive survey includes (but not limited to) visual survey, roughness survey and deflection survey. The destructive survey includes the DCP survey and test pit excavation. Details of each type of survey are as indicated here under, some of the methods are described in the following sub section.

2.3.1 Visual Condition Survey

A visual inspection of the pavement condition, identifying pavement distress types, quantities and severities is an invaluable aid in the evaluation of a pavement's performance, and the causes of poor performance in either structural or functional modes. One of the most comprehensive visual inspection systems developed is the Pavement Condition Index (PCI) procedure, developed by the U.S. Army Corps of Engineers in the early 1970's and extensively refined and improved over the past 20 years. The system is built around the concept of the Pavement Condition Index or PCI. A new pavement (theoretically distress-free) has a PCI of 100. For each distress measured, there are deduct values depending upon the nature of the distress, its severity and quantity. The deduct values are summed, adjusted to take into account the total number of distresses identified, and then subtracted from 100 to give the PCI index for the pavement.

The power of the PCI inspection system revolves around the provision of a defined index between 0 and 100 that all pavements must lie in between. In addition, all of the detailed distress data is available on a section and sample unit basis so that the engineering manager is not reliant upon the PCI alone when deciding what maintenance action to pursue for a specific section. This combination of disaggregate data (the individual distress types) and an aggregated close-ended index for comparison purposes (the PCI) is what makes the PCI inspection methodology particularly appropriate for the current project.
A rough breakdown of pavement classification by PCI is given in Table 2.1.

Table 2.1 Pavement classification by Pavement Condition Index (PCI)

PCI Range	Pavement Condition
85 to 100	Very Good
65 to 85	Good
50 to 65	Fair
40 to 50	Poor
20 to 40	Very Poor
<20	Failed

This section PCI can then be used to compare sections with one another, to monitor pavement performance over time for that section, and to show a picture of the entire network condition by examining the number of sections in each PCI range. In addition, relationships between PCI and cost can be established, making budget estimation and predictions on more accurate and easier to perform. (DEHLG, 2004)

In the present study distress manifestation index was utilized for the evaluation of status of ring road. Distress manifestation index (DMI) is an integral part of the PCI but DMI can also be used independently as a measuring of visible pavement distress. The DMI or particularly some of its component can be used as a proxy for assessing pavement structure adequacy and for identifying pavement section which may require a corrective action due to specific distress condition. DMI is a systematic method for classifying and assessing the visible consequences of various distress mechanisms (i.e., distress manifestation). DMI was developed in 1975 and its use was commenced Ministry-wide in 1978. DMI classifies distress manifestations into 15 categories, which are rated by severity and density (Hajek et al., 1986).

2.3.2 Deflection Survey

This comprises an evaluation of the structural adequacy and load-carrying capacity of an existing pavement and of its various components without destroying its components. For doing so, measurements have to be made at or near to the surface of the pavement and the results of these measurements are related in some way to the structural properties of the pavement section. In nondestructive pavement evaluation the structure of the pavement is not altered by the external force or energy input and hence such measurements can be repeated at the same location as often as necessary. Such testing methods can be further grouped into three classes as;

(i) Measurements of response to a static load or to a single application of a slow moving load.

(ii) Response to a repeated or dynamic load

(iii) Response to a controlled service of nuclear radiation. (Asphalt Institute,1983).

2.3.3 Roughness Survey

Roughness is an indication of the longitudinal irregularities of the pavement surface which influence the vehicle ride. Roughness is a good indicator of how well the road is serving to the travelling public. Studies have shown that roughness affects the costs of vehicle operation and the life cycle costs of pavements. A significant portion of pavements are rehabilitated due to an unacceptable ride rather than the structural problems. For this reason roughness monitoring constitutes an important rehabilitation design input.

Roughness can be measured using a Bump Integrator and expressed through the International Roughness Index (IRI). Typical values of IRI are dependent on the type of road and its condition (Table 2.2) (ERA, 2002 (b) as cited in Hanok Tesfaye, 2012).

Table 2.2 Condition of the Road vs. IRI

IRI Ranges	Road Condition
Lower than 6	Very good
6 to 11	Good
11 to 15	Fair
15 to 19	Poor
Larger than 19	Very poor

2.3.4 Dynamic Cone Penetrometer (DCP) Survey

The dynamic cone penetration test (DCPT) was originally developed as an alternative for evaluating the properties of flexible pavement or subgrade soils. The conventional approach to evaluate strength and stiffness properties of asphalt and subgrade soils involves a core sampling procedure and a complicated laboratory testing program such as resilient modulus, Marshall tests and others (Livneh et al., 1994). Due to its economy and simplicity, better understanding of the DCPT results can reduce significantly the effort and cost involved in the evaluation of pavement and sub-grade soils.

The DCP apparatus, which is an instrument, designed for the rapid in-situ measurements of the road sub-grade. Continuous measurements can be made down to a depth of 850 mm or, when extension shafts are used to a recommended maximum depth of two meters. When the sub-grade consists of different layers with different strengths, the boundaries are identified. The thickness of boundaries is identified from the DCP plots and the thickness of the layer is determined (Salgado and Yoon, 2003)

2.3.5 Pitting, Sampling and laboratory result analysis

Test pits represent one of the common methods of investigation to determine the thickness and type of the various pavement layers and to assess the sub-grade. Samples from each pavement layer and sub-grade can be collected for visual inspection and subsequent laboratory testing can be performed. The test results can be used in the rehabilitation design analysis and to check conformance of the material with standard specifications.

Test pits shall be dug through the pavement layers and into the sub-grade soil for a minimum total depth of 0.80 m (alternatively, the pit should extend at least 0.20 m below sub-grade level). The spacing of the test pits should depend on sound engineering judgment and be guided by a prior review of all possible documents, as well as a visual pavement condition survey. However, as a general guideline, one test pit every 500 m, alternating on either side of the roadway, is recommended. The position of each test pit shall be accurately determined and reported. (ERA, 2002(a)).

According to ERA (2002(a)), the data from the test pits would normally include;

a) Layers of the pavement structure: type, thickness, and maximum size of aggregates of each layer.

b) Sub-grade: in-situ dry density; in situ moisture content; gradation; Atterberg limits; classification according to AASHTO and/or USCS systems; and in situ CBR obtained from correlation with DCP testing.

Laboratory testing should be carried out on samples collected at anticipated subgrade level from each bore/test pit location to collect the result required in Table 2.3. All tests should be carried out in standard registered laboratory and in accordance with relevant test methods.

Table 2.3 Tests required from each test pit

TESTED	RESULT PROVIDED AS
Field moisture content	%
Sieve grading analysis	% passing 2.36 mm % passing 425 µm % passing 75 µm
Liquid limit	%
Plastic limit	%
Plasticity index	%
Linear shrinkage	%
Laboratory soaked CBR	%

Laboratory soaked CBRs should be carried out on samples compacted to a dry density ratio of 100% standard compaction, at standard optimum moisture content and with the appropriate surcharge.

If the sample from adjoining bores/test pits are visually classified as being of same soil type, and their similarity is confirmed by grading and plasticity index result, then laboratory soaked CBRs need only be carried out on one sample from either of two adjoining bores/test pits. (PRSCDM, 2008).

2.3 Maintenance and Rehabilitation Option

Pavement management, in its broadest sense, encompasses all the activities involved in the planning, design, construction, evaluation, maintenance and rehabilitation of the pavement portion of a public works program.

A pavement management system (PMS) is a set of tools or methods that assist decision makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a given period of time. The function of a PMS is to improve the efficiency of decision-making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the agency (ERA, 2002(b)).

2.3.1 Maintenance Priorities

Pavement maintenance is work performed from time to time to keep a pavement, under normal conditions of traffic and forces of nature, as nearly as possible in its as-constructed condition.

It is also very important to allocate the limited resources available for the maintenance purposes in such a way that it satisfies objectives and maintenance polices of the roads authority. The following basic approaches can be used to determine priorities for pavement maintenance:

(i) **Urgent maintenance**- such as emergency repairs to pavements that are cut, removal of debris and other foreign objects.

(ii) **Routine drainage maintenance**; ditch cleaning and deepening, cleaning bridges and culverts, backfilling scoured areas, constructing check dams and etc.

(iii) **Routine maintenance of pavement**- such as patching, sealing and repairing of road furniture.

(iv) **Periodic maintenance**- such as resurfacing.

As indicated above the routine drainage maintenance should get more priority than the routine maintenance on pavements as repairing pavement surface defect caused by drainage problem is wastage of resource unless the drainage is first corrected (ORN 1, 1995, as cited in ERA, 2002(b))

2.3.3 **Rehabilitation Concepts**

Rehabilitation Work undertaken significantly extends the service life of an existing pavement. This may include overlays and pre overlay repairs, and may include complete removal and reconstruction of the existing pavement, or recycling of part of the existing materials. The primary function of the maintenance activity is to preserve the existing pavement so that it may achieve its applied loading, while rehabilitation is undertaken for significant increase in the functional life.

A rehabilitation work comprises activities such as major resurfacing, restoration, rehabilitation and reconstruction. It can be considered as major maintenance operation that is undertaken to considerably extend the service life of an existing pavement. Therefore, rehabilitation operations are different from routine or periodic maintenance in that the primary function of the latter activity is to preserve the existing pavement so that it may sustain the applied loading while rehabilitation is carried out to considerably prolong the functional life.

Pavement rehabilitation can be subdivided into two major categories (ERA, 2002(b));

(i) Rehabilitation methods other than overlay.

(ii) Rehabilitation methods with overlays.

For the present research study a combinations of some of the aforementioned methodologies were adopted. Visual condition survey, Examination and interpretation of existing related maps, satellite imagery data and documents, Construction of a working database in GIS environment based on the collected maps, images and related spatial data, Undertaking detailed analysis on the existing results and procedures, Performing parameter mapping and in-situ investigations, Undertaking filed mapping, proper measurements and sampling, finally updating the existing maps from the new field investigations to provide alternative rehabilitation option.

2.4 Previous pavement distress study in Addis Ababa

Fiker Alebachew (2005**)** conducts a research on pavement distress on Addis Ababa city Arterial road causes and maintenance option. In this research he adopted various distress surveys. Distress surveys can be grouped in to two broad categories; non-destructive and destructive surveys**.** The non-destructive survey includes (but not limited to) visual survey, roughness survey and deflection survey. The destructive survey includes the DCP survey and test pit excavation. According to his research using these various survey, he identified the causes of deterioration of Addis Ababa arterial roads and he stated that the proper maintenance option is required.

Elias Gebreselassie (2012) reported in the conference entitle 'The precarious state of Ethiopia's and Addis Ababa's roads'' on 06 August 2012 indicated that Ethiopian roads and especially those found in the capital city of Addis Ababa have been suffering from damages primarily due to lack of construction management (construction material handling and waste disposal) laws which directly impact on the road drainage systems, causing road flooding problems and premature road pavement failure.

Manaye Ewunetu a Chartered Engineer, Environmental and Water Resources Manager, and Owner and Managing Director of ME Consulting Engineers UK Ltd based in London says that lack of periodical road drainage maintenance is threatening the viability of Addis Ababa city's road infrastructure.

"Construction material handling and waste disposal activities like dumping gravel, sand and excavated materials on the side of the public roads which clog the drainage inlet system are resulting in road flooding and causing considerable inconvenience to the public as well as economic losses," say Manaye adding that road drainage problems can also partly be caused by capacity problems (under designed drainage systems). Other problems mentioned by

AACRA were regarding issues of border demarcation with regards to road projects sometimes overlapping with road side construction projects as well as problems with shoddy cobblestone works and disposal of solid homes and industrial wastes on the city's numerous road inlet systems (Elias Gebreselassie, 2012).

2.5 Genesis of the Present Research Study

From literature review and past experience of Addis Ababa arterial roads, this has been learned that majority of pavement deterioration have caused due to lack of periodical road drainage maintenance, the type of construction material such as; sub base, base course and surfacing, the type of sub grade, drainage system, climate and heavy traffic levels and inappropriate constriction design. The main objective of the present research is to identify that which type of causes are more contributing to the deterioration for the specific span of distress road and accordingly to suggest appropriate remedial measures. An important issue to conduct the present research is that the design life of the ring road construction was for about 20 years. However; it shows manifestation of distress just within 9 years, well before its actual design period. As a matter of fact no attention is being paid for maintenance after the construction of road. Therefore, through the present study an attempt is made to investigate the possible causes of pavement distress and to evolve suitable maintenance options for Ring road within the study area. Besides, it has been observed that this pavement distress is resulting into inconvenience to traffic movement (Plate 2.20). The present research will also present a useful guide for pavement management system (PMS) which may be followed for other road projects in the country.

The present study was focused to identify the possible causes of pavement distress, as discussed in the above paragraph, and to workout appropriate remedial measures for Addis Ababa ring road, routes nearly round the city except the northern section of the city. The road failures, in general, noticeably documented in the form of pavement distress that manifest different associated failures.

The dominant (frequent occurrence) distress types which were observed in the present study area are Pothole, Shoving and Rutting. Besides, other types of distress which is not frequent were also observed these include; Depression, Delamination, Crocodile crack and Raveling. These distress types were identified during visual condition assessment (Plate 2.19). Pavement distress defines the condition of a road; when the maintenance is needed, for ranking or prioritization, and as the number used to forecast pavement condition.

For the present study an integrated approach was followed to meet out the objectives of the study. Various data/ information on geology, engineering geology and structures were delineated through previous maps, observations made during present study and through satellite imagery data interpretation.

Plate 2.19 Pothole, Shoving, Rutting and Raveling distress types

Plate 2.20 Traffic flow disturbance, Kality area

Later, analysis of data was done using statistical approaches and documented in GIS environment. Besides, detailed visual condition survey was done by developing a new method and by utilizing a standard method of PMI (Pavement Manifestation Index). Further, analysis was performed through systematic parameter evaluation techniques using selected descriptive indices.

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Chapter 3 THE STUDY AREA

3.0 Introduction

Roads forms an integral and important part of any transportation system. A city's road network should be efficient in order to maximize economic and social benefits. They play a significant role in achieving national development and contributing to the overall performance and social functioning of the community. It is acknowledged that roads enhance mobility, taking people out of isolation and therefore helps in bringing prosperity in general.

The present research study was selected due to several reasons. Among these, the first and the foremost reason is that the ring road reduced traffic congestion in the area and linked neighborhoods with market places, schools, churches and clinics and the diminishing traffic congestion in turn reduced the risk of traffic accidents. The others were that the road allowed heavy vehicles entering the city of Addis Ababa from the main radial routes to bypass portions of the city; mainly, it became possible to avoid the city center. Therefore, the study needs great emphasis in identifying and assessing the different pavement distress. Besides, the study has also attempted to come up with proper design to enhance the service life of the road.

The geology, physiographic, drainage pattern and hydrogeology, and seismicity of the area are described in this chapter. Besides, the climate and land use and land cove of the study area is also discussed in this chapter.

Most of the data/ Information were acquired as primary data, while secondary data was also utilized for supplementing the data collected during the field session of the present research work.

3.1 Location

The Addis Ababa ring road, the study area, routes nearly round the city except the northern section of the city (Fig.3.1). The city overlies at the western margin of the Main Ethiopian Rift and is a part of western highland of Ethiopian. It is passing through the main squares such as Meganagna, Bole, Kality, Hana Mariham (Haile Garment), Lebu, Mekanissa (Germen), Jemo, Ayertena, Zenebework (Alert Hospital), Total (sost qutir Mzoriya), Torayloch, and Asrasimint Mazoria at the end Winget square. The total length of the road is 33.2 Km. The starting point of the research project road is geographically located at 996802m North & 478108m East at Megenagna and ends at Winget which is geographically located at 1000941m North & 468402m East.

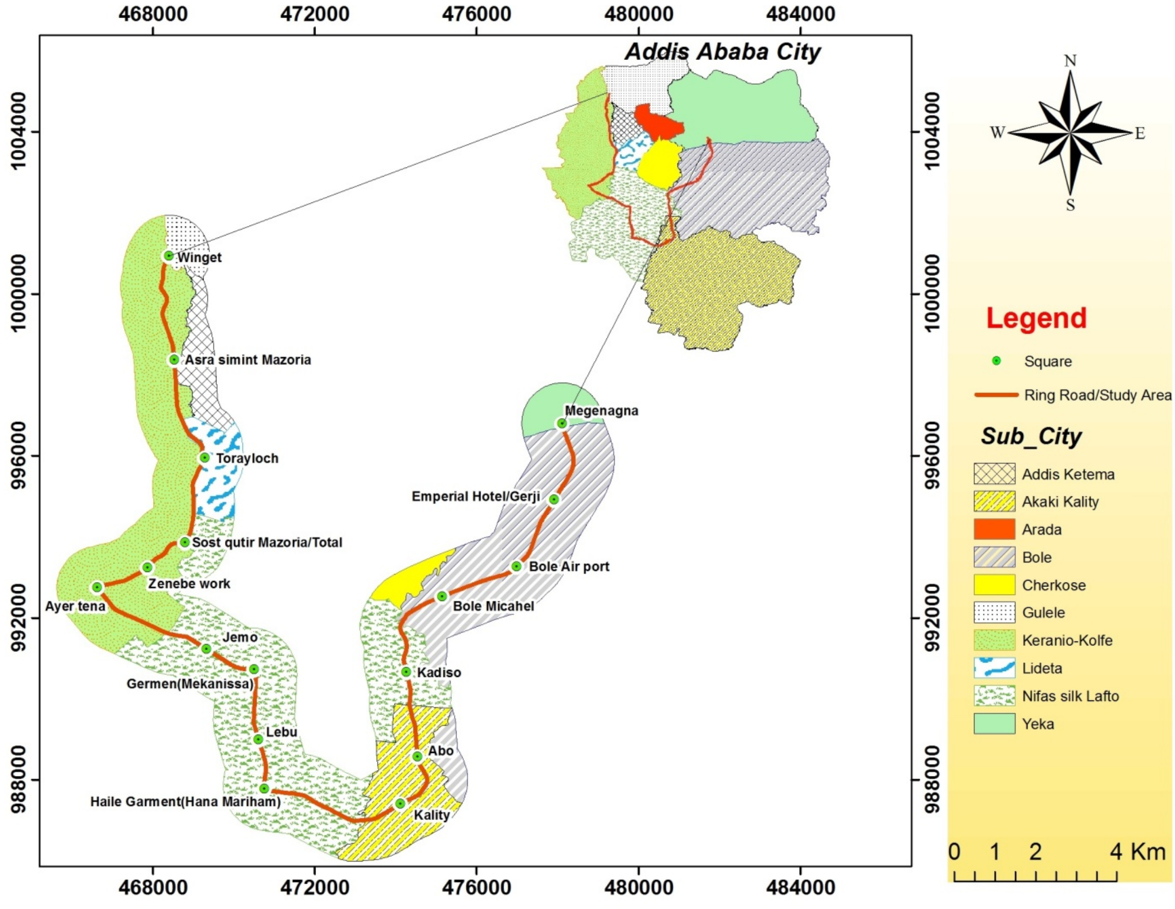

Fig 3.1 Location Map of the Study Area

3.1.1 About road section

The Addis Ababa ring road was initiated as the part of the region's commitment toward implementing the City's Master plan proposal and enhancing peripheral development. The ring road construction plan was divided in to three major phases. These phases connect all the five main gates in and out of Addis from all other regions (Jimma, Debre Zeyit, Mekele, Gojam and Ambo). The present study which is phase one and two consists of highly urbanized eastern and western legs with a semi-urban southern section (Table 3.1). The northern section, which is phase three and will close the loop, is in constructing stage.

The ring road was commenced in 1999 G.C and was completed 2004, six years later (Peng et al., 2008). Now the constructed road is about nine years old. During this service period several types of distresses have occurred on the pavement due to various conditions. In this road section no previous work has been done so far. The present study, therefore, is planned to lay the foundation for future detailed road evaluation with respect to Geotechnical or engineering geological aspect.

Table 3.1 Ring Road Constructed Phase one and two & sub divided in to four as described below

Phase	**Section Description**	**Length (Km)**
1A	Kality to AyerTena Square	11.0
1B	AyerTena to Winged Square	10.0
2A	Kality to Bole Airport Square	8.2
2B	Bole Airport to Megenagna Square	4
		33.2

3.2 Physiographic

Ethiopia can be divided into four major physiographic regions widely known as the Western plateau, Southern plateau, the Main Ethiopian Rift and Afar Depression (Mengesha Tefera et al., 1996).

Addis Ababa is located on a plateau with an elevation ranging from 2000 to 2800 ma.s.l on the shoulder of the western Main Ethiopian Rift (MER) escarpment. The morphology of Addis Ababa is a direct reflection of the different volcanic stratigraphic successions, tectonic activities and the action of erosion between successive lava flows (Tamiru Alemayehu et al., 2006).

The physiographic map of Addis Ababa shows that the City is founded on an area with a well developed morphology. It is surrounded by high rising mountain systems in all directions and the center of the city lies on an undulating topography with some flat land areas. The urban area of the city is deeply dissected by numerous valleys formed by the river systems crossing the city from north to east.

Intoto mountain ridge forms the northern boundary of the city following the East-West trending Ambo - Kassam major fault system. The elevation of this ridge ranges from 2600 to 3200 m. The volcanic mountains; Mt. Weche chain the west, Mt. Furi in the south - west and Mt. Yerer in the south east are the high massive volcanic centers rising to elevations of 3385 m, 2839 m and 3100 ma.s.l, respectively (Fig. 3.2 and Fig. 3.3) (Habtamu Solomon, 2011).

The center of the city lies on an undulating topography with some flat land areas. The topography is undulating and form plateau in the northern, western and southwestern parts of the city, while gentle morphology and flat land areas characterize the southern and south eastern parts of the city. Moreover, it is not uncommon to see sharp changes in the inclination of the slope and some flat land areas in different parts of the city (UNEP/UNESCO/UN-HABITAT/ECA SCIENTIFIC, 2003)

3.3 Drainage Pattern and Hydrogeology

Addis Ababa lies within the Awash River Basin. The water divide between Awash Basin and Blue Nile Basin lies on the top of Intoto Ridge. The catchment area of Akaki River basin that totally includes Addis Ababa area is divided in to two sub basins; the Big Akaki River (Eastern) sub basin and the Little Akaki River (Western) sub basin.

The Akaki and Bulbula are the main rivers crossing the city and draining towards the south before joining the Awash River. The drainage pattern is governed by the geology and physiographic set up of the area.

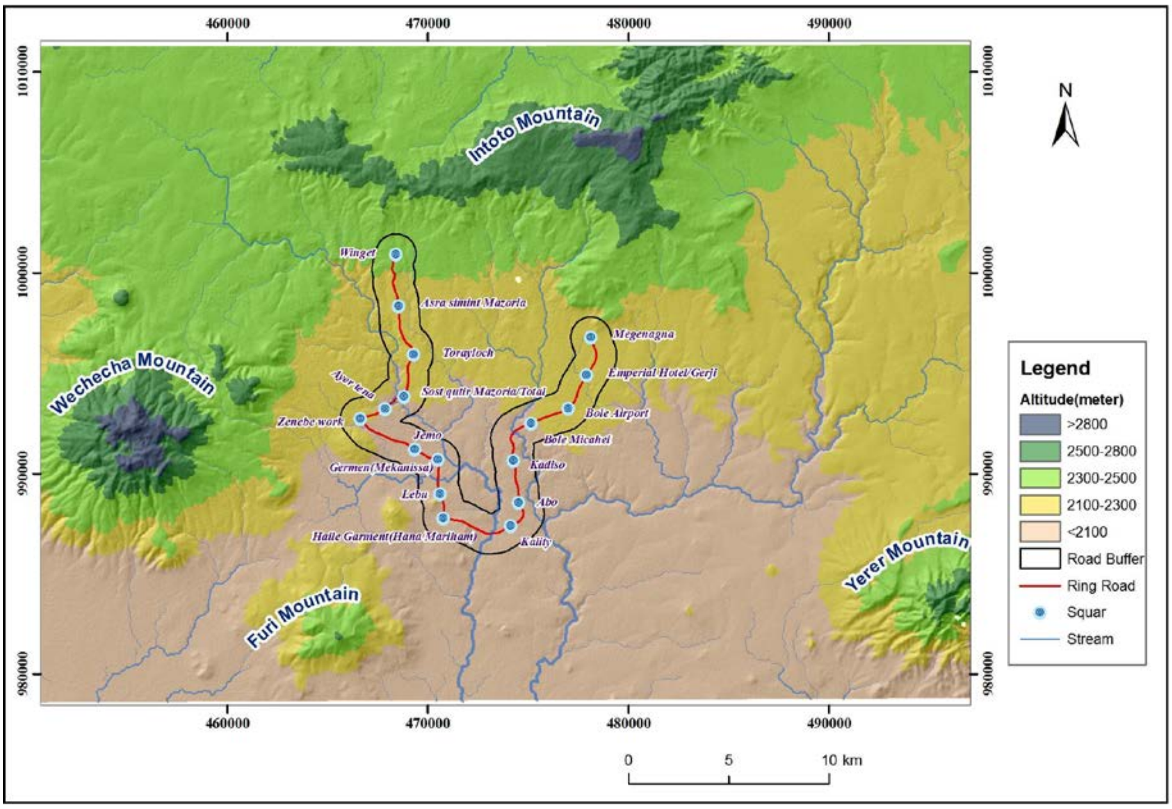

Fig 3.2 Physiographic map of Addis Ababa and the surrounding area (Source: Aster DEM (30m resolution))

The streams of Addis Ababa drain towards south from Intoto ridge, south east from Mt. Wecheca and Mt. Furi and towards southwest from Mt.Yerer and other elevated areas of the eastern out skirts of the city (Fig. 3.5).

The potential streams in the city are Little Akaki, Bantyiketu, Kurtume, Kebena, Lafto, Jemo Ginifile, and Big Akaki. Other streams are intermittent in nature. Streams are dense with deep valleys on top of mountains such as Intoto ridge forming radial and dendritic drainage patterns (Fig.3.4). In the southern part of the city the density of the streams is reduced and the main rivers show meandering type of flow. This is due to the decrease in the gradient of the valley floor. In general, streams are structurally controlled which is characterized by plains, rolling terrains and river gorges. (Fig 3.5)

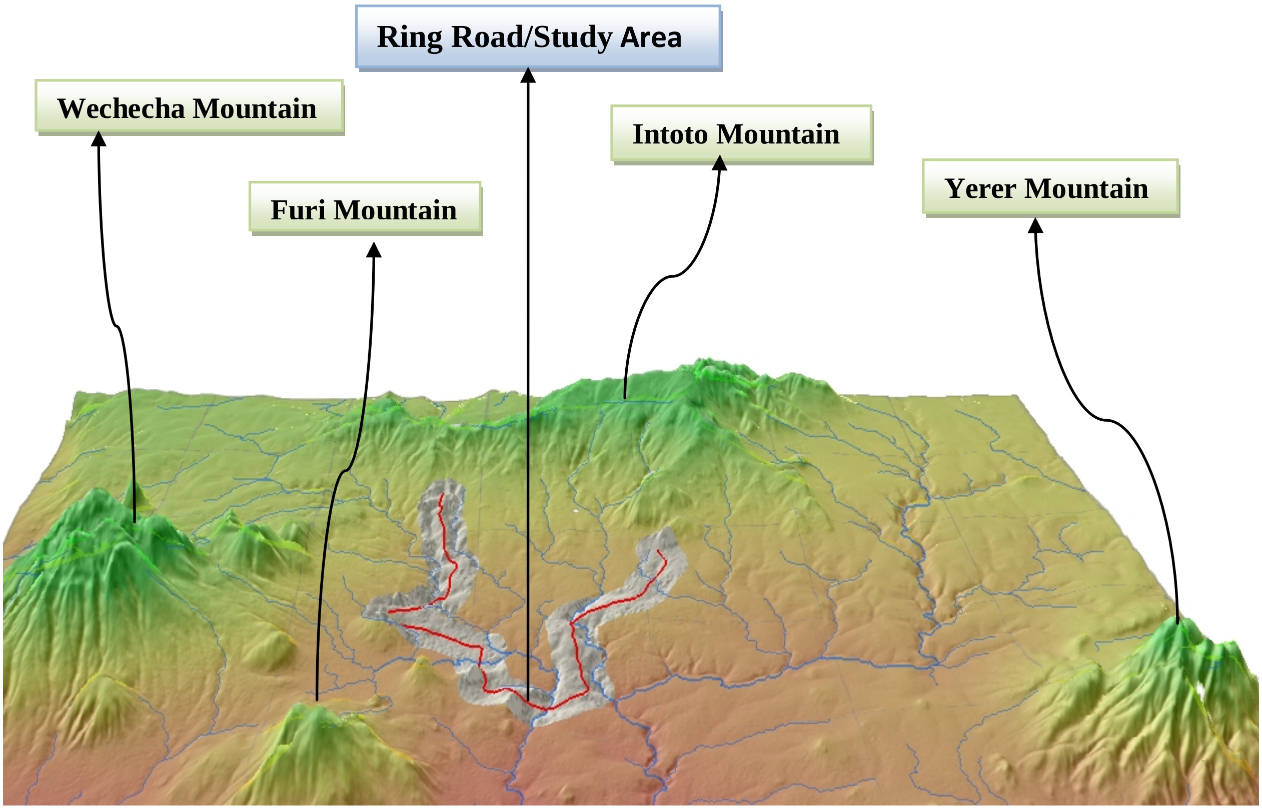

Fig3.3- 3D map of Addis Ababa and the surrounding area (*Source:* Aster DEM (30m resolution))

The major ground water aquifers in Addis Ababa are basalts, rhyolities, trachytes, scoria, trachy basalts, welded tuffs, unwelded tuffs and the unconsolidated materials of volcanic origin as depicted from boreholes previously drilled for water supply. The main aquifers in Addis Ababa area can be categorized into three groups which includes hallow aquifers of the weathered volcanic rocks and alluvial sediments along the river courses, deep aquifers of the fractured volcanic rocks that tap fresh ground water and thermal aquifers along Filwoha fault.

These aquifers are characterized by fracture and inter granular porosity. Basalts are the major water bearing zone in the area due to its fracture porosity where as unconsolidated volcanic sand alluvial sediment sunder favorable conditions stores water. The black cotton soils in the south of Addis Ababa act as impervious material (Tamiru Alemayehuetal, 2006).

The Ground water flow direction in the study area was deduced by using the previous sixty four boreholes data acquired from Addis Ababa water sewerage Authority (AAWSA). Thus, the ground water flow direction map using ground water altitude of borehole data was produced and is presented in Fig.3.6.

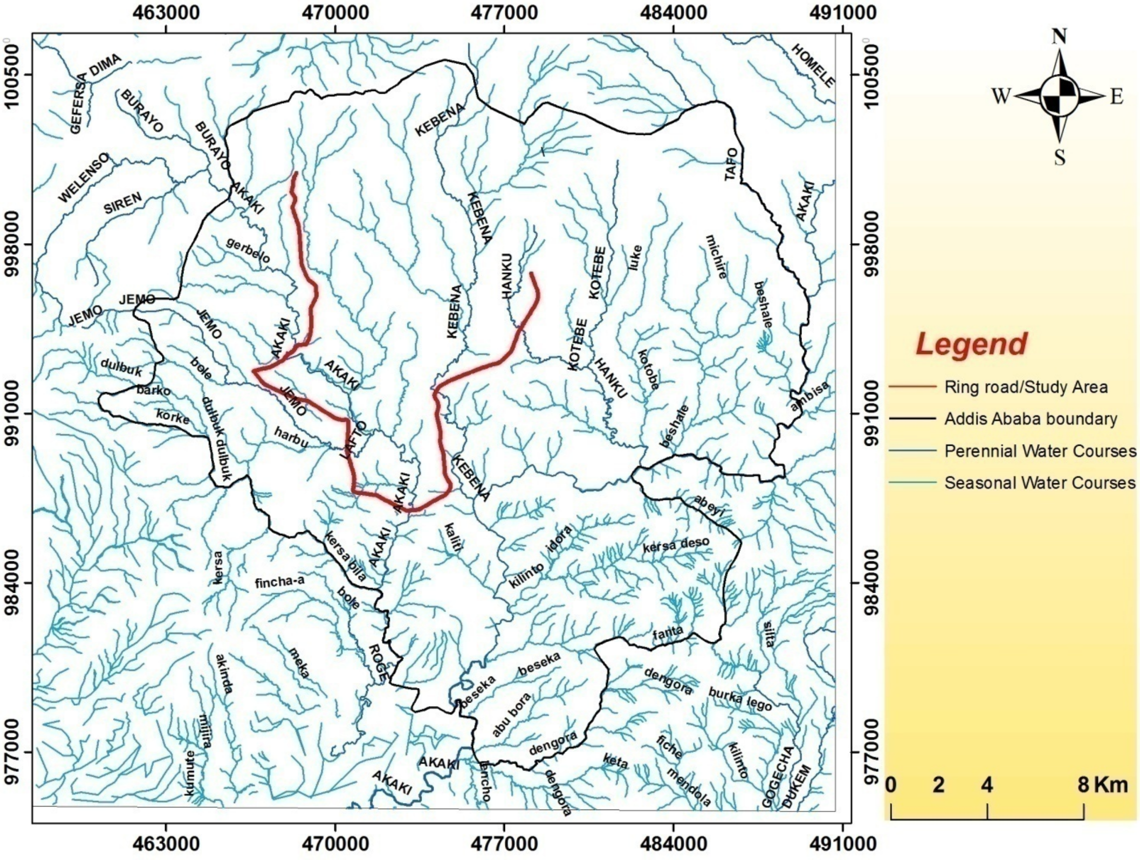

Fig 3.4 Drainage Pattern of Addis Ababa and surrounding area (*Source: Aster DEM (30m resolution)*)

According to this study the ground water movement directions dominated by North-South and South-East flows. In some localities however the ground water flow direction changes, mostly towards the nearby stream sand generally, the ground water movement is sub-parallel to the surface water flow direction and more or less is controlled by the topography of the area (Mesay Gashaw, 2008).

To determine the general direction of ground water flow in Addis Ababa based on elevation of water level in bore holes drilled for water supply data from previous study by Tamiru Alemayehu etal. (2006) was also utilized.

3.4 Geology

3.4.1 Regional Geology

Extensive areas of the highlands of Ethiopia on both sides of the rift valley are covered by Tertiary (Trap series) volcanic rocks which are mainly basalts with subordinate acidic rocks. In the rift valley, subsequent to the formation of the rift valley, the Trap series were overlain by a variety of younger volcanic rocks of basalts, ignimbrites and rhyolites (Tesfaye Chernet, 1993).

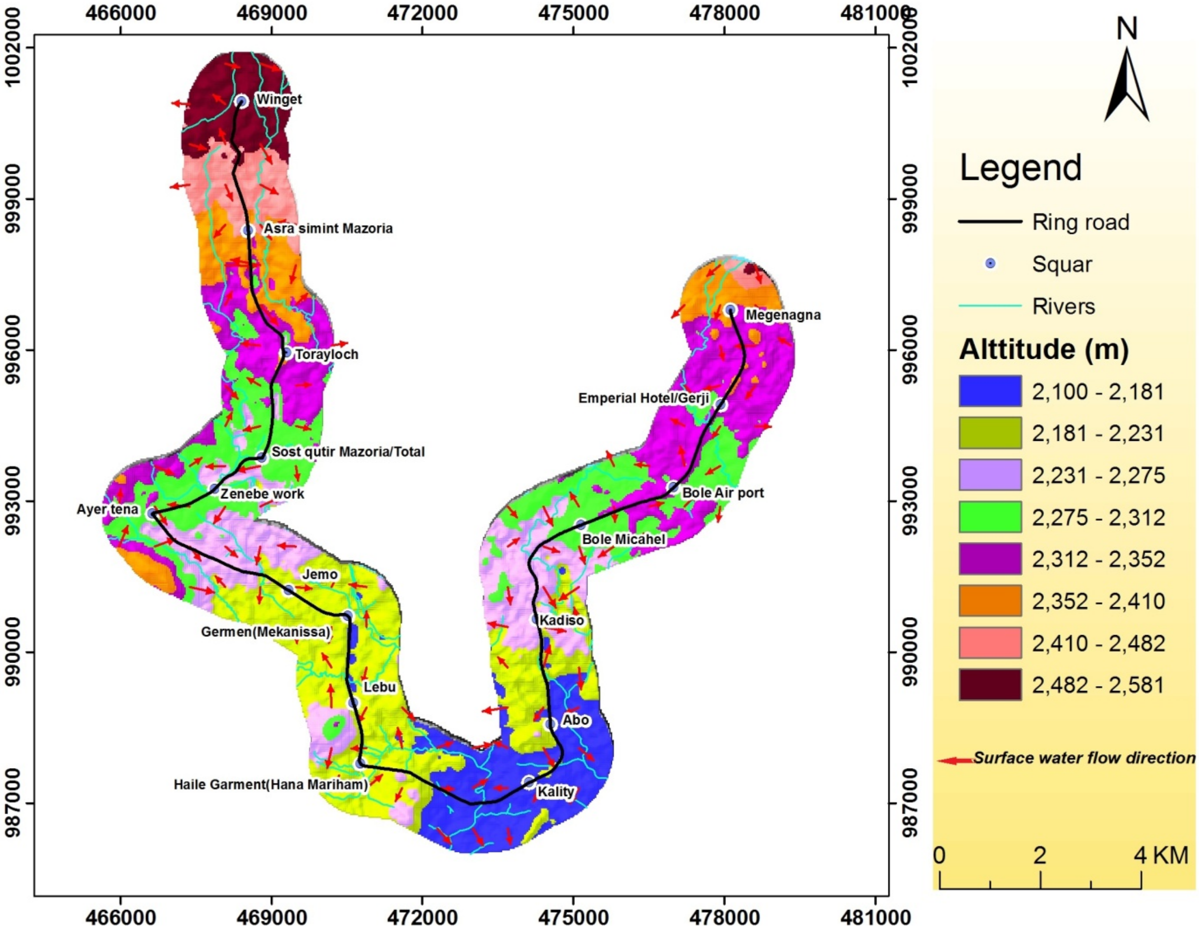

Fig 3.5 Surface Water Flow Direction using *Aster DEM (30m resolution)*

The Tertiary Ethiopian volcanism occurred in three main stages separated by periods of quiescence. These are the pre-Oligocene stage (Ashanti formation), the Oligocene-Miocene stage (Aiba, Alaji and Tarmaber formations) and the Miocene-Pliocene stage (Fursa, Balchi and Bishoftu formations) (Zanettin et al., 1978).

Addis Ababa is located in the western margin of the Main Ethiopian Rift Valley. The margin is more recent, shows Mio-Pliocene volcanic and is characterized by normal faults down thrown towards the rift. The upper (outer) boundary of the margin is marked by the large fault running approximately east-west immediately north of the Addis Ababa-Ambo road. The lower boundary run north east to south west parallel to the principal systems of fissures of the rift-floor from Nazareth to awash Station (Zanettin et al., 1978).

3.4.2 Geology of Addis Ababa

The Geology of Addis Ababa Consist of volcanic rocks ranging from basic to acidic composition being located in the western part of the rift valley system. The surroundings hills and mountains are volcanic intrusions of trachyte and rhyolite. The volcanic plugs such as Wachacha in the north-west, Furi in the south and Yerer in the south east are mainly trachyte in composition.

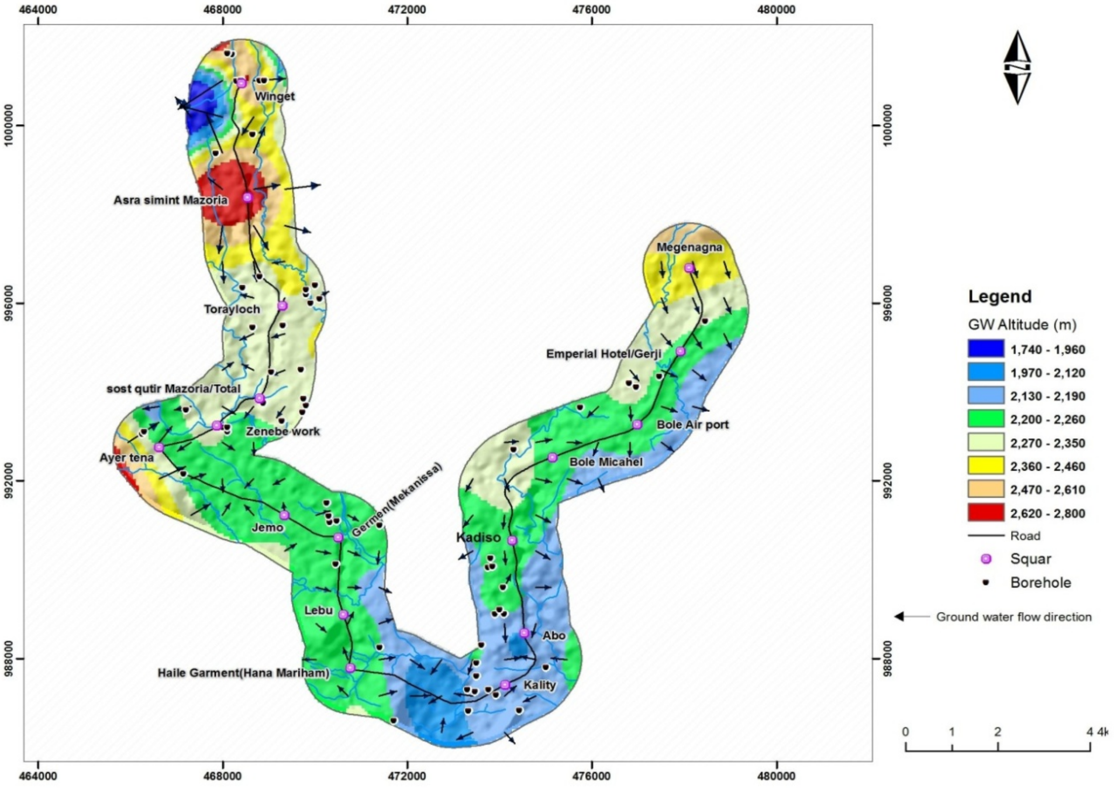

Fig 3.6 Ground Water Flow Direction using Ground water altitude of BHs data

Alaji basalt, rhyolite and trachyte are situated in the north and north-east of Addis Ababa. They form the higher topography of the area with rahyolite being more extensive than trachyte .Corse grained ignimbrite outcrops north of Bole area and around Lideta area, being overlain uncomfortably by the basalt.

The younger volcanoes of Wechecha, Furi and Yerer give intermediate acidic products such as trachy basalt, trachyte, ignimbrite and tuff overlying on the basalt. Trachy basalt outcrops in the south-west along the Akaki River underlying the trachyte. Ignimbrite is located throughout the city but the main outcrop is in the Bole area of the city.

Many researchers have conducted the geological and stereo graphic sequences of Addis Ababa (Haile selassie Girmay and Getaneh Assefa (1989)) and established the straigraphy of Addis Ababa are abased of K/Ar absolute age determination taken from different literature and field work.

The suggested Miocene Pleistocene volcanic succession from bottom to top is as follows;

Alaji Basalts, Entoto Silicics, Addis Ababa Basalts, Nazareth Group and Bofa Basalts

Alaji Basalts (end of Oligocene to Middle Miocene)

This unit is composed of basalts, which show variation in texture from highly porphyrictoa phanitic. The unit is intercalated with gray and glassy welded tuff. The outcrops of Alaji basalts are situated in the North and North eastern part of Addis Ababa .They form high topography and Rhyolites have more area extent than trachytes. Trachytes and rhyolites are contemporaneous in age. The Alaji basalt is underlain by tuff sand ignimbrites and is overlain by the Entoto Trachyites (Haileselassie Girmay and Getaneh Assefa, 1989).

Entoto Silicics (Early Miocene)

The unit is un conformably overlain by Addis Ababa basalt on the foot hills of Entoto hills an discomposed of rhyolites and trachytes with minor amount of welded tuff and obsidian (Haile sellase Girmay and Getaneh Asefa, 1989).

The rhyolitic lava flows outcrop on the top and the foot hills of the Entoto ridge, predominantly in the western side. It also outcrops in the eastern part of the town around Kokebe Tsebah School. The thickness is quite variable as it frequently forms dome structure. The thickness becomes maximum on the top of Entoto ridge and thin both towards the plateau and the plain east of Addis Ababa. The rhyolites are overlain by porphyritic trachytes and underlain by a sequence of tuffs and Ignimbrites.

Tuffs and Ignimbrites are welded and characterized by columnar jointing .The trachytic lava flows outcrop on the top of Entoto Ridge and its foot hills. The trachyte and the Alaji aphanitic basalts are separated by paleosoil indicating time gap.

Addis Ababa Basalts

Stratigraphically, this unit is underlain by the Entoto silicics and overlain by lower welded tuff of the Nazareth group. It is porphyritec in texture and mainly present in the central part of the city (Hailesellase Girmay and Getaneh Asefa, 1989).

Olivine porphyritic basalts outcrop around Merkato, Teklehamanote and sidest Kilo. The Lower Welded tuff overlies both types of basalt near by the building college ,the kolfe Police School, the KokebeTseba School and Yeka Mariam church. On the other hand, only in the gorge of the Ketchene stream the olivine porphyritic basalt is overlain by the plagioclase porphyritic basalt.

Nazareth Series

The units identified in this group are lower welded tuff, a phanitic basalt and upper welded tuff. Welded tuffs have been related to Wachecha and Yerer Volcanisms .The group is underlain by Addis Ababa salt and overlain by Bofa basalts. The rocks outcrop mainly south of Filwoha fault and extended towards Nazareth (Hailesellase Girmay and Getaneh Asefa, 1989).The units in this group are:

Lower Welded Tuff

It out crops as small discontinuous body in Filwoha, western parts of Addis Ababa and Sululta .Generally it is overlain by the a phanitic basalt and underlain by the olivine and plagioclase porphyritic basalt .The age of this unit overlaps with the period of the activity of wechecha trachyte volcanoes.

Aphanitic Basalt

It covers the southern part of the city, especially the area of Bole International Air port and Lideta Old Airfield. The rock body shows vertical curved columnar jointing together with sub horizontal sheet jointing .Along the course of Akaki River large amygdales of calcite occur in this basalt. Kaolinite lenses are present at the contact with the younger ignimbrite

Upper Welded Tuff

It out crops all over the southern part of the city including Bole, Nefas Silk and Railway Station; nevertheless sit is also present in the central and northern part of the city. It is gray colored, vertically and horizontally jointed and composed of sanidine, anortoclase, rebekite, quartz, pumice and un identified volcanic fragments (Haile sellasie Girmay and Getaneh Assefa, 1989).The welded tuff is under lain by a phanitic basalt and overlain by young olivine basalts.

Bofa Basalts

Bofa Basalts outcrop south ward from Akaki River where they appear in the form of boulders reaching a thickness of 10 meters. They are restricted and dominated in the south eastern part of the city. This rock is characterized by big vesicles that are filled by calcite.
This basalt is underlain by the tuffs which cover the welded tuff.

3.5 Soil

The soil development in Addis Ababa area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remain in places and form residual soils or transported and deposited in the low lying flat lands and depressions (Tamiru Alemayehu et al, 2006).

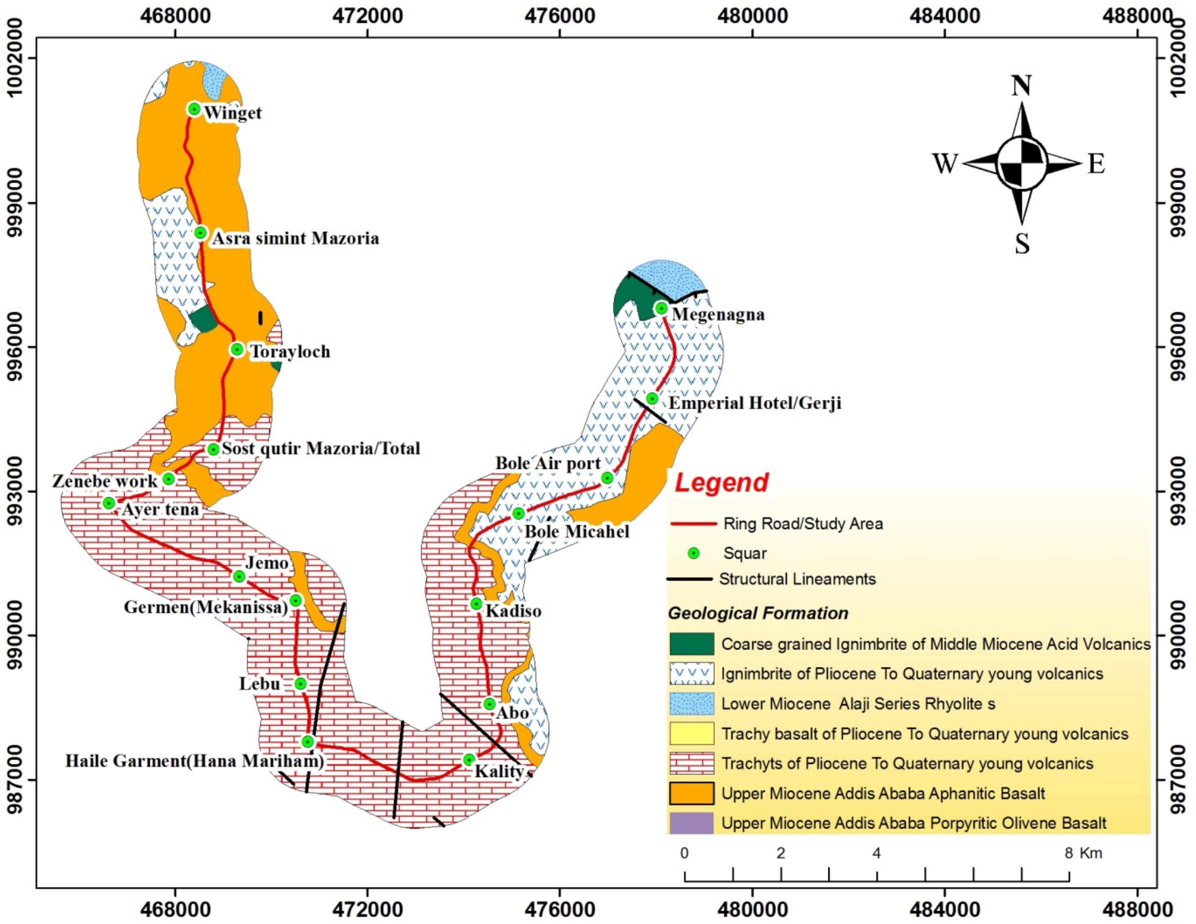

Fig 3.7 Geological Map of the Study Area *(source:-Geological Survey of Ethiopia)*

The differences observed in the type and development of soils in the city depends mostly on the topography, parent rock and the degree of weathering. Although there is significant difference in the degree of weathering on the slopes, mostly soils are highly eroded and result in thin soil cover. In the localities where the topography is plain to gentle there is thick soil profile. The type of parent material and the length of time to which the parent material is subjected to weathering, control the variation in the thickness of soil. Thus, old basic and acidic rocks that outcrop in the central, western and south western parts of Addis Ababa are weathered and form thick soil profile. In places where young basalt and welded tuffs occur, the thickness of the soil cover is reduced.

The deterital materials that are derived from elevated areas of Intoto, Wechecha, Furi and Yerer are transported and deposited in the piedmont and along the stream courses of Addis Ababa. It covers most parts of Mekanisa, AyereTena, Kaliti, Akaki, Lideta, and Bole. The soil is black in color and the thickness varies from place to place primarily depending on the slope of the area.

Kebede Tsehayu and Tadese Hailemariam (1990) classified the soil units of Addis Ababa based on their origin as alluvial, alluvial fan, colluvial, residual and lacustrine alternatively called black cotton soils (Fig.3.8). In the present study the soil map produced by Kebede Tsehayu and Tadese Hailemariam (1990) was modified by utilizing data from seventy test pits, dug during geotechnical investigation for the ring road construction. The test pits logs are shown in Annexure I (AARRP, 1997).

The alluvial soils which include channel and terrace deposits are found in some places along Akaki River in the west and south western parts of Addis Ababa and along Kebena River north of Bole area. The alluvial soils consist of more or less stratified deposits of gravel and clay transported by streams. The study indicated that sample taken from terrace deposits near Bole consists of 46% silt, 34% clay and 20% sand and classified as ML in USCS system.

Alluvial fan is deposited where there is a decrease in gradient from a hill to a plain along a river section. It is coarser near the mouth of the river and become finer outwards and found in the Entoto region dissected by deep gullies (Kebede Tsehayu and Tadese Hailemariam, 1990). Residual soils developed insitu by the decomposition of rocks are mainly located in Gulele and Kolfe area. Sample tested provided grain size of 62% clay, 33% silt and 5% sand. In some localities reddish brown soil with a thickness of more than 10 m is commonly seen.

Lacustrine soils, commonly known as ‘Black cotton soils’ are found in Bole, Lideta and Mekanisa areas which are flat and relatively low lying (Kebede Tsehayu and Tadese Hailemariam, 1990). Samples taken from Bole and Mekanisa area has shown that the soil contains 76 % clay, 22 % silt and 2 % sand and accordingly it is classified as MH (rarely CH) as per USCS system.

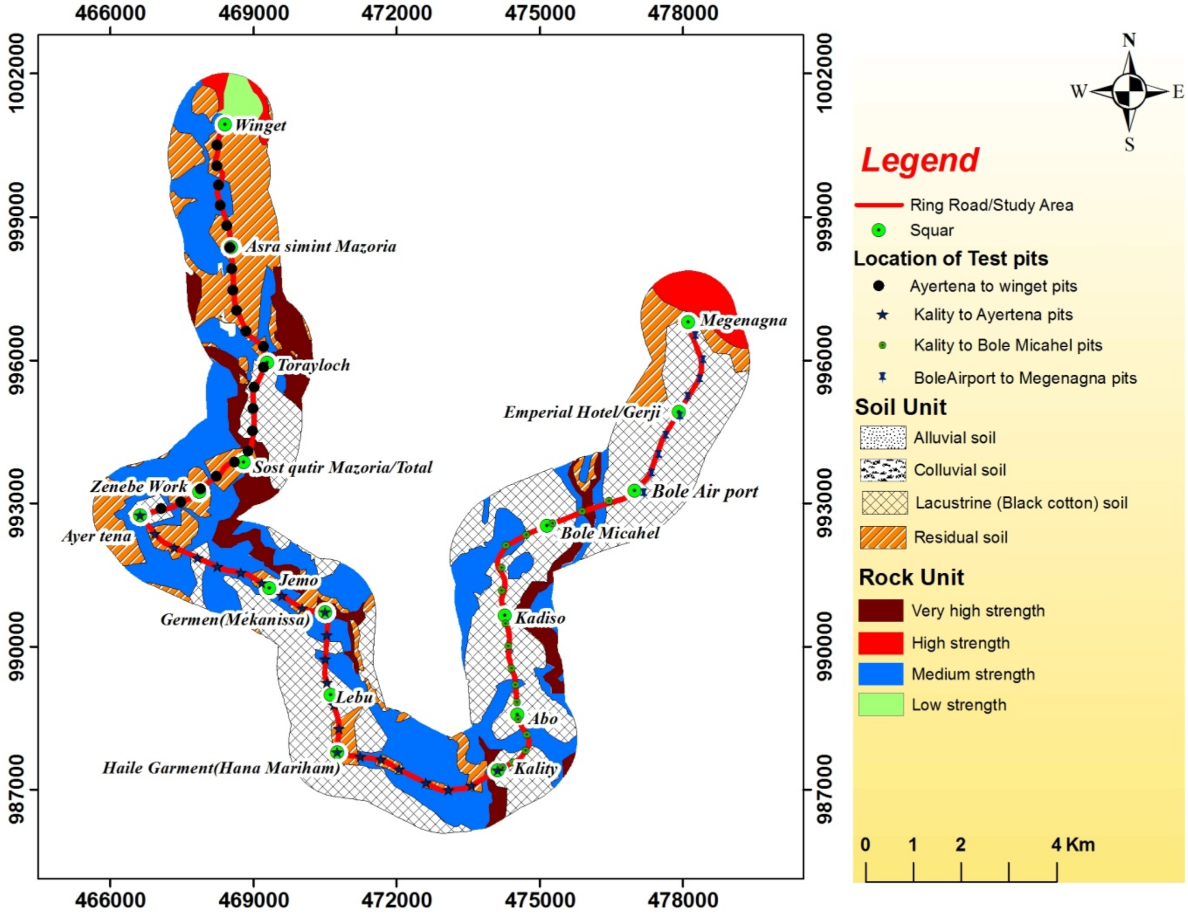

Fig 3.8- Engineering Geological Map of study area *(Source: modified after Kebede Tsehayu and Tadese Hailemariam, 1990 by utilizing seventy test pits data from geotechnical investigation for the ring road construction)*

Observations and tests show that the low lying flat areas around Addis Ababa are dominated by black cotton soils. These soils have extremely high plasticity and very high degree of swelling as compared to the other identified soil types found in Addis Ababa. The thickness of this soil varies at places from 2m to 10m. The highest thickness is found in Bole area and in Beklo Bet area it is about 5m thick (Kebede Tsehayu and Tadese Hailemariam, 1990).

The ring road is mainly located over these three types of deposits such as alluvial, residual and lacustrine and predominately over the black cotton soil (lacustrine deposit).

3.6 Structural Set up of the Area

The area is highly tectonized and is complex in structure because of its vicinity to the Main Ethiopian Rift. The main diastrophic structures encountered are lineaments whereas the non diastrophic structures are bedding and volcanic layering (Fig 3.9).

3.6.1 Lineament

Different geomorphic features align mostly to the NE-SW direction which is parallel to the structure of the rift or rift margin. Most of these lineaments are observed in all units as interpreted from the digital elevation model and mainly observed in the south and south eastern parts of the map area generally crosses the entire road width (unit). They have a structure trending in NE-SE direction (Assiged Getahun, 2007).

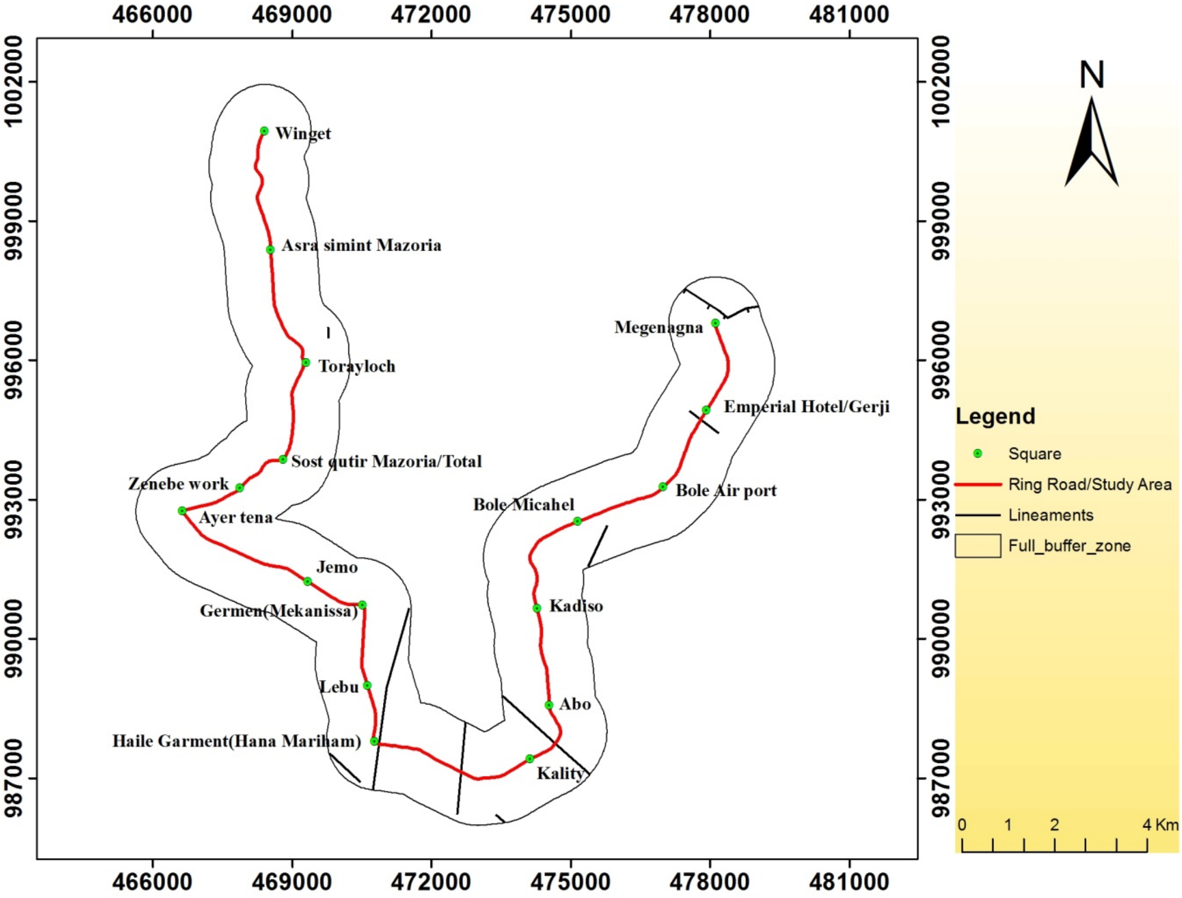

Fig 3.9 Structural map of the study are (Source: Google earth)

3.7 Land use and Land cover

The land use and land cover have shown the general increase in the built-up areas in Addis Ababa city and is characterized by horizontal physical expansion against crop, forest and grasslands. Even though this phenomena is inevitable, the highest rate of built-up area expansion against highest rate of forest and cropland decline entails the sustainability of the provisioning, regulating, and supporting services of the ecological resources in peri-urban areas is in question.

In order to assess the land use and land cover dynamics, Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) Landsat images taken in 1986, 2000, and 2010 were accessed from NASA’s Global Land Cover Facility (GLCF).The rate of change of land use and land cover in *Addis Ababa* City during 1986-2011, built-up area has increased by 5.04 km^2 per annum against 5.20 km^2 per annum decrease of forest cover areas. However, the rate of the declining trend of forest cover was reducing significantly between 2000 and 2010. This could be attributed to the improved tree plantation activities conducted in the city (Table 3.2) (Leulsegged Kasa et al., 2011).

The land use and land cover map was produced from shape file of the project area using ARC GIS 9.3 software.

Table 3.2 Rate of change (%) of land use and land cover in Addis Ababa (1986-2011) *(Source: Computed based on data extracted from analysis of Land sat images of 1986, 2000, and 2010)*

LULC	**Years**		
	1986-2000	**2000-2010**	**1986-2010**
Build-up	4.11	6.34	5.04
Forest Land	-7.98	-1.3	-5.2
Grass Land	0.24	-0.49	-0.06
Cultivated	3.63	-4.54	0.22

3.8 Climate

Addis Ababa is located at 09^0 02' N Latitude and 38^0 44' E Longitude. It is built on the steep escarpment of Mt. Intoto in the North (2900 m) to the South with an average altitude of 2400 m. This varying topography of the city has affected its spatial expansion favoring the relatively flat landscape in the south as a major factor contributing more pavement distress.

The city is crossed by streams namely Kechenie, Kebena, Ginfile and Akaki and their tributaries all rising from the steep slopes of Mt. Entoto in the North and following southwards to join the Akaki river, the tributary of the Awash river. Thus, Johnson had amply described *"…the site of Addis Ababa is overwhelmingly made up of sloping terrain, deeply incised by swiftly flowing streams, with scattered hills, ridges and eroded land predominating. The nature of the topography of the city coupled with deforestation, considered to be the main factors for land degradation and soil erosion."* Despite the fact that Addis Ababa is located within the tropics, it has an ideal climate throughout the year (Bamlaku Amente., 2009).

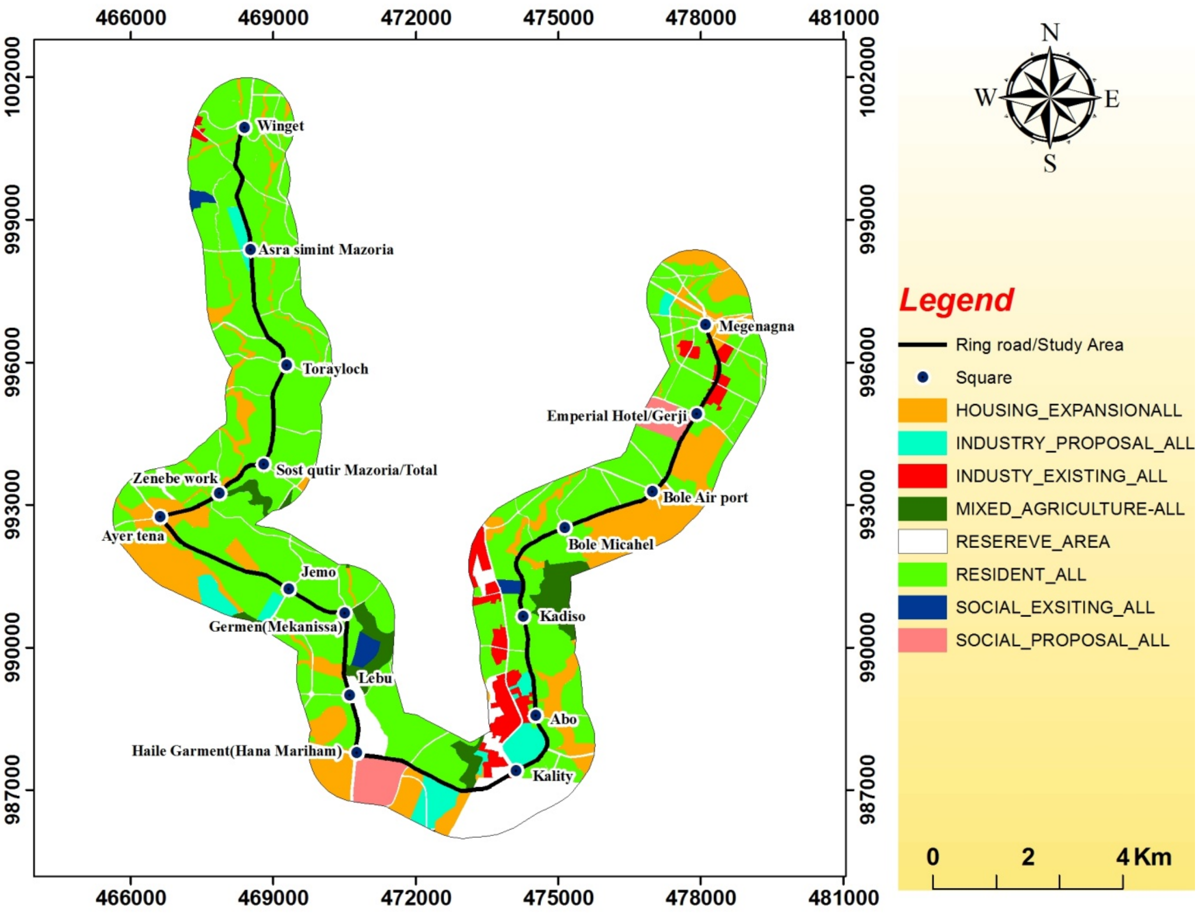

Fig. 3.10 Land Use and Land Cover Map of the Study Area (Source: - Google Earth)

3.8.1 Rain fall

The rains occur mainly in the summer months of June to September with heaviest rain falling between Junes to August. The rain is moderate during the months of October to May with the annual distribution being influenced by the south-west equatorial westerly wind originating from Indian Ocean. The short rain which occur between March, April and May arrive from the Gulf of Aden and the Indian Ocean (AARRP, 1997).

Monthly total rain fall records of three stations for the year from 1964 to 2004 for Addis Ababa Bole, from 1951 to 2004 for Akaki Beseka and from 1900 to 2004 for Addis Ababa observatory were utilized to analyze monthly mean rain fall and annual mean rain fall. The mean monthly and annual mean rain fall of National Meteorological Services Agency (NMSA) stations in Addis Ababa located at Addis Ababa Bole, Addis Ababa Observatory (Tekelehaimanot) and Akaki Beseka Stations are shown in Table3.3. All stations are located at different elevations of 2350m, 2408m and 2000ma.s.l. respectively.

As indicated in Table 3.3 the precipitation occurs throughout the year and shows variation in amount from month to month. The monthly mean records of rain fall shown for each station indicates that the mean annual rain fall at Addis Ababa Bole, Addis Ababa Observatory (Tekelehaimanot) and Akaki Beseka stations were 1074 mm, 1201 mm and 1109 mm, respectively. Thus, the city receives mean annual rain fall of about 1128 mm.

At All the stations the heaviest rainfall occurs during August where as the minimum rainfall occurs in December at Addis Ababa Bole and Akaki Beseka stations and in November at Addis Ababa Observatory.

Table 3.3 **Mean monthly and mean annual rainfall of Addis Ababa** *Source: National Meteorological Services Agency*)

Station	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Ann. Mean**
A.A. Bole (1964-2004)	14	37.4	68.6	93	76.4	119	235	243	143	32.7	7.2	5	1074
Akaki Beseka (1951-2004)	14	36.8	67.5	91	67.1	123	264	284	131	24.5	3.8	3.1	1109
AA Observatory (1900-2004)	16	42.9	65.9	93.4	85.5	131	259	278	175	38.1	7.5	9	1201
Mean monthly	15	39	67.3	92.5	76.3	124	243	268	150	31.8	6.2	5.7	1128

(

Furthermore, Addis Ababa Observatory which is located at a higher elevation than Addis Ababa Bole and Akaki Beseka stations, records greater amounts of mean annual rain fall. This shows that there is variation in the amount of rain fall with in Addis Ababa with difference in altitude.

"Rainy months "and" dry months "of any year is distinguished by calculating rain fall coefficient (RC). It is the ratio between the mean monthly rain fall and one twelfth of the annual mean (Tamiru Alemayehu et al, 2006). Rainy months have rain fall coefficient (RC) of above 0.6 where as those of dry months have less than 0.6 (Tamiru Alemayehu etal, 2006).

The rain fall coefficient is shown in Table 3.4. From Table 3.4 it is observed that the rainy months of Addis Ababa are from March to September and the dry months are from October to February. The small rain occurs from March to May as observed in Addis Ababa Observatory and Akaki Beseka Stations, while in Addis Ababa Bole Station it was observed in March and May.

Table 3.4 Rainfall Coefficient at Addis Ababa Bole, Addis Ababa Observatory and Akaki Beseka Stations *(Source: National Meteorological Services Agency)*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A.A. Bole (1964-2004)	0.15	0.42	0.75	1.04	0.85	1.33	2.63	3.17	1.6	0.37	0.08	0.06
Akaki Beseka (1951-2004)	0.15	0.4	0.73	0.98	0.73	1.3	2.86	3.07	1.41	0.27	0.04	0.03
AA Observatory (1900-2004)	0.14	0.42	0.66	0.93	0.85	1.33	2.59	2.78	1.75	0.38	0.07	0.09

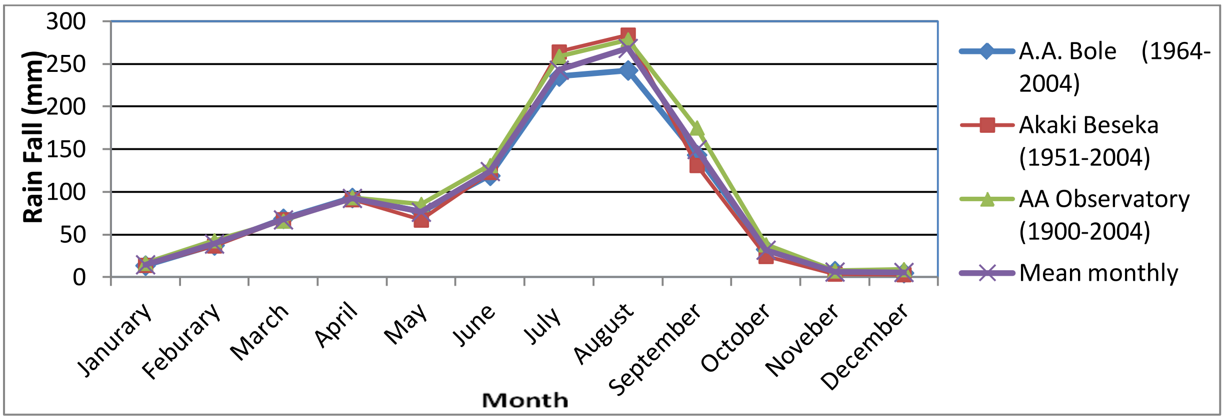

Fig. 3.11 Mean monthly rainfall of Addis Ababa based on Addis Ababa Observatory, Addis Ababa Bole and Akaki Beseka stations *(Source: National Meteorological Services Agency)*

The big rains from June to September as observed in Addis Ababa Observatory and Akaki Beseka stations, with mode rate concentration occurs in June to September. In Akaki Beseka Station high and very high concentration were recorded in July and August, respectively. In Addis Ababa Bole Station big rain with moderate concentration was recorded in April, June and September, high concentration in July and very high concentration in August.

3.8.2 Temperature

The mean monthly maximum and minimum temperature records of Addis Ababa Observatory for the years between 1951 and 1998 were utilized to calculate monthly and annual averages. The computed average maximum and minimum temperature is presented in Table 3.4.

Further, perusal of Table 3.4 indicates that the highest mean monthly maximum temperature occurs in the months of March with 24.6^0 C and the lowest is in the month of August with 20.1^0 C. While the mean monthly minimum temperature ranges for the lowest from 7.5^0 C in December to the highest 11.7^0 C in the month of March. Thus, the average temperature of Addis Ababa is 16^0 C. The temperature is moderate during the dry months of November to May.

Table 3.5: Monthly and annual mean maximum and minimum temperatures of Addis Ababa *(Source: National Meteorological Services Agency)*

Description (^{o}C)	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Ann. Mean**
Average Maximum	23	24	24.6	23.9	24.6	22.9	20.3	20.1	21.1	22.4	22.6	22.8	22.7
Average Minimum	8.2	9.5	10.9	11.5	11.7	10.8	10.8	10.8	10.5	9.2	7.9	7.5	9.9

The Principal effects of climate on pavement design are in relation to sub-grade moisture condition, drainage requirement, surfacing type selection and design and the selection of construction materials (AASHTO, 1993).

Climate also affects the nature of the soils and rocks encountered in the tropics. Soil-forming processes are still very active and the surface rocks are often deeply weathered. The soils themselves often display extreme or unusual properties which can pose considerable problems for road designers (ORN 31, 1992).

3.9 Seismicity of the area

The seismicity of Ethiopia is controlled and influenced by the active Ethiopian Rift System which divides the country into two along the NE–SW direction (Tilahun Mamo, 2005).

The seismically and volcanically active northern Main Ethiopian rift (MER) and Afar rifts are virtually the only places worldwide where the transition between continental and oceanic rifting is exposed on land. (Keir et al., 2006).

The effect of earthquake is very significant on engineering structures like buildings, dams and roads to the least. Hence, seismicity is highly associated with faults and fractures, which initiated problems on roads and railroads. The disconnection of the road/railroad due to the displacement of fault or fracture can cause great damages (Tilahun Mamo, 2005).

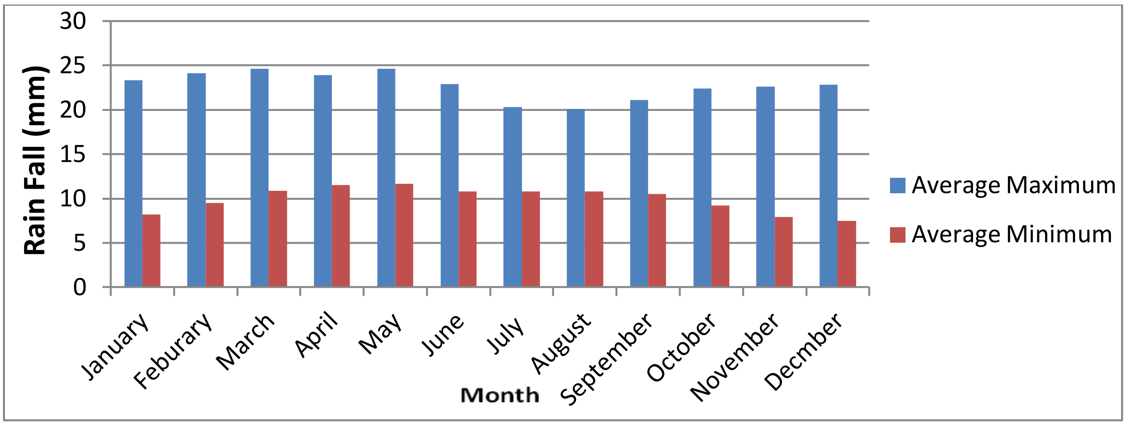

Fig 3.12 Monthly mean maximum and minimum temperatures of Addis Ababa. (*Source: National Meteorological Services Agency*)

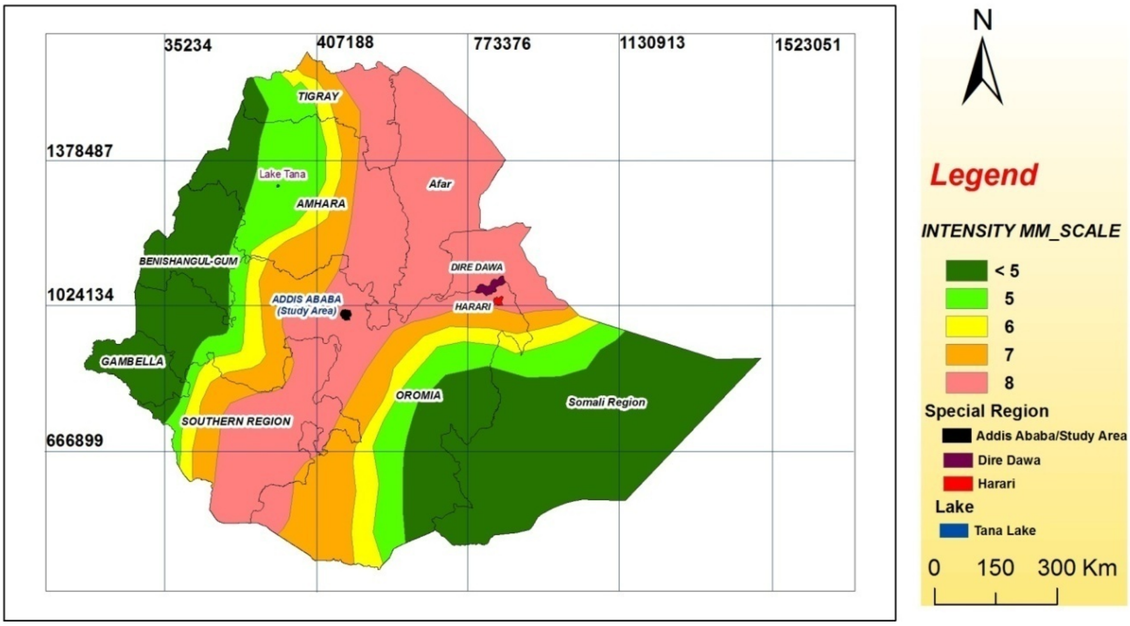

Fig. 3.13 Seismic risk map of Ethiopia 100 year return period, 0.99 probabilities *(Source: Laike Mariam Asfaw, 1986)*

Addis Ababa is located in a seismically active zone and it will have impact on road pavements and sub-grade soils (Fig.3.13). However, it requires consideration and a systematic study to know exactly the damage an earth quake can cause to these structures. Such study is beyond the scope of the present research.

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Chapter 4 EXISTING PAVEMRNT CONDITION ASSESSEMENT

4.0 Preamble

Pavements of roads are constructed to give smooth and safe rides for traffic. However, most of the time pavements deteriorate and lacks to perform their functions with passage of time and application of high volume of traffics. Alligator cracking, longitudinal and transverse cracking, potholes, and shovels are some of the damages that affect the structure and functional performance of a pavement.

Damages can be due to many reasons happened individually or collectively to decrease the performance of the pavement. The main causes for the deterioration of pavement can be because of poor sub-grade material, low quality construction materials, poor drainage, high rate of traffic application, poor construction and workmanship, and so on. (Henok Tesfaye, 2012)

There is a growing awareness of the road maintenance problem in the actual world. Many countries are incurring extremely high costs because of inadequate maintenance of their road network. Lack of effective maintenance is leading to the need for premature rehabilitation of their roads and is causing high costs for vehicle operation indirectly it is also affecting the industrial and agricultural sectors.

Assessment of pavement condition could be subjective, depending on visual inspection and evaluator experience, or objective, depending on standardized evaluation procedures and equipment. Due to the fact that experience is difficult to transfer from one person to another and that individual decisions made from similar data are often inconsistent. The final output of the pavement condition assessment is to identify the type and nature of damages for specific road section and recommend specific type of rehabilitation measure. These methods of evaluating the pavement performance are discussed in the following sub-sections. (Andrei et al., 2010).

4.1 Assessment of Existing Pavement Condition

During the present study pavement condition assessment was mainly conducted to identify damage which might have affected the structural capacity of the pavement and the possible causes for the deterioration of road. Assessment of Pavement condition is normally measured using the following four factors.

4.1.1 Surface Distress

This factor involves identification of various surface distresses in different types of pavements. The method of evaluating such distress could be as simple as a visual manual (walking) or an auto windshield survey of randomly selected section of the pavement scheduled for repair, or it could be a more sophisticated one using a high-speed van equipped with laser-video technology and automated processing of collected data (PPM, 2010). In the present study attempt were made to identify various surface pavement distress through visual manual or walking assessment. Based on the identification of the existing distress, potential treatment(s) can be selected to correct the problem.

4.1.2 Structural Capacity

This factor can be measured using non-destructive testing of the pavement. Such evaluation is necessary to evaluate the load carrying capacity of the pavement. Selection of the right treatment is dependent on known structural condition of the project at the project level (PPM, 2010).

4.1.3 Roughness (Ride Quality)

This important factor is the measure of the surface distortion and provides an estimation of the ability of pavement to provide a comfortable ride to the users. It is often expressed as Present serviceability index (PSI) or IRI.

4.1.4 Surface Friction

This is a safety-oriented factor and is generally considered as a separate measure of condition of pavement surface. It is often used to determine a need of remedial maintenance by itself.

The above four pavement condition factors can be used to determine the overall pavement condition and to identify the most cost effective and optimum maintenance and rehabilitation treatment for the pavement. It should be noted that any treatment selected to correct the structural-load carrying capacity of the pavement can also take care of all other deficiencies that might be present including roughness. Likewise any treatment recommended for correcting roughness will necessarily improve the surface friction and will correct any surface distress as well (PPM, 2010).

In the present study the performance of pavement was evaluated through existing pavement condition survey (Visual inspection), existing laboratory testing of pavement construction material, destructive sampling and laboratory testing of sub-grade. All these methods of assessment are discussed briefly in the following paragraphs.

4.2 Existing Ground Condition (Sub-grade) and Preparations of Pavement Construction

The performance of a pavement depends on the quality of its sub-grade and sub-base layers. As the foundation for the pavement's upper layers, the sub-grade and sub-base layers play a key role in mitigating the detrimental effects of climate and the static and dynamic stresses generated by traffic. Therefore, building a stable sub-grade and a properly drained sub-base is vital for constructing an effective and long lasting pavement system (Schaefer et al., 2008).

In the present study area, seventy test pits were dug all along the route before the road was constructed. An average depth of the pits was 2.5 m at every 500 m. On phase 1A and 2A the pits were located in the partially completed earth work and on phase 1B and 2B at a distance 10 m from the centerline of existing road. The trial pits location is show in Fig 4.1. Later, representative disturbed samples were taken for appropriate laboratory tests.

Analysis of the test pits investigation indicates that black cotton soil (expansive soil) is the predominant soil type. The extent of black cotton soil is tabulated below in Table 4.1.

Table 4.1 Extent of Black cotton soil *(Source: AARRP, 1997*)

Phase	Name & Length of road (Km.)	Extent(Km.)	Extent of Section (%)
1A	Kality to AyerTena Square /11.0/	10.5	95.5
1B	AyerTena to Winget Square /10.0/	5.5	67.0
2A	Kality to Bole Airport Square /8.2/	4.0	40.0
2B	Bole Airport to Megenagna Square /4.0/	4.0	100.0

The black cotton soil generally exhibit very high swell value upwards to 10% as measured from the California Bearing Capacity (CBR) test. During test pit investigation, no free water in the form of a water table was encountered (AARRP, 1997).

Proper sub-grade and base preparation lays the foundation for the entire pavement structure. This support system is critical for the success of the construction process and the service life of the pavement. For a new pavement, surface preparation involves compacting, grading and possibly stabilizing the underlying sub-grade. In the present study areas, as discussed in the previous paragraph, the sub-grade comprises predominantly black cotton soils. In order to mitigate the expansive behavior of black cotton soils in the sub-grade, black cotton soils were cut up to a desired depth and were replaced by the suitable non-expansive soils.

A brief discussion on each phase of construction of Ring road is presented in the following sub-sections;

4.2.1 Phase 1A- Kality to Ayertena Square (11km)

Nearly 96% of the road length had black cotton soil excavated and replaced with a 0.5 m depth of selected borrow material. There was however, a significant depth of already constructed fill along this phase. The existing embankment was utilized as a part of the new embankment construction with at least first 0.5m of the existing fill material was scarified and re compacted.

It should be noted however, that the median and shoulder bunds comprise thick layers of black cotton soil which must be entirely removed during the new construction. Although the existing unprotected fill is currently in a reasonable condition in terms of compaction, the situation will deteriorate over time particularly with the current passage of heavy vehicles carrying quarried rock along the fill. The integrity of the existing fill should therefore be checked prior to recommencement of works (AARRP, 1997).

4.2.2 Phase 2A- Kality to Bole Airport square (8.2km)

It also has nearly 67% of the road section with black cotton soil which has an average thickness of 1.5 m. It was excavated 1.2 m and replaced with a 0.5m depth of selected borrows material such as 0.2 m selected fill compacted at the bottom and 0.3m covered by capping. The last 0.7 m is pavement structure. The remaining 23% of the length of the road section is decomposed rock mixed with clay soil. As in phase 1A, the existing embankment can be utilized as the part of the new embankment construction provided that at least the first 0.5m of the existing file material is scarified and re-compacted (AARRP, 1997)

4.2.3 Phase 1B-Ayertena to Winget square (10km)

Approximately 40% of the road length is black cotton soil, 25% very soft reddish clay soil and 35% is of hard decomposed rock. On average black cotton soil and soft reddish clay has 2.0 m thickness. It is excavated about 1.5 m and replaced by selected borrow material for about 0.8 m such as 0.5 m selected fill and 0.3 m capping at the bottom of pavement structure. The pavement structure has about 0.7 m of thickness. No previous earth works have been carried out. For phase 1B, it is imperative that the black cotton soil and the soft reddish soil be removed and replaced with a suitable selected fill material to a minimum depth of 1.5 m (AARRP, 1997).

4.2.4 Phase 2B- Bole Airport to Megenagna square (4km)

The entire road length is comprises of black cotton soil and has an average thickness of about 2.0 m. It was also excavated for about 1.5 m and replaced by selected borrow material for about 0.65m so that 0.3 m selected fill at the bottom and 0.35 m capping layer below the bottom of pavement structure. In this phase also it is imperative that the 2 m of black cotton soil be removed and replaced with a suitable selected fill material to a minimum depth of 0.3 m with capping layer and full pavement construction above (AARRP, 1997).

The general boundaries of each significant type of soil occurring along ring road alignment have been identified by thoroughly examining freshly excavated trial test pits. For each layer, the soil type, thickness, color, texture, consistency and structure of each material has been recorded. The log data and laboratory test of sub-grad are presented in Annexure-I.

4.3 Existing Pavement Design Assessment

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed the bearing capacity of the sub-grade (Mathew and Rao, 2006).

According to Mathew and Rao (2006) the pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil.
- Structurally strong to withstand all types of stresses imposed upon it.
- Adequate coefficient of friction to prevent skidding of vehicles.
- Smooth surface to provide comfort to road users even at high speed.
- Produce least noise from moving vehicles.
- Dust proof surface so that traffic safety is not impaired by reducing visibility.
- Impervious surface, so that sub-grade soil is well protected
- Long design life with low maintenance cost.

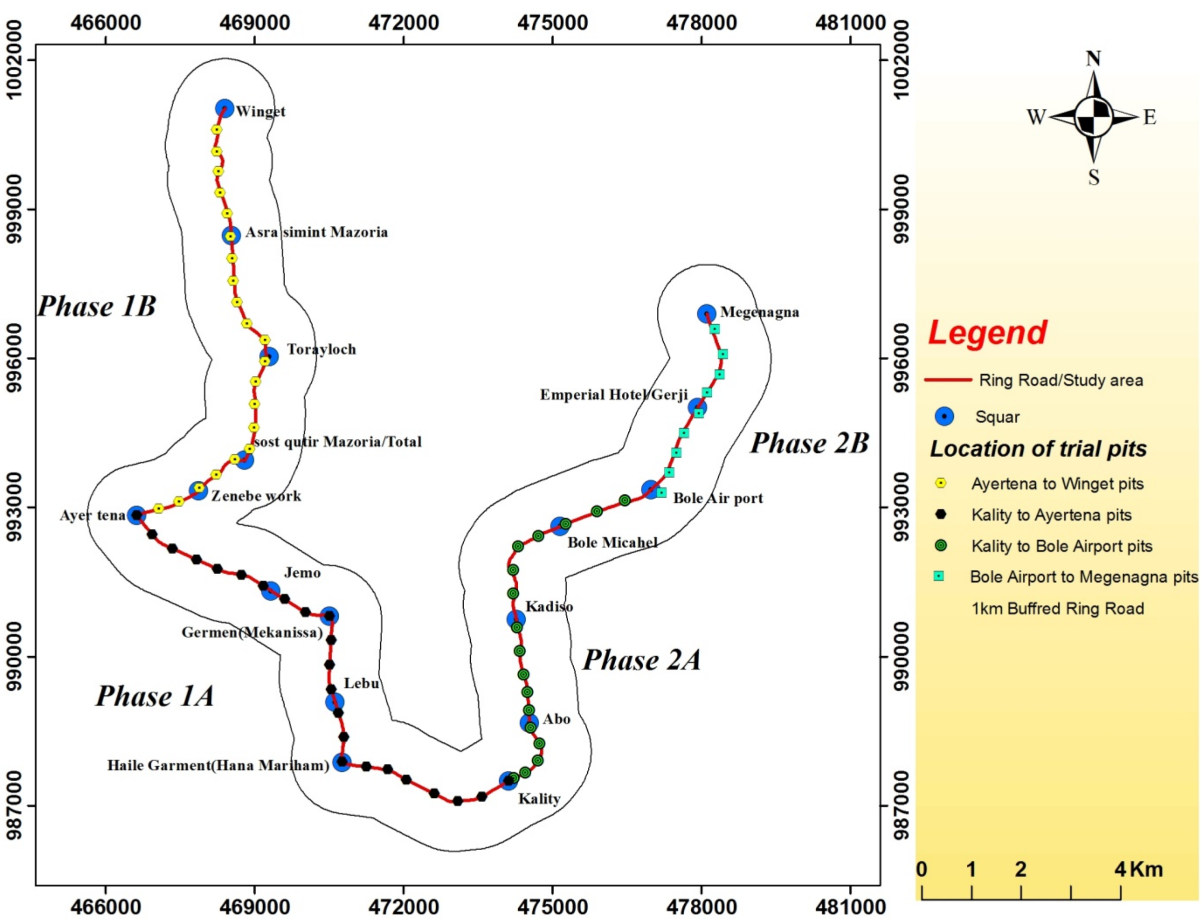

Fig 4.1 Location of trial pits

Pavements do deteriorate due to time, climate and traffic. Therefore, the goal of the pavement design is to limit, during the period considered, deteriorations which affect the riding quality, such as, in the case of flexible pavements, cracking, rutting, potholes and other such surface distresses to acceptable levels.

At the end of the design period, a strengthening overlay would normally be required, but other remedial treatments, such as major rehabilitation or reconstruction, may be required. The design method aims at producing a pavement which will reach a relatively low level of deterioration at the end of the design period, assuming that routine and periodic maintenance are performed during that period (ERA, 2002(a)).

In the present study data/ information on type of pavement material, its quality and design thickness was reviewed. During the design of Ring road pavement various standards were referred, these were;

- American Association of State Highway and Transport Office (AASHTO) Design Guide for Pavement Structure (AAHTO, 1993).

- TRL Overseas Road Note No.31'A Guide to the structural Design of Bitumen-surfaced Road in Tropical and Sub-tropical countries (4th Edition-1993) (TRL, 1993).
- TRL Road Note 29 'A Guide to Structural Design of Pavement for New Roads' (1970 with updates) (TRL, 1970).
- Kenyan Road Design Manual (Part III-1981) (KRD, 1981) (AARRP, 1997)

For the analysis the following points have been derived from different design comparisons;

- The overall structural number from the different design method was found to be similar, especially on account of only top 30cm of 'capping' material in the derivation of the structural Number which is strictly correct.

- AASHTO's first recommendation is a thicker bituminous surfacing and a thinner base course compared to the other design methods. However, by keeping the same over all structural Number, the component layer thickness can be varied with a reason to give the most economic design.

An assessment is also made of the distribution of heavy vehicles using the slow and fast lanes, the pavement design being based on the slow lane traffic which is the heaviest used.

4.3.1 Pavement Layers thickness according to design traffic and Equivalency factor

Several procedures can be used to calculate the thickness of the proposed asphalt pavement. All are based on the volume and weight of the traffic that will use the facility and on the load-supporting capability of the underlying soil. The AASHTO Road Test and other studies have indicated that heavy-vehicle wheel loads cause much greater damage to roads than do light loads. Thus, where large volumes of traffic with heavily loaded trucks are anticipated, an in depth analysis of the pavement thickness is important. Because all of the higher functional classifications have the potential for heavy loadings, a traffic analysis is an important part of the preparation for thickness computations (AASHTO, 1986).

In the present study the axial loading indicates the cumulative Equivalent Standard Axles (ESA) by road section, for one direction and for different design periods. The ring road has been designed in high way capacity terms as a dual two-lane road principal arterial (AASHTO definition). A lane distribution factor should be taken in to account which allows for the distribution of the heavy vehicle traffic in to the slow (inner) and the fast (outer) lanes.

For a principal Arterial road AASHTO recommended as a guide, a distribution of between 80% and 100% of heavy vehicles using the slow lane. We have chosen the medium of 90% traffic using the slow lane. The pavement design is not considered sensitive to this distribution factor. The Table 4.2 defines the final cumulative ESA after applying the 90% distribution factor for Ring road. Using the AASHTO nomograph for each road section, various pavement options have been derived for 10, 15 and 20 years design period (AARRP, 1997).

Table 4.2:- Cumulative ESA's by Road section after applying the 90% Distribution Factor. (*Source: AARRP, 1997*)

Road Sections	**Cumulative ESA x 10^6 in one direction**		
	2010 for 10 years	**2015 for 15 years**	**2020 for 20 years**
BOLE – MEGENAGNA SQUARE	26.39	42.72	62.33
AYERTENA-KALITY –BOLE SQUARE	11.22	18.16	26.50
AYERTENA –WINGET SQUARE	12.68	20.52	29.94

The proposed pavement design of the ring road is summarized for each road section by using their design life and layer thicknesses (Table 4.3). The cost difference in the pavement designing for 10-years compare to 20-years is 11 million Birr (of the order of 1.6 million US$) which although in itself is a significant amount, is only about one percent of estimated total construction cost of the entire project. Therefore, the ring road pavement design had been built for full 20-years design life (Table 4.4). Finally, following construction method was recommended (AARRP, 1997).

- Surfacing to be 6cm of binder course and 4cm of wearing course laid in two layers
- Crushed stone base course to be laid in two equal layers
- Crushed or ‘as-dug’ sub-base to be laid in two equal layers

The structure number and hence the layer thickness for road section Ayertena to Kality to Bole square and the road section Ayertena to Winget square were almost similar therefore same design was recommended for both road section. Whereas the structural number and layer thickness for the road section Bole to Megenagna square are significantly different from the remainder that is why separate layer thickness was considered for this section (Table 4.4).

Table 4.3- Summarized proposed layer thickness each layer with design life (*Source: AARRP, 1997*)

Road section Bole to Meganagna square					
Pavement Layer Thicknesses (cm)					
Period	**Surfacing**	**Base**	**Sub-base**	**Capping**	**Total Thickness**
10-Years	10	26	33	32	101
15-years	10	30	41	25	106
20-years	10	34	52	18	114
Road section Ayertena to Kality to Bole square					
Pavement Layer Thicknesses (cm)					
Period	**Surfacing**	**Base**	**Sub-base**	**Capping**	**Total Thickness**
10-years	10	18	30	25	83
15-years	10	23	35	25	93
20-years	10	28	40	19	97
Road section Ayretena to Winged square					
Pavement Layre Thicknesses (cm)					
Period	**Surfacing**	**Base**	**Sub-base**	**Capping**	**Total Thickness**
10-years	10	19	31	28	88
15-years	10	24	36	25	95
20-years	10	29	41	16	96

Table 4.4- The existing Ring road pavement layer thickness for 20-years design life. (*Source: AARRP, 1997*)

Pavement Layer Thickness (cm)					
Based on 20 Years Design Life					
ROAD SECTION	**Surfacing**	**Base**	**Sub-base**	**Capping**	**Total Thickness**
BOLE TO MEGENAGNA SQUARE	10	35	40	35	120
AYERTENA TO KALITY TO BOLE SQURE AND AYERTENA TO WINGET SQUARE	10	30	30	30	100

4.3.2 Overall assessment of pavement Design

Assessment of pavement design is an important task to provide long life service without deterioration of the pavement structure. Roads that are used for public and commodities transport from one place to another may be subjected to heavy loadings with harsh environmental conditions which with time may result into deterioration. However, the rate of such deterioration may depend on many factors such as; the quality of construction material used, design considerations, construction and maintenance history, rate of loading and environmental conditions. Therefore, it is mandatory that road performance must be monitored regularly to evaluate the rate of deterioration, assessment of needs for maintenance and rehabilitation, and proper scheduling of maintenance and rehabilitation activities.

The objective of pavement design is to provide a structural and economical combination of materials to carry traffic in a given climate over the existing soil conditions for a specified time interval.

The overall assessment of pavement design in the study area has considered the type of sub-grade material (ground condition), axial loading (traffic condition), pavement construction material type and quality, climate condition and method of construction. As shown in the Table 4.4, the total design pavement thicknesses of the road section Ayertena to Kality to Bole squre and Ayertena to Winget square (29.2 km in length) was taken as 1.0 m. Also, the design pavement thickness of the road section Bole airport to Meganagna square (4km in length) was taken as 1.2 m. In general, the design pavement layers thickness was more or less uniform in all sections of the road.

4.4 Assessment of Existing pavement Condition Using Visual Inspection Survey

Visual condition survey should be carried out in order to see the degree of damage the pavement has experienced. During the present study different distresses types, severity and extent were recorded in detailed manner. The pavement condition of the ring road was investigated along the road sections Winget square -Asrasimit - Torayloch- Zenebework- Ayertena – Jemo-Mekanissa (Germen)-Lebu- HaileGarment - Kality-Bole and along Meganagna square. The total length of the road is *33.2 kilo meters*.

As a part of road distress assessment during the present study length and the width of the deteriorated parts of the road were measured. In general, the condition (status) of the road can be classified as poor and fair. The dominant surface distresses types, as observed, were; Potholes, Shoving, Rutting, Raveling, Depression, Delamination and Cracking (Longitudinal, Block, Crocodile). The Summarized the raw data on distress survey is presented in Table 4.5 below.

4.4.1 Pavement Damage Quantifiers and Inventory Mapping

One of the purposes of pavement condition surveys is to make quantifications of damages that are found on the road section. In order to make knowledgably decision about rehabilitation needs and strategies for the improvement of road section condition, detailed information is required. In the present study, visual condition survey was carried out along the road section between two consecutive squares and the number of different pavement distress was counted.

4.4.1.1 Distress Density Method

In order to define the road condition status based on the number of defects (distress) per km length of the road section a new method was evolved for the present study. Thus, the road distress classification was done following "*distress density method*". In this classification the range of distress per km length of road were divided into equal sized sub ranges of distress and accordingly five road condition status classes were formed. In order to quantify the distress of pavement, for inventory mapping purpose, the number of defects (distress) per km length of the road section between two consecutive squares was computed and is presented in Table 4.5.

The distresses were quantified for sixteen sections along the ring road and the maximum and minimum distress per km comes out to be 15.7 and 1.5 distress/km, respectively (Table 4.5).

Table 4.5 Summarized Visual Conditional Survey by distress density method

No	Road section	Types and extent of distress	No of Distress & Their Severity			Road Length (Km)	No of Distress per km	Road Status
			Poor	Fair	Total			
1	From Winged to Asrasimint Mazoria Square	PH=10,RUT=1, DEP=1,CC=4, DEL=9,RAV=3	13	9	22	2.72	8.1	Fair
2	From Asrasimit to Torayloch Square	PH=13,SHOV=7 ,RUT=2,DEP=3,CC=3 ,DEL=2,RAV=1	19	9	28	2.62	10.7	Poor
3	From Torayloch to Sost qutir mazoria Square	PH=17,SHOV=7, RUT=4,DEP=2,CC=4, DEL=1	31	3	34	2.16	15.7	Very Poor
4	From sot quite mazoria to Zenebework Squre	PH=1,SHOV=2, RUT=1,RAV=1	5	0	5	1.15	4.3	Good
5	From Zenebwork to Ayertena Squre	PH=7,SHOV=6, RUT=2,DEP=1	10	6	16	1.35	11.8	Poor
6	From Ayertena to Jemo Squre	PH=11,SHOV=2,RUT =6,DEP=2,CC=3, DEL=1,RAV=1	20	5	25	3.16	7.9	Fair
7	Frome Jemo to Germen(Mekanissa)Square	PH=1,DEP=1	2	0	2	1.33	1.5	Excellent
8	From Germen(Mekanissa) to Lafto Squre	PH=10,SHOV=2, RUT=3,RAV=2,LC=1	8	10	18	1.75	10.3	Poor
9	From Lafto to Haile Garment(Hana.M) Squre	PH=2,SHOV=1, RUT=3,DEP=3	5	4	9	1.31	6.9	Good
10	From Haile Garment(Hana.M) to Kality Squre	PH=23,SHOV=11, RUT=8,DEP=2,CC=4, DEL=2	47	2	49	3.62	13.5	Very poor
11	From Kality to Abo squre	PH=7,SHOV=2, RUT=6,LC=2	16	1	17	1.55	11.0	Poor
12	From Abo to Kadiso Squre	PH=6,SHOV=8, RUT=5,DEP=1, CC=1,DEL=1	20	2	22	2.12	10.3	Poor
13	From Kadisko to Bole Micahel Squre	PH=7,SHOV=10, RUT=1,DEP=3,DEL=1	15	7	22	2.5	8.8	Fair

14	From Bole micahel to Bole Airport Squre	PH=5,SHOV=2, RUT=2,DEP=1, CC=2	9	3	12	2	6.0	Good
15	From Bole Airport to Emperia Hotel Squre	PH=12,SHOV=3, RUT=2,DEP=3,CC=1, DEL=1	15	5	20	1.8	11.0	Poor
16	From Emperial Hotel to Megenagna Squre	PH=8,SHOV=6,RUT=4,DEP=1,CC=1, DEL=2, RAV=2	21	2	23	2	11.5	Poor

Abbreviations: PH-Pothole, SHOV-Shoving, RUT-Rutting, DEP-Depression, CC-Crocodile crack, DEL-Delamination, RAV-Raveling, LC-Longitudinal Crack

The road section having ≤ 3 number of distress per km length of the road section is classified as “Excellent” and that having ≥ 12 number of distress per km length of the road section is classified as “very poor”. Similarly, with an equal interval of 3 number of distress per km length of the road section, intermediate classes “Good”, “Fair” and “Poor” classes were defined (Table 4.6). Distress density method classification based on the number of distress per km facilitates to make a relative comparison of quality of road sections.

Table 4.6 Road condition classification based on distress density method

No of Distress/km	Road Condition
≤ 3	Excellent
3 - 6	Good
6 - 9	Fair
9 - 12	Poor
≥ 12	Very poor

Further, based on the road condition classification and the visual observations made along the ring road, road condition map was produced. For mapping purpose a buffer zone of 1 km from the center line of ring road was considered. Thus, the road condition status delineated through *distress density method* based on various distress classes is marked over the map (Fig.4.2). The area coverage of different distress class along the ring road was also computed and is presented in Table 4.7.

A perusal of Table 4.7 clearly shows that about 53% of the road falls into poor or very poor class and about 47% road is classified as fair, good or excellent. This clearly indicates the necessity for immediate attention for maintenance or rehabilitation of the pavement sections which falls into poor or very poor class. Besides, attention needs to be given to sections falling in fair and good classes too.

The *distress density method* described above for road distress classification only account for number of distress per km of road section. The method do not account for the severity of distress type. Each type of distress will have varied degree of severity. Say for instance a "*longitudinal crack*" along the shoulder of the road may not be significant in terms of its severity to traffic movement as compared to a "*pothole*" of considerable dimensions in the crown portion of the pavement. However, in *distress density method* each distress type will be counted as distress number without considering its severity.

Thus, the results obtained by the *distress density method* may always exaggerate the pavement condition status.

Table 4.7- Area coverage of different distress class along the ring road

Total Area of 1km Buffered Zone of The Study Area - 65.72 km^2		
Road Status	**Area (km^2)**	**Percentage (%)**
Excellent	3.02	4.6
Good	6.36	9.68
Fair	18.50	28.15
Poor	25.84	34.75
Very poor	11.99	18.24

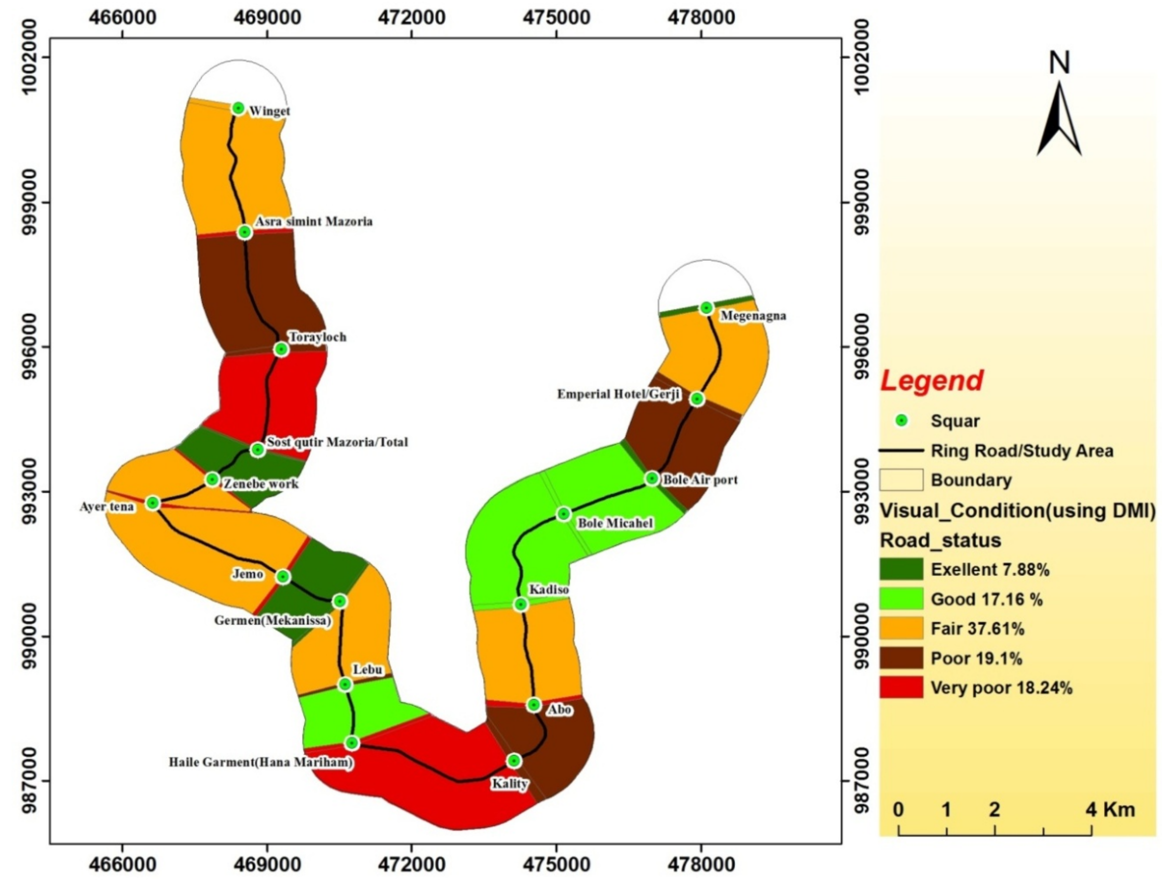

Fig 4.2- Visual inspection (Inventory) Map (Using DDM)

In the present case it may be noted that as per the classification by *distress density method* more than 50% of the road falls into poor or very poor class which is not the actual situation. Thus, to verify the facts another standard method known as *distress manifestation index* (DMI) was utilized.

The DMI method utilizes type, severity and extent of each pavement distress in defining the pavement status condition. Thus, the method may provide more reasonable assessment of pavement condition.

4.4.1.2 Visual Condition Survey Using Standard Method of Distress Manifestation Index (DMI)

Distress surveys are often required as part of the planning and design of pavement rehabilitation projects. These surveys gather information on the various distress types, their location, severity and the extent to which they exist. The accuracy of the survey is dependent upon the consistency of the data gathered.

Pavement condition index (PCI) comprises two different physical parameters such as riding comfort rating (RCR) and distress manifestation index (DMI).

RCR (Ride Comfort Rating)

- The roughness component can be measured using electronic device
- Objectively measured using various mechanical/electronic devices, such as PURD (Portable Universal Roughness Device) or the Mays Meter.

In the present study ride comfort rating (RCR) could not be used due to unavailability of mechanical or the electronic device which measures the roughness of the pavement. However, distress manifestation index (DMI) was used to evaluate the pavement condition.

DMI (Distress Manifestation Index)

- A systematic method for classifying and assessing the visible consequences of various distress mechanisms.
- DMI classifies distress manifestations into 15 categories, which are rated by severity and density (extent).

Distress manifestation index is an integral part of the PCI (Pavement condition index) but DMI can also be used independently as a measure of visible pavement distress (Hajek et al., 1986).

The DMI or particularly some of its component can be used as a proxy for assessing pavement structure an adequacy and for identifying pavement section which may require a corrective action due to specific distress condition. DMI (Distress Manifestation Index) is a systematic method for classifying and assessing the visible consequences of various distress mechanisms (i.e., distress manifestation) was developed in 1975 and its use commenced Ministry-wide in 1978.

Initially, the method classifies distress manifestation in to 27 distress categories. Each category of distress is further characterized by its severity and density. To ensure uniformity of interpretation and reporting, a compressive manual was prepared. The manual provide detailed guidelines, accompanied by many photograph, how to classify distress manifestation and how to evaluate their severity and density so that this characteristic can be expressed on ratio scale from 0 to 4.

The above methodology of classifying and evaluating distress manifestation has been kept. However, based on experience gained since 1978; the number of distress manifestation categories has been reduced from 27 to 15. The reduction achieved by combining 2 or 3 similar distress in to one. For example, the two distress categories “rippling” and “shoving” were combine in to one. The new 15 distress manifestation categories are listed in Tables 4.8 (Hajek et al., 1986).

Tables 4.8- Assessments of Distress Manifestation (Hajek et al., 1986)

DISTRESS TYPE	DESCRIPTION OF DISTRESS	Weighting Value Wi
SURFACE DEFECT	1)Raveling and Aggregat Loss	3
	2)Flushing	0.5
	3)Ripping and Shoving	1
SURFACE DEFORMATION	4)Well Truck Rutting	3
	5)Distortion	3
CRACKING	6)Logitudinal Wheel Track -Single- Multiple	1
	7)Logitudinal Wheel Track -Alligator	3
	8)Center line - Single-Multiple	0.5
	9)Centerline -Alligator	2
	10)Pavement Edge -Single- Multiple	0.5
	11)Pavement Edge - Alligator	1.5
	12)Transverse - Halfe- Full - Multiple	1
	13)Transverse - Alligator	3
	14)Longitudinal Meander and midelane	1
	15) Random	0.5

Severity of Distress, Si

DESCRIPTION	Severity, Si
Very Slight	0.5
Slight	1
Moderate	2
Severe	3
Very Severe	4

Density of Distress, Di

DESCRIPTION	Percentage (%)	Density, Di
Few	< 10	0.5
Intermittent	10 - 20	1
Frequent	20 - 50	2
Extensive	50 - 80	3
Throughout	> 80	4

4.4.1.3 Identifying Dominant Distresses Type in the Study Area

As a part of DMI attempt was made to estimate the distribution of various distress types along the ring road in the study area. Distribution and classification of total distress number per km of road length is already described in the previous section and presented as Table 4.5 & Figure 4.2. The summarized about intensity of individual distress densities on various road sections are presented in Table 4.11 below.

Within the road sections under present study manifestations for 8 types of distress were observed (Table 4.9). These distress are; Potholes, Shoving, Rutting, Depression, Crocodile Cracking, Delamination, Raveling and Longitudinal Cracking. Perusal of Table 4.8 clearly shows that Pothole, Shoving and rutting alone contribute more than 75% of the total distress. Remaining 5 distress types collectively account for only about 25%.

Table 4.9 The type and extent of distress on the study area

Distress No	Distress Type	Total Distress Density (Number)	Percentage (%) Distress indicator
1	Pothole	140	41.3
2	Shoving	69	20.35
3	Rutting	49	14.45
4	Depression	26	7.67
5	Crocodile Cracking	23	6.79
6	Delamination	20	5.9
7	Raveling	10	2.95
*8	Longitudinal Cracking	2	0.59
Total number of distress		**339**	**100**

* In significant

Calculation of DMI (Distress Manifestation Index)

The formula is based on application of the utility theory. This enables us to put all distress on the same scale and combine their contribution in terms of the DMI. The DMI is calculated by combining the density and severity of all distresses using the following formula:

$$DMI = \sum (\text{of all distresses})\ Wi \times (Si + Di) \qquad \text{……….eq. 4.1}$$

Where:

‘*I*’ is one of the following 15 distresses.

‘*DMI*’ is the Distress manifestation index. DMI is an overall characteristic (or a multi-attribute utility) describing pavement surface condition in terms of distress manifestation.

‘W_i’ is the Weight value representing the relative weight of each distress manifestation (attribute) given in table 4.9

‘S_i’ is the Severity of distress manifestations expressed on a scale from 0 to 4 as given in table4.9

'*Di*' is the Density of distress occurrence expressed on a scale from 0 to 4 as given in table 4.9.

The sums of (si + di) represent the contribution or utility of each distress (attribute) scale from 0 to 8 (Hajek et al., 1986).

In the present study area there are eight distressed types as presented in Table 4.10. The first three distress type (Pothole, Shoving and rutting) are the dominate distress types in the study area which account for more than 75 % of the total distress type. Also, longitudinal cracking is insignificant as it account for less than 1% of the total distress types. The weighting value (Wi) was assigned to each distress type in accordance to Table 4.8 (Hajek et al., 1986) and is presented in Table 4.10.

Table 4.10- Weighting of Distress Manifestation in the Study area (as per Hajek et al., 1986)

DISTRESS TYPE	DESCRIPTION OF DISTRESS	Weighting Value, Wi
SURFACE DEFECT	1)Raveling	3
	2) Shoving	1
SURFACE DEFORMATION	3)Rutting (Distortion)	3
	4) Pothole	3
	5)Depression (Distortion)	3
	6)Delamination (Distortion)	3
CRACKING	7) Crocodile Crack (Random Crack)	3
	8)*Longitudinal crack (insignificant)	1

There are total sixteen road sections in the study area which are defined in between two consecutive squares along the ring road. For each road section DMI was computed individually by utilizing eq. 4.1. For the computation of DMI distress type, its severity and density of distress was considered. Each distress type was assigned with the weight value and was assigned with appropriate values for severity and density from the standard Table 4.8. Thus, the computed DMI values for various road sections are presented in Table 4.11.

In order to define the road condition status based on DMI, road distress classification was evolved. In this classification the range of DMI were divided into equal sized sub ranges of distress and accordingly five road condition status classes were formed. The road section having < 2.4 DMI is classified as "Excellent" and that having > 9.6 DMI is classified as "very poor".

Similarly, with an equal interval of 2.4, intermediate classes "Good", "Fair" and "Poor" classes were defined (Table 4.12). These classifications have been defined through arithmetic ratio on the basis of the maximum and the minimum percentage of DMI/Km. Further, this quantitative classification based on DMI provides a relative comparison of quality of road sections.

Table 4.11 Summarized Visual Conditional Survey on the ring road Using DMI

No	Road section	Types and extent of distress	Sum of DMI	Road Length (Km)	DMI/ Km	perc. of DMI/KM (%)	Road Status
1	From Winged to Asrasimint Mazoria Square	PH=10,RUT=1,DEP=1,CC=4, DEL=9,RAV=3	313.5	2.72	115.3	7.06	Fair
2	From Asrasimit to Torayloch Square	PH=13,SHOV=7,RUT=2,DEP=3,CC=3,DEL=2,RAV=1	310.5	2.62	118.5	7.25	Poor
3	From Torayloch to Sost qutir mazoria Square	PH=17,SHOV=7,RUT=4,DEP=2,CC=4,DEL=1	451.5	2.16	209.0	12.78	Very poor
4	From sot quite mazoria to Zenebework Squre	PH=1,SHOV=2,RUT=1,RAV=1	39.5	1.15	34.3	2.1	Excellent
5	From Zenebwork to Ayertena Squre	PH=7,SHOV=6,RUT=2,DEP=1	141.8	1.35	105.0	6.43	Fair
6	From Ayertena to Jemo Squre	PH=11,SHOV=2,RUT=6,DEP=2,CC=3,DEL=1,RAV=1	285.5	3.16	90.3	5.53	Fair
7	From Jemo to Germen (Mekanissa)Square	PH=1,DEP=1	21	1.33	15.8	0.97	Excellent
8	From Germen (Mekanissa) to Lafto Squre	PH=10,SHOV=2,RUT=3,RAV=2,LC=1	155.5	1.75	88.9	5.44	Fair
9	From Lafto to Haile Garment (Hana.M) Squre	PH=2,SHOV=1,RUT=3,DEP=3	83.5	1.31	63.7	3.9	Good
10	From Haile Garment (Hana.M) to Kality Squre	PH=23,SHOV=11, RUT=8,DEP=2,CC=4,DEL=2	574	3.62	158.6	9.71	Very poor
11	From Kality to Abo squre	PH=7,SHOV=2,RUT=6,LC=2	207	1.55	133.5	8.18	Poor
12	From Abo to Kadiso Squre	PH=6,SHOV=8,RUT=5,DEP=1, CC=1,DEL=1	221.5	2.12	104.5	6.4	Fair
13	From Kadisko to Bole Micahel Squre	PH=7,SHOV=10,RUT=1,DEP=3,DEL=1	180	2.5	72	4.41	Good
14	From Bole micahel to Bole Airport Squre	PH=5,SHOV=2,RUT=2,DEP=1, CC=2	116.5	2	58.25	3.57	Good
15	From Bole Airport to Emperia Hotel Squre	PH=12,SHOV=3,RUT=2,DEP=3,CC=1,DEL=1	270.5	1.8	150.3	9.2	Poor
16	From Emperial Hotel to Megenagna Squre	PH=8,SHOV=6,RUT=4,DEP=1, CC=1,DEL=2,RAV=2	231	2	115.5	7.07	Fair

Abbreviations:-PH-Pothole, SHOV-Shoving, RUT-Rutting, DEP-Depression, CC-Crocodile crack, DEL-Delamination, RAV-Raveling, LC-Longitudinal Crack

A perusal of Table 4.11 clearly indicates that about 37% of road section according to DMI falls into poor or very poor class. However, with distress density classification method based on total distress numbers per km of road length the poor and very poor road sections accounted for more than 50%. Thus, DMI method provides pavement condition more realistic and well supported by severity and density of various distress types.

Table 4.12- Equal interval classification system

Percentage (%) of DMI/KM	Road Status
< 2.4	Excellent
2.4 - 4.8	Good
4.8 - 7.2	Fair
7.2 - 9.6	Poor
> 9.6	Very poor

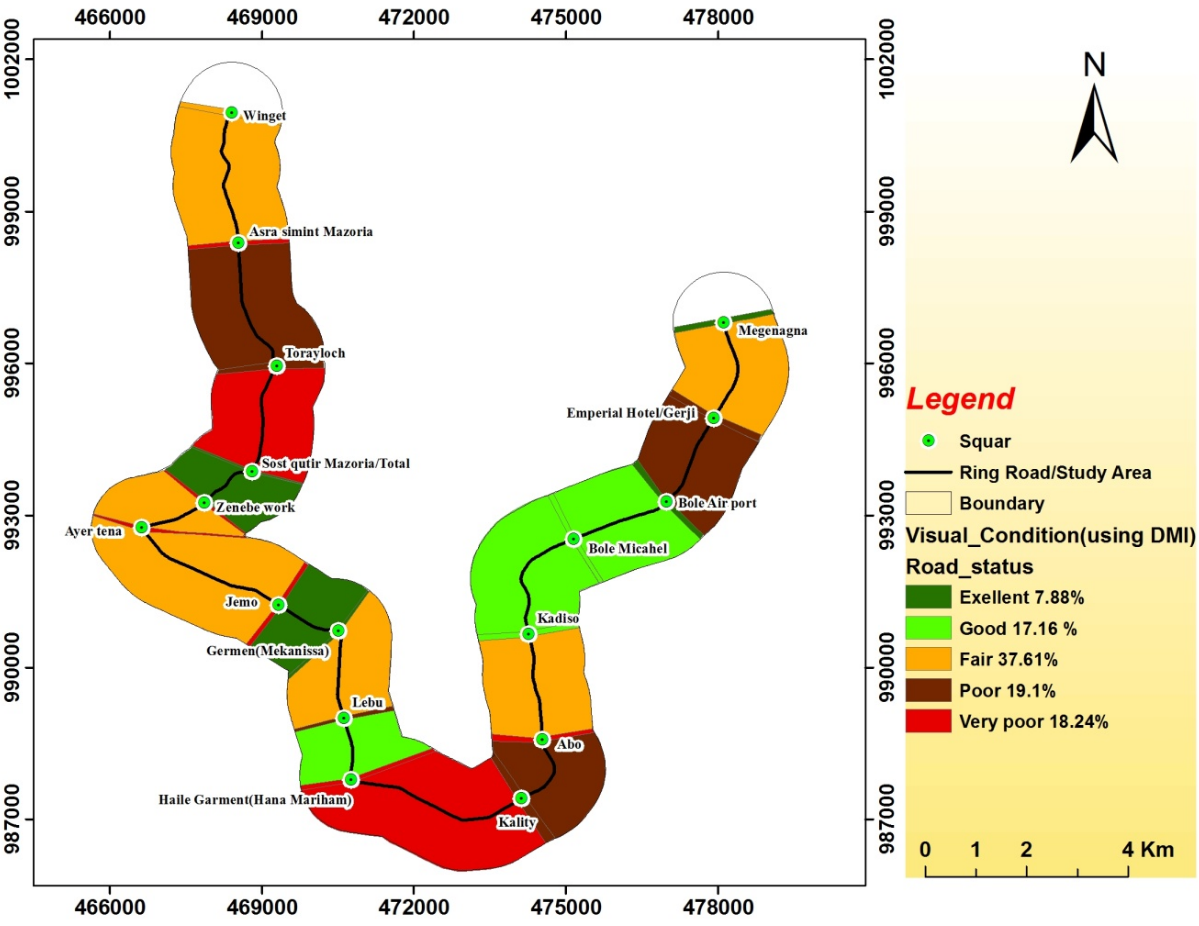

Fig 4.3- Visual Condition Survey map using the standard Distress Manifestation Index (DMI)

Further, based on the road condition classification based on DMI values, road condition map was produced. For mapping purpose a buffer zone of 1 km from the center line of ring road was considered. Thus, the road condition status according to various distress classes, delineated with the help of DMI, was marked over the map (Fig.4.3). The area coverage of different distress class along the ring road was also computed and is presented in Table 4.13.

Table 4.13 Area coverage of road status

Total Area of 1km Buffered Zone of The Study Area is 65.72 km^2		
Road Status	**Area (km^2)**	**Percentage (%)**
Excellent	5.18	7.88
Good	11.28	17.16
Fair	24.72	37.61
Poor	12.55	19.1
Very poor	11.99	18.24

4.4.2 Comparison between Distress Density Method and Distress manifestation index

In the present study to evaluate the condition of pavement two methods were applied for distress assessment. The first method, which was evolved during the present study, was Distress Density Method and other a standard method known as Distress Manifestation Index (DMI). The Distress Density Method is based on the number of distress per km of road length and it do not account for distress type, its location, its severity and density. Whereas, DMI method considers all pertinent information related to distress such as; type, severity, density etc. For both methods similar 5 Road status classes were formed but these classes were based on distress density in distress density method and DMI values in case of DMI method.

Table 4.14 Comparison between Distress Density Method (DDM) and Distress manifestation index (DMI)

Road Status	**Area (km^2)**				**Percentage (%)**			
	DDM		**DMI**		**DDM**		**DMI**	
Excellent	3.02		5.18		4.6		7.88	
Good	6.36		11.28		9.68		17.16	
Fair	18.50		24.72		28.15		37.61	
Poor	25.84	37.83	12.55	24.54	34.75	**52.99**	19.1	**37.34**
Very poor	11.99		11.99		18.24		18.24	

The road condition as evaluated by Distress Density Method indicates that more than 50% of the road falls into poor or very poor class whereas by DMI method about 37% of road is falling in poor or very poor class. Here it is worth mentioning that during field survey it was observed that the road condition was deteriorated because of various distresses at various locations but such deterioration has not made the overall condition of road as worst as what is indicated by Distress Density Method. Moreover, the result obtained by DMI methods seems reasonable and more realistic. Since DMI method consider distress types, their location, severity and the extent to which they exist therefore it is obvious that this method will provide more reasonable results which will be in accordance to the actual road condition status. The same has been demonstrated with the results obtained in the present study.

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Chapter 5 ASSESSMENTS OF POSSIBLE CAUSES OF PAVEMENT DISTRESS

5.0 Preamble

Road and transport authorities around the world spend tremendous amount of money each year in enhancing and maintaining their road networks. Road users in the majority of countries around the world continue to desire better and smoother roads, despite pressure on road authorities to further reduce expenditure. This pressure is brought about, because funding for road infrastructure is only one of the many priorities competing for Government funds.

The goal of pavement management is to produce optimized pavement work programs at the network level, as well as optimized pavement rehabilitation designs at the project level. Within the pavement management process, performance predictions are very important in developing optimized multiyear work programs, as well as for evaluating the life cycle cost-effectiveness of project designs (Cheetah, 1998 as cited in Phil Hunt, 2001).

In the present chapter attempt is being made to investigate and make an assessment of possible causes which might have contributed for the pavement distress and deterioration in the study area. It has already been presented in the previous chapter that pavement has suffered to various kind of distress such as; Pothole, Shoving, rutting, longitudinal cracks etc. With all such distress features, reasonably, about 37% of pavement status is poor or very poor within the study area. Thus, it becomes important to assess the possible causes which might have affected the pavement to such a deteriorated condition well before its designed life period.

Investigation and assessment of the possible causes of pavement distress will not only help in pavement condition management but may also help in evolving possible rehabilitation methods.

It is believed that the distress or deterioration of pavement in the study area might have resulted due to combined effect of various inherent and external factors. For the present study the factors which were considered are; *Engineering geology*, *Drainage* (*Rivers, Surface flow direction, GW table and GW flow direction*), *Elevation (Altitude), Slope terrain, Curvature, Slope aspect* and *Structural set up of the area*.

All these factors might have interacted with the pavement, in due course of its performance, with relative varied impact in combination or significant effect individually.

In order to assess the relative influence of various causative factors on pavement distress, analysis was made in GIS environment. For this purpose overlay analysis was performed using various tools in ArcGIS. To know the relative contribution of each of the causative factors on pavement distress, Raster Calculator - a tool in Arc GIS, was used. The following systematic steps were followed to analyze the relative contribution of each of the parameter on pavement condition (DMI);

- Maps for each of the causative factors (*Engineering geology*, *Drainage*, *Elevation*, *Slope terrain*, *Curvature*, and *Slope aspect)* were prepared on same scale and similar projection system.

- Visual condition survey map prepared by using Distress Manifestation Index (DMI) (Fig.4.3, Chapter 4) and all factor maps were converted to Raster form with similar pixel size (50 x 50 m).

- Later, each of the causative factor maps was overlaid on visual condition survey map. By using Raster calculator total pixel count for each of the sub-class of causative factor falling within respective visual condition survey classes (very poor, poor, fair, good and excellent) was determined.

- Further, ratio between poor and good pavement class for each sub-class of causative factors was determined. For convenience of computation very poor and poor visual condition survey classes were clubbed together to define “Poor status” of road. Similarly, fair, good and excellent visual condition survey classes were combined to redefine “Good status” of road. The ratio between “Poor status” and “Good status” defines the relative correlation of respective sub-class of a causative factor with pavement distress condition. It implies that if the ratio value is more than 1 the respective sub-class of a causative factor has relatively more impact on the pavement distress.

Thus, the overlay analysis has facilitated in understanding quantitatively the relative impact of each causative factor sub-class on pavement distress. Though the information obtained is on individual causative factor basis but it may be vital in deciding most suitable rehabilitating method for pavement condition improvement. The causes of deterioration combined with the extent of the failures must be considered together when selecting the most appropriate method of maintenance or rehabilitation (ORN 18, 1999).

5.1 Impact assessment of Engineering Geological Parameters on Road Status Condition (DMI)

All transportation systems are built either on, in, or with soil and products from the ground. Soil is arguably the most critical component of the transportation system, since most construction is dependent upon project soil properties and characteristics. The characterization and evaluation of soil is critical for the performance of pavement structures (ERN, 2003).

The road status assessment is an important task for road authorities. The evaluation process will assess the performance levels of the system in terms of its effects in mitigating existing work zone problems. Periodic road maintenance and rehabilitation will be done based on the road status assessment data to enhance long-term effect treatments on pavement performance.

To assess engineering geological problem with regional scale, the geotechnical data referenced by spatial geographic coordinate should be interpolated or extrapolated across the area of interest based on the existing and/or obtained known geotechnical data. Advanced computer-based expert system is required for the management and estimation of geotechnical data in spatial domain. As advances in the computer technology, geographic information system (GIS) in recent years has emerged to be a powerful computer-based technique that integrates spatial analysis, database management, and graphic visualization capabilities (C. Guk Sun, 2010). The following section presents GIS-assisted information of overlay analysis for road status evaluation in terms of engineering geological parameters which might have possibly affected the pavement of the present study area.

As stated above for the present study engineering geological parameters were identified namely; *Rock and Soil type*, *Drainage* (*Rivers, Surface flow direction, GW altitude(table) and GW flow direction*), *Elevation (Altitude), Slope, Curvature and Slope aspect*. It is believed that these are the prominent causative engineering geological factors which might be responsible for the pavement distress or distortion. Therefore, in order to assess the relative degree of impact of these factors on the pavement condition a spatial joint overlay analysis in GIS environment was performed. For this purpose geo-processing was done and each of the individual factor maps was overlaid on visual survey condition map. Following, paragraphs presents a detailed description on methodology followed, results obtained and interpretation made on results for each spatial joint overlay analysis for various causative factors.

5.1.1 Relationship Between Rock and Soils on Road Condition

The rocks and soils, which obviously cover the ground surface, form the foundation as sub-grade material for pavement. The behavioral characteristic of these soils and rocks will define the suitability for placement of pavement layers over it. Such behavioral characteristic of foundation soils and rocks will entirely depend on the properties of rocks and soils. Such properties will influence location, planning, design, construction, operation and maintenance of pavement.

The strength of a soil is dependent on its moisture content, density and confinement. The control of pavement moisture is an essential prerequisite to reliable moisture prediction and satisfactory pavement performance (ERN, 2003).

For the present study rock and soil property map was prepared by modifying the engineering geological map prepared by Kebede Tsehayu and Tadese Hailemariam (1990). Besides, data from 70 test pits, dug for geotechnical investigation for Ring Road was also procured and used in depicting the soil properties.

The rock and soil coverage map was prepared in Arc GIS and a buffer zone of 1 km from the center line of ring road was delineated to mark all rock and soil types falling in the study area (Fig. 5.1). For mapping purpose the soil units were geotechnical classified as expansive and non-expansive soil. The expansive soils which are genetically lacustrine or black cotton soils cover 41% of the study area whereas, non-expansive soils which are genetically residual, alluvial and colluvial soils covers 19% of the study area. Similarly, the various rock units present in the study area were classified on the basis of their relative strength. The strength classes considered were; very high, high, medium and low strength rocks. Thus, in terms of area coverage the dominant type are medium strength and very high strength rocks which covers 29.4% and 8.79% of the study area, respectively. The area coverage of high strength and low strength rocks collectively account for only 3.88% of the study area

<u>Overlay analysis of Rock and soil units with Pavement Condition</u>

In order to analyze the relative impact of rock and soil units on pavement condition a spatial joint overlay analysis by using ArcGIS was performed. Rock and soil coverage map defined with appropriate soil and rock classes based on expansive and strength characteristics, respectively along with visual distress condition survey map (DMI) was converted to Raster form with similar pixel size (50 x 50 m). Later, spatial joint correlation between the two maps was performed and by utilizing Raster calculator tool in GIS total pixel count for each sub-class of Rock and Soil factor map falling within respective visual condition survey classes (very poor, poor, fair, good and excellent) were determined. The results thus obtained are presented in Fig. 5.2 and Table 5.1.

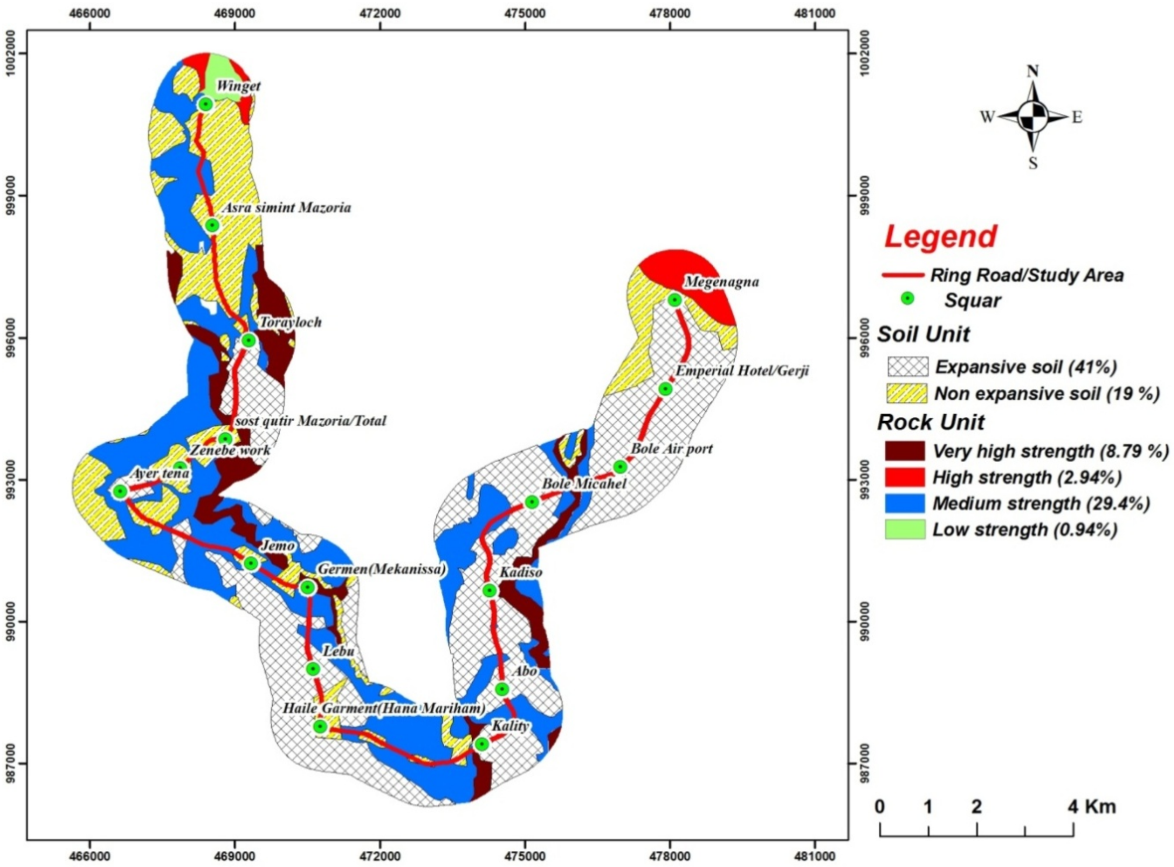

Fig 5.1 Rock and Soil Coverage Map *(Source: Modified after Kebede Tsehayu and Tadese Hailemariam, 1990 and by utilizing test pits data procured from geotechnical investigation for the ring road construction)*

Fig. 5.2 and Table 5.1 demonstrate a relative coverage of each rock and soil sub classes falling on respective sub-classes of visual condition map. By using raster calculator tool in ArcGIS total pixel of each sub classes of rock and soil falling within respective pavement visual condition were determined and later were converted to percent with respect to total coverage area. As already mentioned for convenience of computation very poor and poor visual condition survey classes were clubbed together to define "Poor status" of road.

Similarly, fair, good and excellent visual condition survey classes were combined to redefine "Good status" of road.

A perusal of Table 5.1 clearly indicates that about 30.5% of pavement classified as Poor status belongs to Alluvial whereas 25% and 25.5% of poor pavement sections relates to residual and Lacustrine (Black cotton) soils, respectively. About 10% of pavement classified as poor pavement relates to colluvial type of soil. Further, 9% of pavement classified as poor pavement falls on medium strength rocks. In contrast if the good pavement condition is compared with various sub classes of rock and soils 26% of pavement falls on residual soils and about 18.33% falls on Lacustrine (Black cotton soil). Similarly, relation of good pavement condition with rocks indicates rocks with high strength, medium strength and very high strength accounts for 7.66%, 39% and 9%, respectively.

Further, ratio between poor and good pavement class for each sub-class of Rock and Soil unit was determined. This ratio defines the relative correlation of respective sub-class with pavement distress condition. It implies that if the ratio value is more than 1 the respective sub-class of rock and soil unit has relatively more impact on the pavement distress. A perusal of Table 5.1 indicates that ratio between poor and good pavement class is more than 1 for alluvial, colluvial and lacustrine (Black cotton) soils. Ratio value more than 1 shows a clear correlation between distress and these soil types. Thus, it is reasonable to infer that probably alluvial, colluvial and lacustrine (Black cotton) soils are more related to pavement distress than the residual soils and the other rock units present in the study area.

5.1.2 Relationship Between Drainage and Road Status

5.1.2.1 Surface Drainage

Drainage characteristics have a significant effect on pavement performance. Pavements with poor surface and sub-surface drainage properties prematurely exhibit distress and have higher life-cycle cost. Shorter service life and higher maintenance cost are some of the reasons for the higher life-cycle cost (Rokade et al., 2012).

Providing adequate drainage to a pavement system has been considered as an important design consideration to prevent premature failures due to water related problems such as; pumping action, loss of support, and rutting, among others. Most water in pavements is due to rainfall infiltration into unsaturated pavement layers, through joints, cracks, shoulder edges, and various other defects, especially in older deteriorated pavements. Water also seep upward from a high groundwater table due to capillary suction or vapour movements, or it may flow laterally from the pavement edges and side ditches. Therefore, 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.

To minimize premature pavement distresses and to enhance the pavement performance, it is imperative to provide adequate drainage to allow infiltrated water to drain out from the base and sub-base, thus avoiding saturation of base and sub grade soils (Rokade et al., 2012).

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, if counter measures are not undertaken. Water-related damage can cause one or more of the following forms of deteriorations: (a) Reduction of sub-grade and base/sub-base strength, (b) Differential swelling in expansive sub-grade soils, (c) Stripping of asphalt in flexible pavements, (d) Frost heave and reduction of strength during frost melt, and (e) Movement of fine particles into base or sub-base course materials resulting in a reduction of the hydraulic conductivity considerably (Rokade, 2012 as cited in Lytton et al., 1993).

Table 5.1 – The possible effects of soil and rock units on the pavement distress

No	SOIL AND ROCK UNITS	ROAD STATUS															
				Poor						**Good**							
				Very poor		Poor				Fair		Good		Excellent			
		Total Soil & Rock unit COUNT	Total Soil & Rock unit percentage%	Count	%	Count	%	Total Poor		Count	%	Count	%	Count	%	Total Good	Ratio, Poor/Good
1	Residual soil	3830	18	1652	27	890	23	2542		2416	43	890	35	0	0	3306	0.77
2	Alluvial soil	246	1	0	0	2416	61	2416		0	0	0	0	0	0	1	2416.00
3	Colluvial soil	36	0	1272	20	0	0	1272		0	0	0	0	0	0	1	1272.00
4	Lacustrian soil(Black cotton soil)	8686	41	2162	35	636	16	2798		0	0	0	0	1526	55	1526	1.83
5	Rock high strength	112	1	0	0	0	0	0		509	9	0	0	381	14	890	0.00
6	Rock medium strength	6513	31	1143	18	0	0	1143		1144	20	1653	65	890	32	3687	0.31
7	Rock very high strength	1686	8	0	0	0	0	0		1526	27	0	0	0	0	1526	0.00
TOTAL COUNT SUM = 21109		**21109**	**100**	**6229**	**100**	**3942**	**100**	**10171**		**5595**	**100**	**2543**	**100**	**2797**	**100**	**10937**	**0.93**

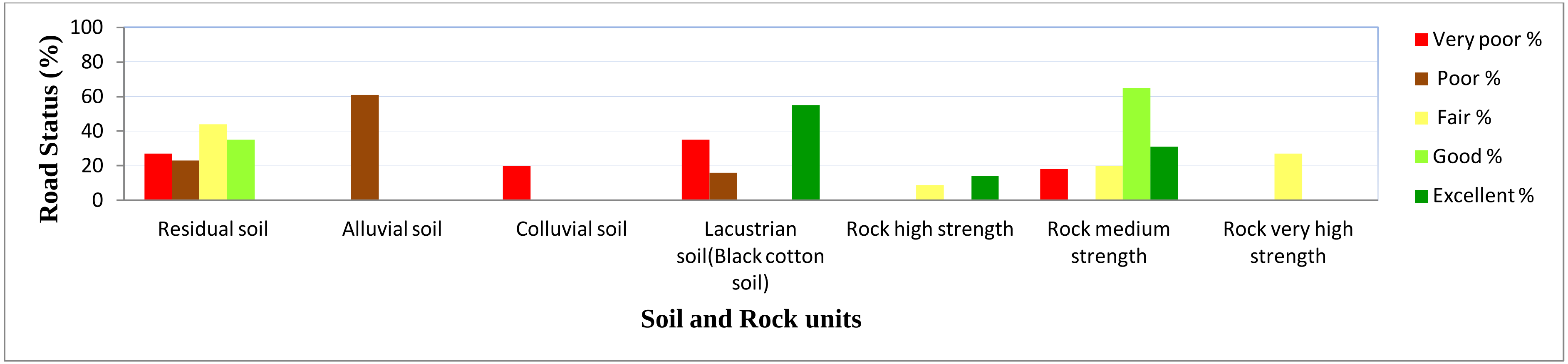

Fig 5.2 Road Status Verses Rock and soil unite

In the present study area, various perennial and seasonal streams are crossing the ring road. The major streams which crosses the ring road in the study area are; Hanku (Kotebe), Jemo (Lebu), Kebena and Akaki. Akaki River crosses the ring road twice, in western and in southern parts of the study area. Generally, all these streams crosses ring road at 5 different places within the study area (Fig.5.3).

From the visual observations during the field visit attempt was made to assess the pavement condition in those reaches where the streams crosses the road within the study area. In between Megenagna and Bole square Hanku (Kotebe) river crosses. The pavement is categorized as poor in span where Hanku River crosses the road section. Further, in between Bole Micahel and Kadisko square Kebene River crosses the ring road. The condition of pavement in reaches where Kebene River crosses the road section is characterized as good. As already mentioned, Akaki River crosses the ring road at two places one in between Kaliti and Hile Garment square where the pavement status is very poor and second in between Zenebework and Sost Qutir Mazoria near Alert Hospital where pavement is characterized as having excellent condition. Gemo (Lubu) Stream crosses the ring road near Lebu in between Lebu and Germen square, the pavement in this section is characterized as having fair condition (Fig.5.4).

Overlay analysis of Surface Drainage with Pavement Condition

Attempt was made to analyze the possible interaction of perennial and seasonal streams with pavement condition. Further, it was also attempted to analyze the pavement condition with respect to surface water flow direction. For analysis purpose surface water flow direction was characterized as; (i) Flow direction towards and along the side of the pavement and (ii) Flow direction away and along the side of the pavement (Fig.5.5).

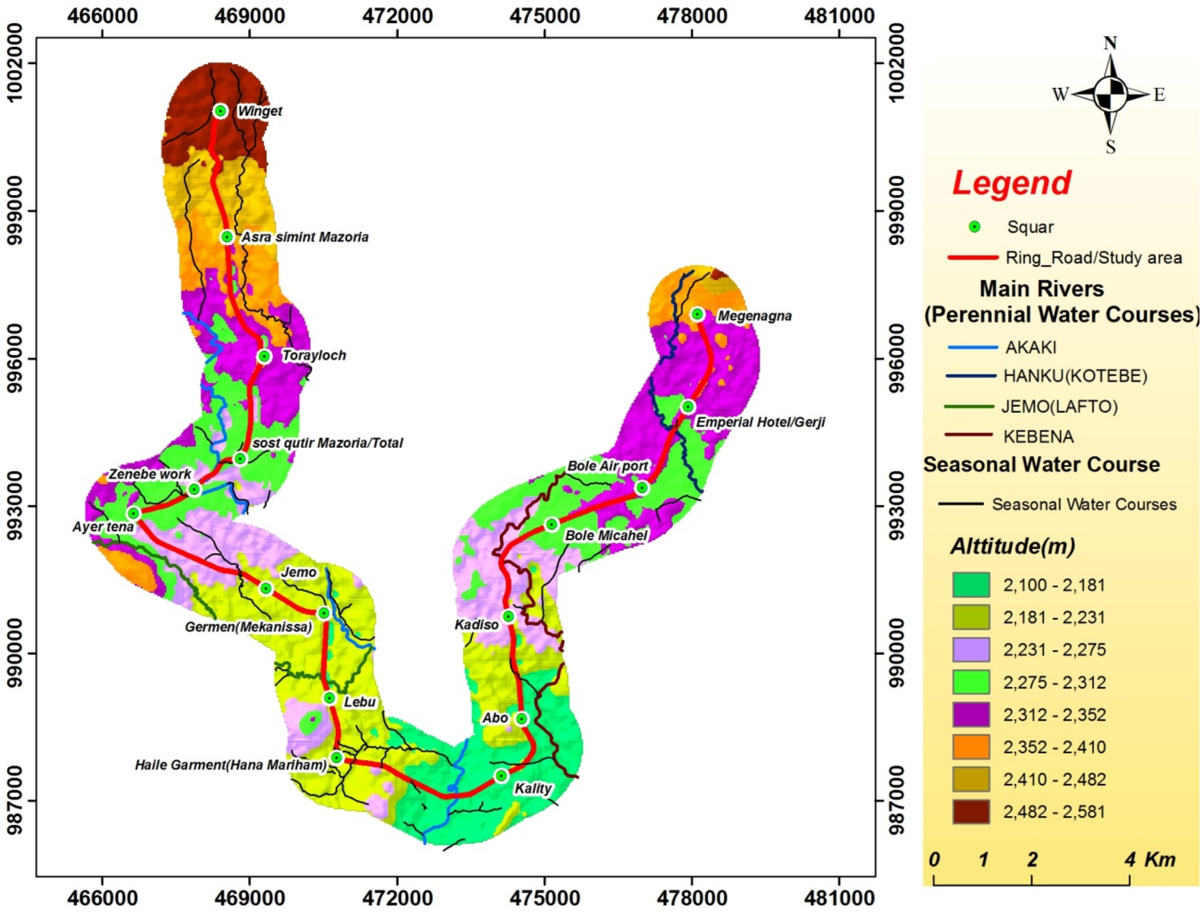

Fig 5.3- The main rivers (Streams) crossing the ring road in the study area *(Source: Aster DEM (30m resolution))*

In order to analyze the relative impact of surface drainage on pavement condition again spatial joint overlay analysis by using ArcGIS was performed. For overlay analysis firstly the relative influence of nature of surface drainage (perennial or seasonal) on pavement condition was assessed (Table 5.2 and Fig.5.6) and secondly the overlay analysis was made to assess the influence of surface drainage flow direction on pavement condition (Table 5.3 and Fig.5.7).

The results from the overlay analysis of surface drainage with pavement condition presented in Table 5.2 and Fig.5.6 reveal that in terms of area coverage 67.5% of pavement under poor condition is related to seasonal streams whereas about 32.5% of the poor condition pavement is related to Perennial streams. Majority of Pavement under good condition is associated (88%) to seasonal streams and only 12% of pavement in good condition is associated with perennial streams. Further, with regards to the ratio between poor pavement classes to good pavement class Perennial streams sub-class show the ratio value greater than 1 which clearly shows a good correlation between perennial streams and pavement distress.

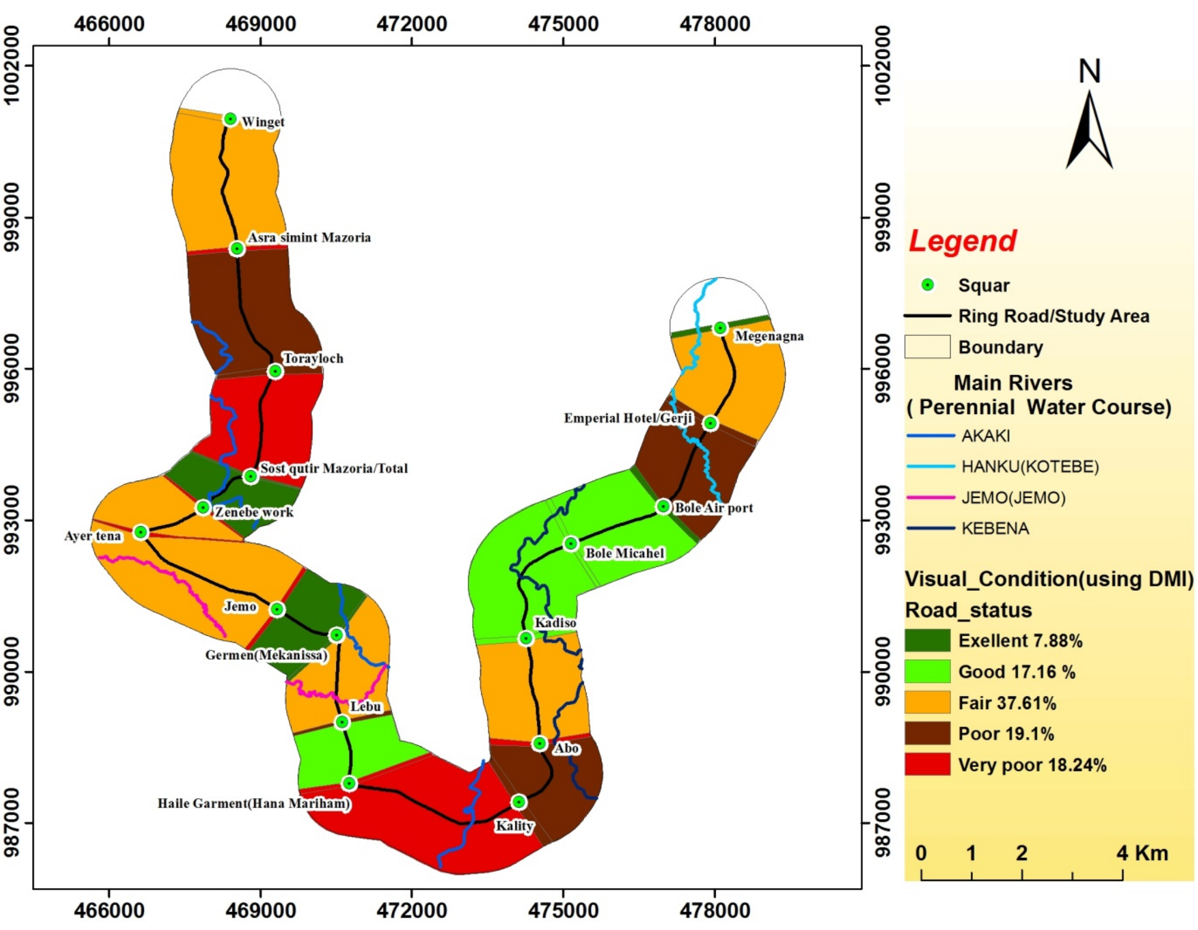

Fig 5.4 Major streams overlaid on pavement condition status map

Thus, the results obtained from the overlay analysis of surface drainage with pavement condition clearly shows a good relation of poor pavement condition with perennial streams. It is reasonable and logical to have this type of corelation as perennial streams may influence the pavement through out the year. It is also known that the soil properties considerable changes when it is saturated. Also, the analysis has shown that seasonal streams are less associated with pavement condition. Further, a good corelation between pavement condition and the surface drainage can be observed in graph (Fig. 5.6). In case of Perennial streams as the pavement condition improves from poor to excellent the percentage coverage of perennial streams decreases. Similarly, seasonal streams show reverse trend as the pavement condition improves from poor to excellent percentage coverage of seasonal streams increases.

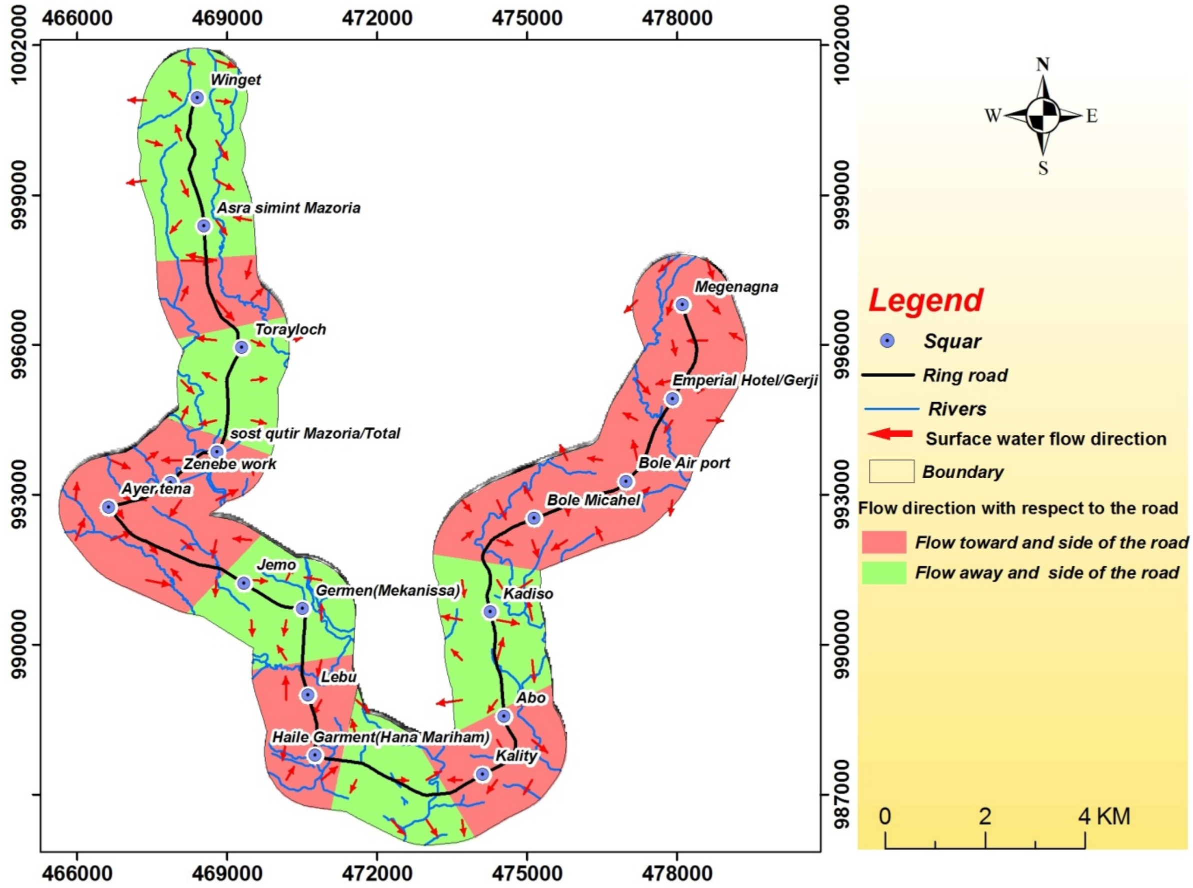

Fig 5.5- Surface water flow direction in the study area

Overlay analysis of Surface Drainage flow direction with Pavement Condition

Surface flow direction with respect to pavement may have significant effect on pavement distress and its performance. The possible surface flow direction in the present study area were deduced with the help of elevations. The elevation map of the study area was generated from DEM with 30m resolution. This is well known that the surface flow direction is governed by relative elevation difference and will be from higher towards lower elevations in the given area. Therefore, surface flow direction was deduced and marked over map with arrows by using Surfer-8 software (Fig.5.5).

The overlay analysis of surface drainage flow direction with the pavement condition was performed and the results thus obtained are presented in Table 5.3 and Fig.5.7. The results indicates that in 61% of the area surface flow direction is towards and along the side of the pavement whereas, in 39% of the area surface flow direction is away and along the side of the pavement.

Table 5.2- Relation between surface drainage and the Pavement condition

		ROAD STATUS															
No	**Stream Type**	Total Rivers COUNT	Total Rivers percent%	Poor				Total Poor		Good						Total Good	Ratio, Poor/Good
				Very Poor		Poor				Fair		Good		Excellent			
				Count	%	Count	%			Count	%	Count	%	Count	%		
1	Seasonal streams	1127	61	346	65	163	70	509		348	75	186	89	395	100	929	0.55
2	Perennial streams	708	39	186	35	70	30	256		116	25	23	11	0	0	139	1.84
TOTAL SUM = 1835		1835	100	532	100	233	100	765		464	100	209	100	395	100	1068	**0.72**

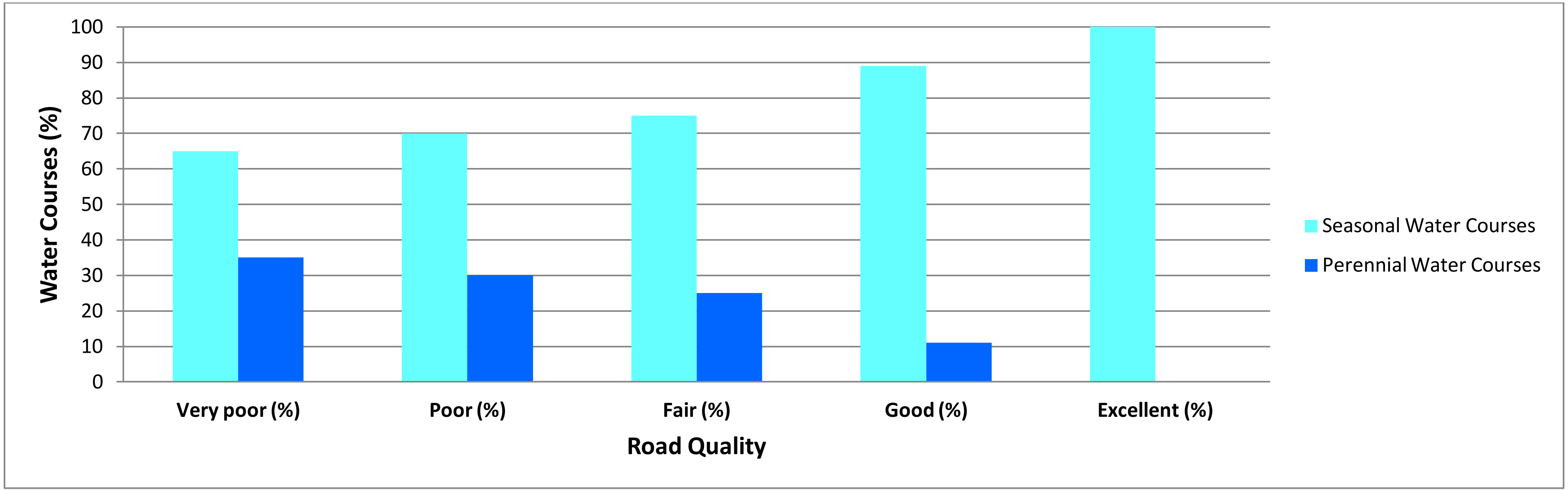

Fig 5.6 – Surface drainage versus Pavement condition

Further, for 46% of the pavement under poor condition receives surface water due to flow direction towards and along the side of the pavement whereas, 54% of the poor condition pavement has Flow direction away and along the side of the pavement. Similarly, 62.66% of pavement under good condition receives surface water due to flow direction towards and along the side of the pavement however 37.33% of pavement in good condition has Flow direction away and along the side of the pavement. Moreover, the ratio between poor condition to good condition do not reveal any relative influence of surface flow direction on pavement condition as for both the flow directions the ratio value is more than 1.

However, when compared with each other the Flow direction towards and along the side of the pavement has a higher ratio value (2.38) in comparison to Flow direction away and along the side of the pavement (1.83). Thus, it may be concluded that Flow direction towards and along the side of the pavement is more related to pavement distress condition. Indeed it is logical and sensible that when the Flow direction is towards and along the side of the pavement it may result into saturation of pavement layers which ultimately may result into pavement distress.

5.1.2.2 Subsurface Drainage

Excessive moisture within a pavement system is one of the most influential factors in contributing to the early deterioration of pavements. Moisture enters the pavement through surface infiltration, cracks, and joints and through movement of subsurface moisture. Subsurface moisture may be present in the pavement system because of areas of high water table, interrupted aquifers and springs, subsurface flow, and capillary action. Excessive moisture in the pavement structure will cause one or more of the following: (i) a reduction in the shear strength of unbound subgrade/sub-base materials, (ii) creation of weak layers by movement of unbound fines into flexible pavement sub-base/base courses, (iii) frost heave, (iv) reduction of strength during frost melt, (v) durability cracking, (vi) loss of support by pumping of fines in rigid pavements, and (vii) stripping in asphalt pavements.

Properly designed and constructed sub-surface drainage systems enhance the life of pavement structures. Clogged under-drain outlet pipes are detrimental to the performance of the pavement structure. Therefore, it is recommend that regular inspection of the under-drain outlet pipes needs to be a key part of maintaining a pavement that includes sub-surface drainage features (Rokade, 2012).

Table 5.3-The possible effects of surface water flow direction on the pavement condition

		ROAD STATUS															
				Poor						Good							
				Very Poor		Poor				Fair		Good		Excellent			
No	**Surface drainage flow directions**	Total sw flow dir. COUNT	Total sw_flow dir.percent %	Count	%	Count	%	Total Poor Count		Count	%	Count	%	Count	%	Total Good count	Ratio, Poor/Good
1	Flow toward & side of the road	12956	61	8639	75	480	17	9119		1439	38	1918	100	480	50	3837	2.38
2	Flow away & side of the road	8154	39	2878	25	2398	83	5276		2398	62	0	0	480	50	2878	1.83
TOTAL SUM = 21110		21110	100	11517	100	2878	100	14395		3837	100	1918	100	960	100	6715	**2.14**

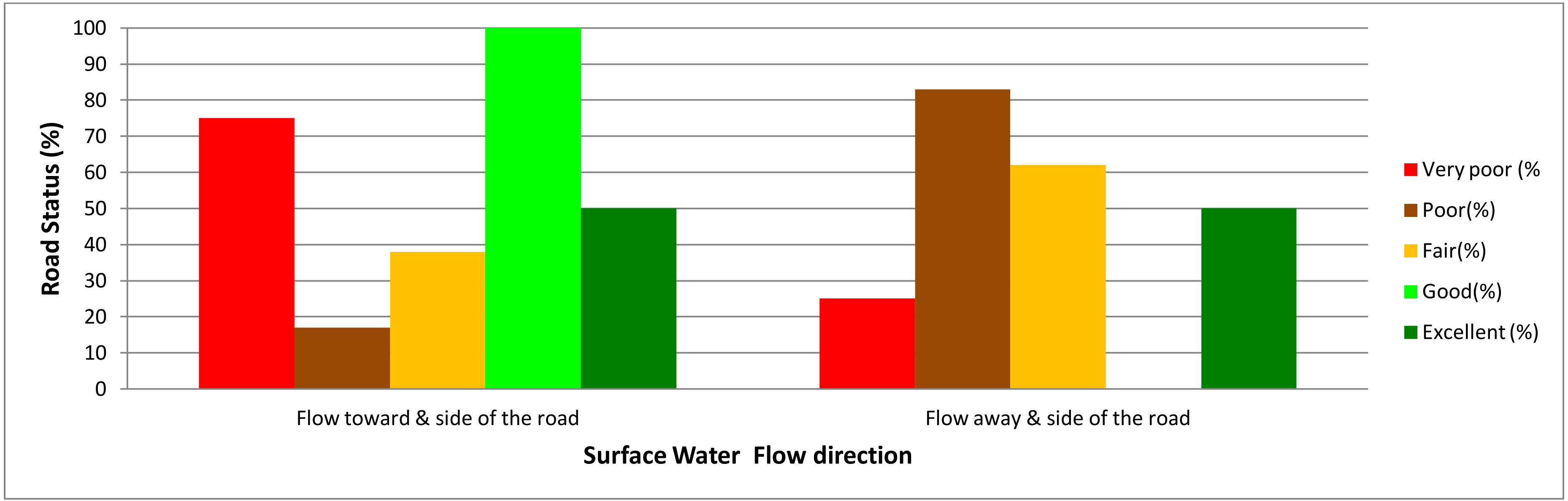

Fig 5.7- Road status versus Surface water flow direction

Relation of Depth to Water Table with Pavement Condition

For the present study depth to water table in the study area was deduced from 62 water wells. The water well data was procured from Addis Ababa water sewerage Authority (AAWSA). The location of these water wells is shown in Fig 5.9. The water well data was analyzed with respect to the various visual pavement condition classes and the results are presented in Table 5.4 and Fig.5.8. Perusal of results presented in Table 5.4 clearly indicates that average groundwater table depth in entire study area is far below the pavement and does not have any possible adverse effect on pavement condition.

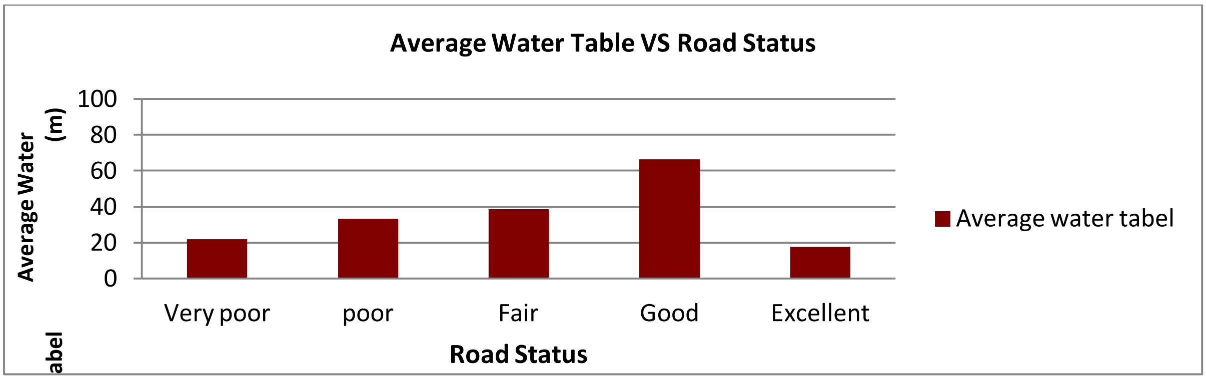

Fig 5.8- Average water table versus Road Status

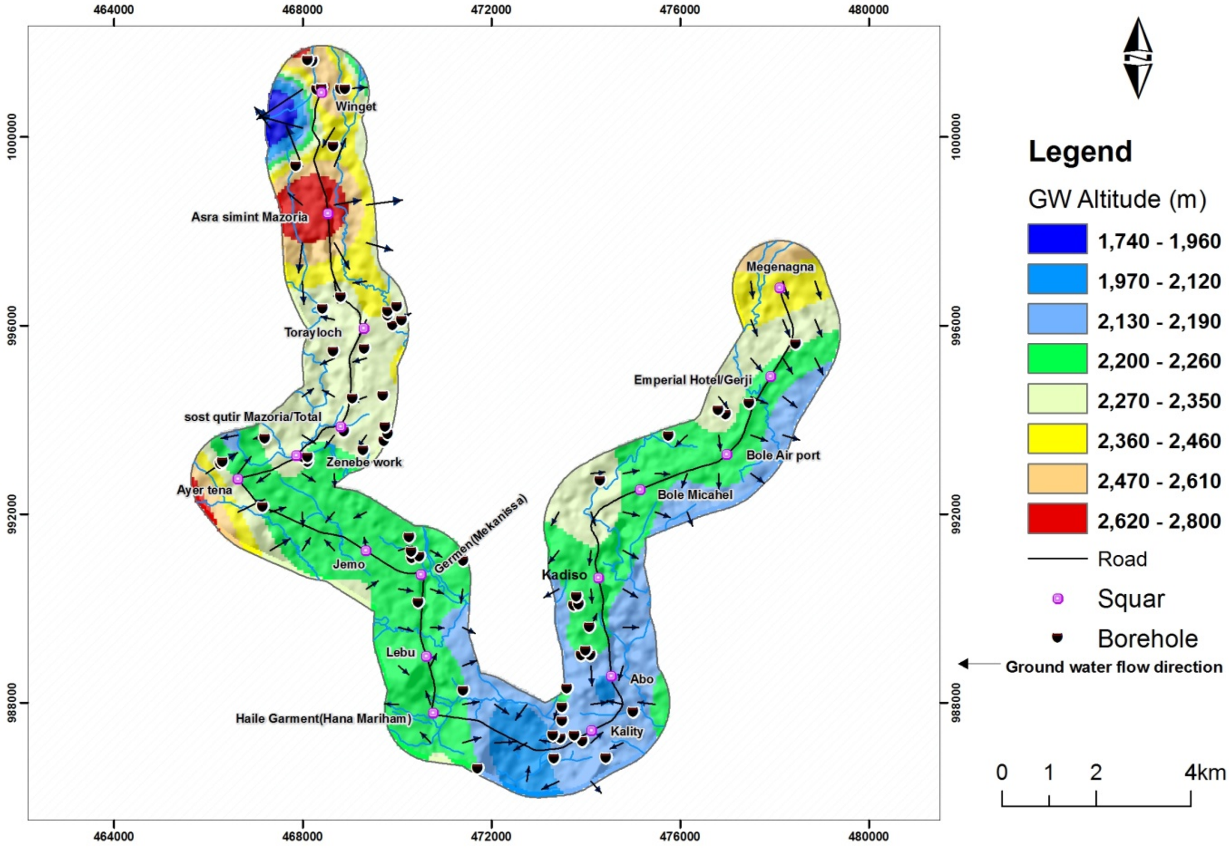

Fig 5.9 - Boreholes locations and Ground water flow direction (*Source of data AAWSA*)

Table 5.4- Relation between Depths to Groundwater table with pavement condition

Pavement Status & Number of BH	Depth of BH (m)	GW Altitude (m)	Water Table (m)	Average Water Table (m)
Very poor (15 BH)	81	2193.9	26.1	**21.9**
	87	2154.8	25.2	
	86	2130.7	19.3	
	72	2159.4	15.6	
	65	2155.75	9.25	
	120	2127.61	35.39	
	110	2157	23	
	91	2185.9	9.1	
	80	2255	50	
	170	2303.33	26.62	
	150	2306	14	
	120	2293.5	26.5	
	152	2325.3	6.7	
	126	2393.6	26.4	
	107	2331	16	
Poor (13 BH)	187	2136.5	40.5	**33.2**
	102	2183.1	11.3	
	151	2285	52	
	170	2243.14	91.86	
	67	2321.3	13.7	
	45	2322	30	
	60	2335	7	
	52	2348.5	1.5	
	68	2300.4	19.6	
	132	2276.5	72.5	
	38	2321	14	
	172	2152.2	27.8	
	124	2309.65	50.35	
Fair (22 BH)	94	2246	29	**38.6**
	126	2185	35	
	58	2207	18	
	146	2198.4	51.6	
	100	2206.3	40.7	
	75	2207.2	37.8	
	115	2205	15	
	38	2214.1	25.9	
	142	2285	50	
	202	2178.6	45.4	
	60	2211	24	
	171	2266.35	86.65	
	112	2257	60	
	84	2272	48	
	120	2442	3	
	172	2393.5	68.5	
	63	2484	41	
	42	2511	18	
	116	2468	72	
	192	2577	3	
	150	2532.1	45.9	
	150	2553.31	31.69	
Good (3 BH)	84	2192.5	12.5	**66.2**
	129	2291.8	89.2	
	149	2212.85	97.15	
Excellent (9 BH)	170	2212	10	**17.65**
	124	2204	16	
	20	2210	10	
	40	2212	8	
	48	2263.2	16.8	
	83	2255	45	
	122	2275.36	19.64	
	120	2301.76	22.24	
	130	2286.84	11.16	

**BH-Borehole* *(Source: Addis Ababa Water Sewerage Authority, AAWSA)*

Relation of Ground Water Flow Direction with Pavement Condition

It is known that groundwater flow direction is followed by the hydraulic gradient. In the present study ArcGIS tool was utilized to generate the groundwater contour from 62 water well data procured from AAWSA. Groundwater altitude is an elevation difference between ground surface and the depth to groundwater table. Thus, groundwater table altitude map was prepared and 8 different groundwater table altitude classes were formed (Fig. 5.9 & Fig. 5.10). Later, groundwater flow directions were deduced. For overlay analysis groundwater flow directions were classified into three sub classes namely; (i) Flow toward both side the road (ii) Flow toward one side and the other side away from the road and (iii) Flow both side away from the road. Further, overlay analysis by using ArcGIS tool was performed in between groundwater flow direction and the pavement condition map. The results thus obtained are presented in Table 5.5 and Fig. 5.11.

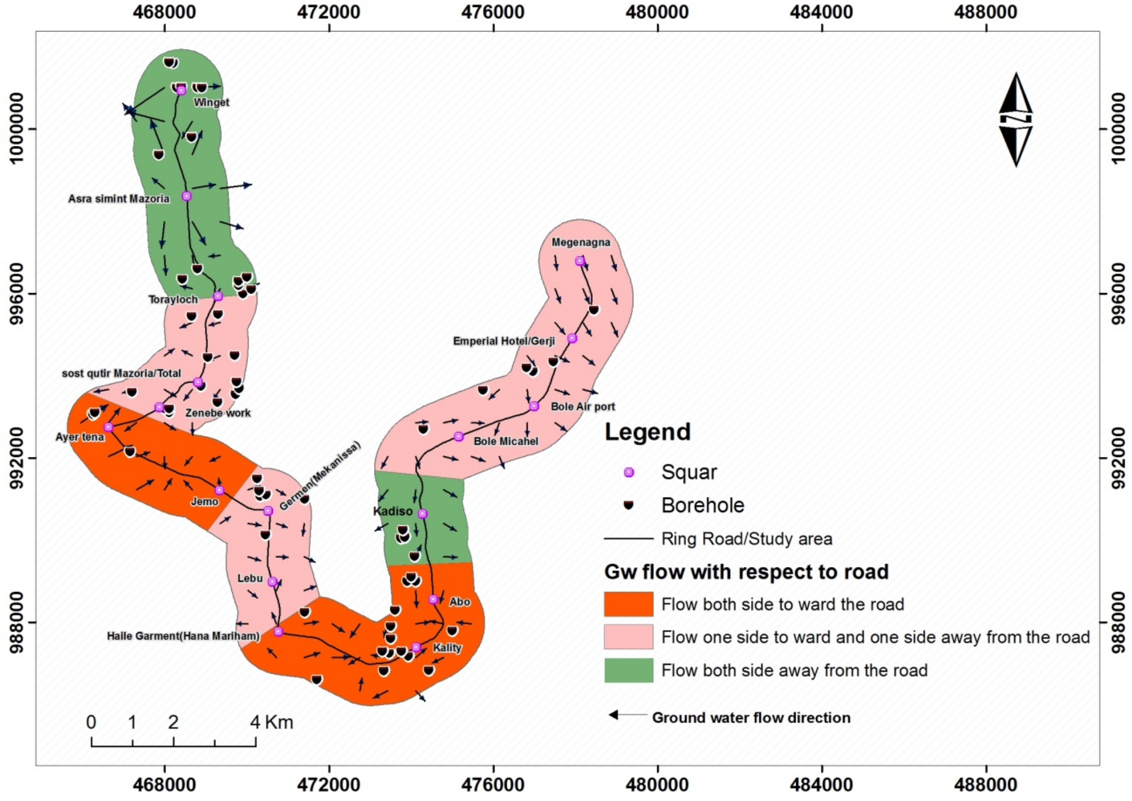

Fig 5.10 - Ground water flow direction with respect Pavement condition

Perusal of Table 5.5 indicates that in 21% of the study area groundwater flow is towards both sides the pavement, whereas in 53.5% of the study area groundwater flow is toward one side and on the other side away from the road. In remaining 23% of the study area groundwater flow is away from both sides the road.

Table 5.5 – Relation between Ground water flow direction and pavement condition

No	**Groundwater flow direction with respect to Pavement condition**	**ROAD STATUS**																
		Total GW flow dir. COUNT	Total GW flow dir. percent%	Poor				Total Poor		Good						Total Good	Ratio, Poor/Good
				Very Poor		Poor				Fair		Good		Excellent			
				Count	%	Count	%			Count	%	Count	%	Count	%		
1	Flow both side toward the road	4328	21	2705	28	541	20	3246		0	0	0	0	1082	40	1082	3.00
2	Flow one side toward and the other side away from the road	13524	64	6492	67	1082	40	7574		2163	57	2164	100	1623	60	5950	1.27
3	Flow both side away from the road	3255	15	541	6	1082	40	1623		1632	43	0	0	0	0	1632	0.99
TOTAL COUNT SUM = 21107		**21107**	**100**	**9738**	**100**	**2705**	**100**	**12443**		1623	**100**	**2164**	**100**	**2705**	**100**	**6492**	**1.92**

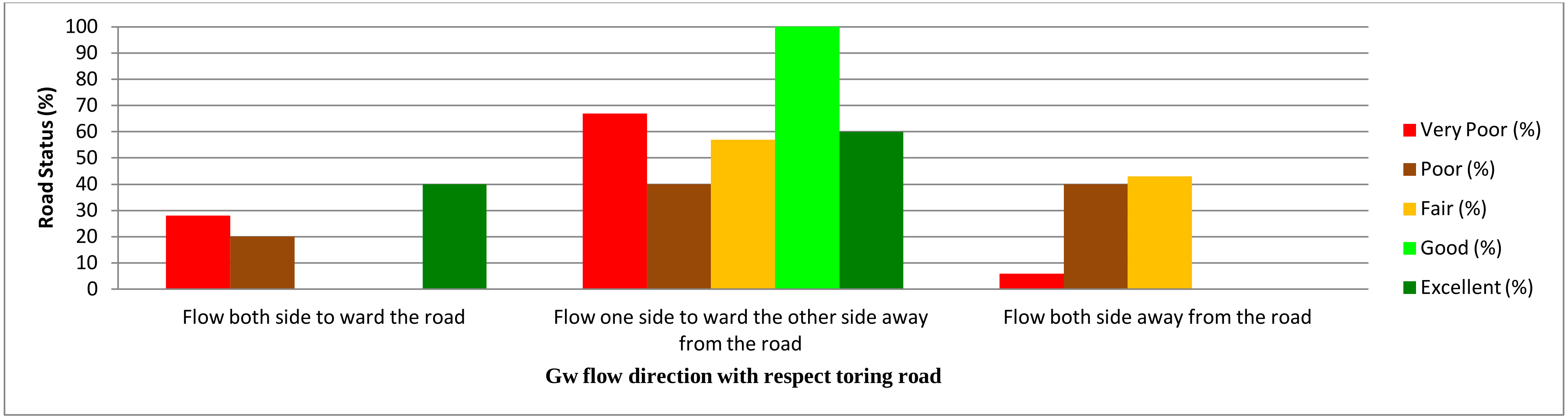

Fig 5.11 -Pavement condition versus Ground water flow direction

The ratio between poor condition of pavement to good condition pavement reveal that the groundwater sub-classes “Flow toward both the sides of the road” and “Flow towards one side and the other side away from the road” both have ratio value greater than 1. This implies that these groundwater flow direction classes are having significant relation with pavement distress. On comparison relatively “groundwater flow direction toward both sides of the road” is more strongly related to pavement distress condition than the class “flow towards one side and the other side away from the road”. Thus, it is reasonable to understand that when the “groundwater flow direction is towards the both sides of the road it will have more effect on the pavement.

Though with overlay analysis some correlation seems to exist between groundwater flow direction and pavement condition but here it is worth mentioning that the average depth to groundwater table is relatively at great depth (17.65 m to 66.2 m) and interaction of groundwater with pavement distress condition has remote possibility. Thus, it may be concluded that groundwater has not contributed towards any kind of pavement distress or deteriorations in the study area.

5.1.3 Relationship Between Elevation (Altitude) and Pavement condition

Variation in elevation of an area may be a factor which might affect the pavement condition. The elevation of an area may have a direct bearing on change in temperature or variation in rainfall intensity, governing geological or engineering geological conditions, change in surface and groundwater regime of the area. Thus, altitude varriation in an area will be responsible directly or indirectly in changing the pavement condition.

For the present study the elevation variation within the study area was prepared from Aster data and the Dgital Elevation Model (DEM) with 30m resolution was used. Fig. 5.12 presents the map showing elevation variation within the study area. For analysis purpose DEM data was classified into five elevation classes namely; 2100 - 2194 m, 2194 - 2266m, 2266 - 2341m, 2341 - 2438m and 2438 - 2581 m. Perusal of Fig.5.12 indicates that Winget and Megenagna area fall in the heighest elevation class whereas relatively Kality, Mekanissa, Lebu and Abo sarie falls in lowest elevation class in the study area.

Further, elevation variation map was overlayed on pavement condition map and joint overlay spatial analysis was performed using ArcGIS software. The results thus, obtained are presented in Table 5.6 and Fig.5.13. Perusal of Table 5.6 clearly indicates that majority of the study area (43%) falls within “2,341 - 2,438 m” elevation class. Whereas, remaining study area fall into elevation classes “2,194 - 2,266 m” (19%), “2,100 - 2,194 m” (16%), “2,266 - 2,341m” (14%) and “2,438 - 2,581m” (8%).

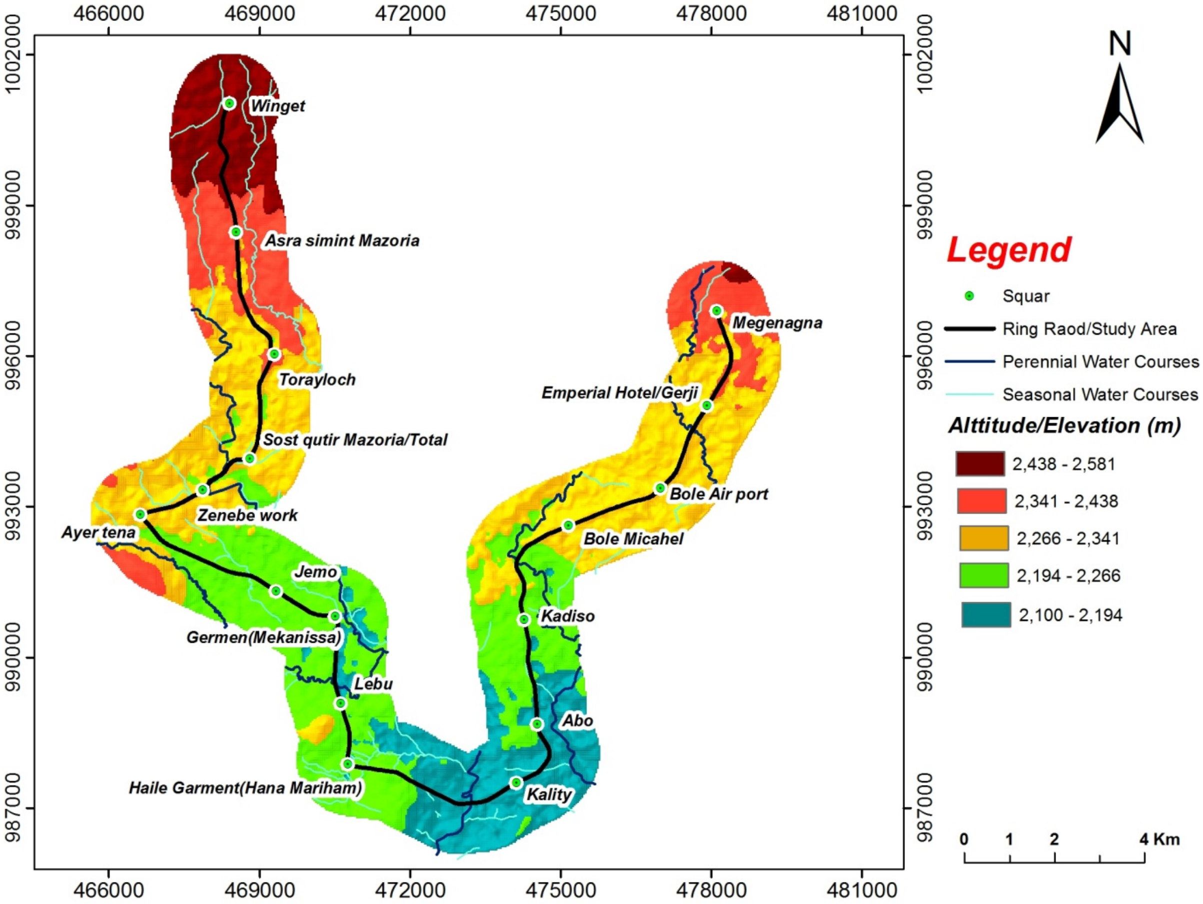

Fig 5.12 - Elevation variation in the study area *(Source: Aster DEM 30m resolution)*

In terms of relation of elevation with poor pavement condition it may be noted (Table 5.6) that 54% of the poor pavement falls into “2,341 - 2,438 m” elevation class whereas, 43% of poor pavement falls into “2,100 - 2,194 m” elevation class. Similarly, about 33% each of good pavement falls within “2,194 - 2,266 m” and “2,341 - 2,438 m” elevation classes. About 26% of the good pavement falls into 2,266 - 2,341m elevation class.

Further, it may be noted that (Table 5.6) ratio between poor pavement condition to good pavement condition for elevation class “2,100 - 2,194 m” have ratio value greater than 1 which explains a good relation between this elevation class and pavement distress condition. As a matter of fact elevation class “2,100 - 2,194 m” is the lowest elevation class in the study area. All other elevation classes, other than “2,100 - 2,194 m” are higher elevation classes and do not show relation to poor pavement distress.

Table 5.6- Relation of Elevation (Altitude) variation on pavement condition

No	**ALTITUDE INTERVAL (m)**	**ROAD STATUS**														
		Total Elevation COUNT	Total Elevation percent%	Poor				Total Poor	Good						Total Good	Ratio, Poor/Good
				Very Poor		Poor			Fair		Good		Excellent			
				Count	%	Count	%		Count	%	Count	%	Count	%		
1	2,100 - 2,194	3335	16	2300	60	1035	26	3335	0	0	0	0	0	0	1	3335.00
2	2,194 - 2,266	4037	19	55	1	44	1	99	2372	30	761	21	805	49	3938	0.03
3	2,266 - 2,341	2952	14	94	2	0	0	94	0	0	2858	79	0	0	2858	0.03
4	2,341 - 2,438	8992	43	1339	35	2946	73	4285	3863	48	0	0	844	51	4707	0.91
5	2,438 - 2,581	1791	8	48	1	0	0	48	1743	22	0	0	0	0	1743	0.03
TOTAL COUNT SUM = 21107		**21107**	**100**	**3836**	**100**	**4025**	**100**	**7861**	**7978**	**100**	**3619**	**100**	**1649**	**100**	**13247**	**0.59**

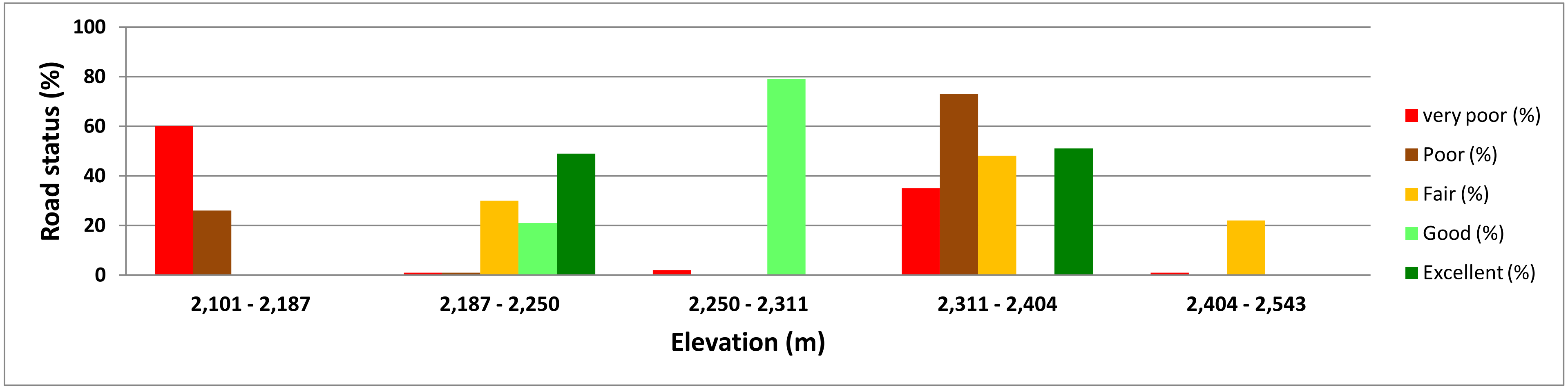

Fig 5.13 - Elevation (Altitude) variation versus Pavement condition

It may be inferred from this that high elevated areas have better surface drainage than the low elevated area and perhaps for this reason the lowest elevation class “2,100 - 2,194 m” show better correlation with pavement distress condition.

5.1.4 Relationship Between Slope and Pavement condition

Road failures can exert a tremendous impact on mission success. It is vital that personnel engaged in road-building activities be aware of the basic principles of slope stability. They must understand how these principles are applied to construct stable roads through various geologic materials with specific conditions of slope and soil. There are certain geologic features that have a profound effect on slope stability and that can consequently affect road construction in an area (http://www.itc.nl/~rossiter/Docs/FM5-410/FM5-410_Ch10.pdf).

For the present study area slope was derived from Digital Elevation Model (DEM) with 30 m resolution. For slope classification five classes were considered these classes are; Flat (0^o – 2^o), Low slope (2^o – 4^o), Medium slope (4^o – 7^o), High slope (7^o - 11^o) and Very high slope - almost cliff (11^o – 22^o) (Fig.5.14).

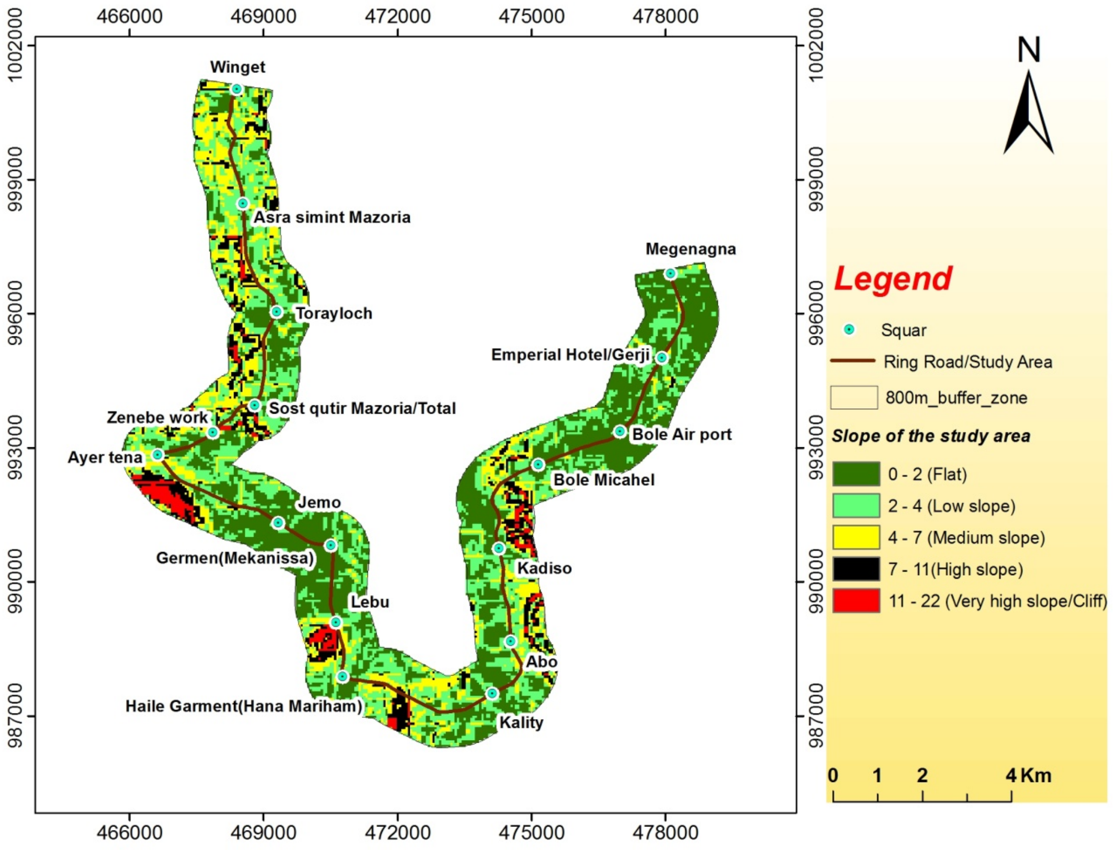

Fig 5.14 - Slope map of the study area buffered 800 m with center of ring road (*Source: Aster DEM 30m resolution*)

A perusal of Table 5.7 indicates that a majority of the study area (49%) falls within Low slope (2^o – 4^o) class, followed by flat (18%), Medium slope (14%), High slope (13%) and Very high slope (6%).

Further, elevation slope map was overlayed on pavement condition map and joint overlay spatial analysis was performed using ArcGIS software. The results thus, obtained are presented in Table 5.7 and Fig.5.15. Perusal of Table 5.7 indicates that majority of pavement under “poor condition” falls in Low slope (46.5%) class. Similarly, majority of pavement under “good condition” falls in Flat slope class (53%). However, with respect to ratio between poor pavement condition to good pavement condition “High Slope class” shows the ratio value greater than 1 which indicates a good correlation between “High Slope class” and the pavement distress condition. This correlation may further be explained with a fact that High slope provide more gradient to pavement and traffic movement over high slope gradients may expert static and dynamic loads for relatively longer durations. Thus, the pavement structure in such high slope gradient reaches will be more prone for distress and deterioration. The same fact was also realized in field in between Asrasimint Mazoria and Sost qutir Mazoria squares where the pavement is over high slope gradient class and in visual pavement condition survey it was classified as “poor pavement”.

5.1.5 Relationship Between Slope Aspect and Pavement condition

The slope aspect is defined in terms of geographical direction in which slope is inclined. For the present study slope aspect was deduced through DEM with 30m resolution (Fig.5.16). In total 9 slope aspect classes were considered for further analysis. These slope aspect classes are; Flat, North, North-East, East, South-East, South, South-West, West and North-West.

Further, slope aspect map was overlayed on pavement condition map and joint overlay spatial analysis was performed using ArcGIS software. The results thus, obtained are presented in Table 5.8 and Fig.5.17. Perusal of Table 5.8 indicates that 30% slopes of the study area are towards South-East direction followed by slopes towards North-East (22%), South-West (17%), North (11%) and Eastwards (11%). Only 5% slopes are towards Southward and 4% of slopes towards westward. None of the slopes are towards North-West direction and none are flat. Further, with respect to the relation between Slope aspect and pavement condition it may be noted from Table 5.8 that 31% of the pavement classified with poor condition falls into “East aspect class” followed by “South - West aspect class” (21%) and “North-East aspect

Table 5.7- Relation between terrain slope and pavement condition

No	Slope	ROAD STATUS															
				Poor						**Good**							
				Very poor		Poor				Fair		Good		Excellent			
		Total slope COUNT	Total slope count percentage%	Count	%	Count	%	Total Poor		Count	%	Count	%	Count	%	Total Good	Ratio, Poor/Good
1	0 - 2(Flat)	3725	18	1386	36	0	0	1386		0	0	761	21	1578	96	2339	0.59
2	2 - 4 (Low slope)	10318	49	2313	61	1293	32	3606		6712	84	0	0	0	0	6712	0.54
3	4 - 7 (Medium slope)	2977	14	48	1	0	0	48		0	0	2863	79	66	4	2929	0.02
4	7- 11(High slope)	2790	13	49	1	2741	68	2790		0	0	0	0	0	0	1	2790.00
5	11 - 22(Very high slope (almost cliff).	1297	6	10	0	0	0	10		1287	16	0	0	0	0	1287	0.01
TOTAL COUNT SUM = 21107		**21107**	**100**	**3806**	**100**	**4034**	**100**	**7840**		**7999**	**100**	**3624**	**100**	**1644**	**100**	**13268**	**0.59**

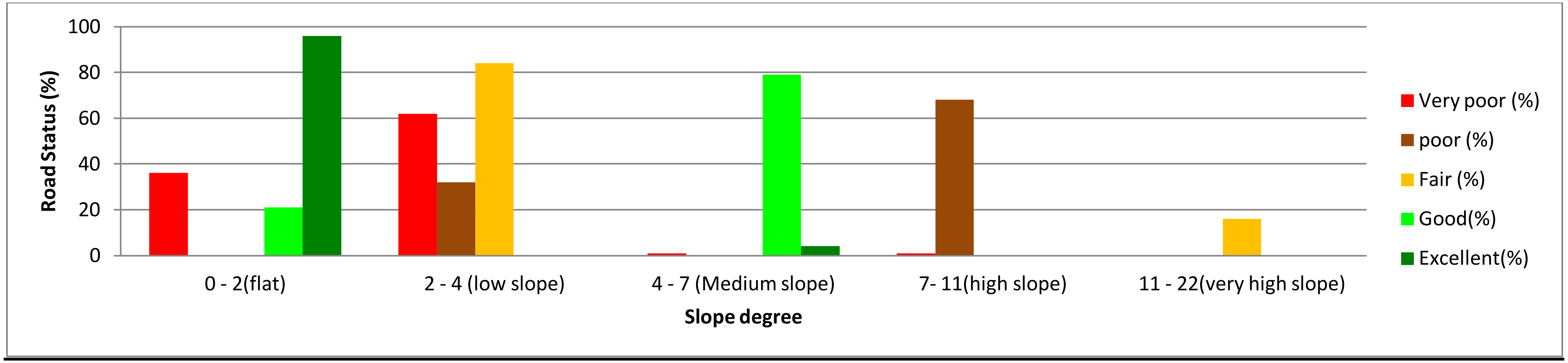

Fig 5.15 – Terrain slope versus Pavement condition

class" (18.5%). Similarly, majority of pavement classified as Good condition falls into "South-East aspect class" (49.33%).

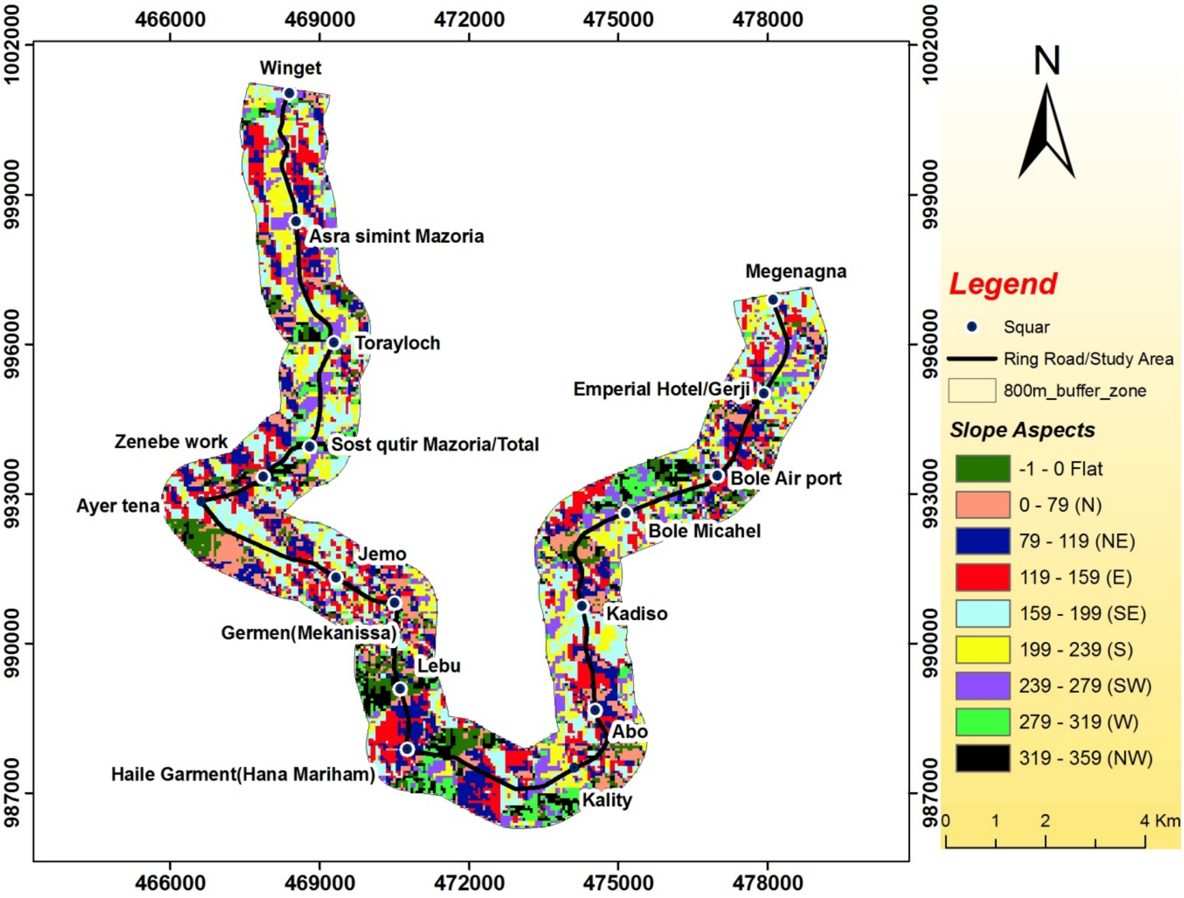

Fig 5.16 – Slope Aspect map of the study area buffered to 800 m with center of ring road *(Source: Aster DEM 30m resolution)*

When compared the ratio between poor pavement conditions to good pavement condition slope aspect classes Eastwards and North-Westward demonstrates a good correlation with pavement distress as in both the cases the ratio value is more than 1. Thus, from this correlation it may be concluded that pavement in the study area which falls over the slopes inclined towards East or North-West directions are probably more susceptible to distress and distortion.

Moreover, slope aspect directly or indirectly is related to surface drainage, variation in climatic factors – exposure to sunshine, wind action, temperature etc. Thus, all such factors may possibly affect the pavement condition. However, to understand such effects of slope aspect on pavement condition may require more elaborate studies which perhaps are beyond the scope of present study.

5.1.6 Relationship Between Curvature and Pavement condition

For the present study slope curvature was deduced from DEM with 30m resolution (Fig.5.18). In total 5 curvature classes were considered for further analysis. These classes are; (i) -2.07 - -0.54 (Convex), (ii) -0.54 - -0.14, (iii) -0.14 - 0.14, (iv) 0.14 - 0.56 and (v) 0.56 - 2.04 (Concave). The negative values indicate convex curve shape whereas positive values indicate concave curve shape.

Further, slope curvature map was overlayed on pavement condition map and joint overlay spatial analysis was performed using ArcGIS software. The results thus, obtained are presented in Table 5.9 and Fig.5.19.

Perusal of Table 5.9 indicates that majority (44%) of the study area falls into “0.14 - 0.56” curvature class followed by curvature classes “-0.14 - 0.14” (33%), “-2.07 - -0.54 (Convex)” (11%), “0.56 - 2.04 (Concave)” (8%) and “-0.54 - -0.14” (4%), respectively.

Further, with respect to relation between slope curvature and pavement condition it may be noted (Table 5.9) that majority of pavement (45.5%) classified as Poor falls in “0.14 - 0.56” curvature class. Similarly, pavement classified as Good falls 40.66% in -0.14 - 0.14 and 39.33% in 0.14 - 0.56 curvature classes, respectively. With respect to ratio between poor conditions pavements to good condition pavement it may be noted that only 0.56 - 2.04 (Concave) curvature classes has ratio value greater than 1 and shows a good correlation between curvature and pavement distress condition. The concave curve is curved inward and might accumulate surface water during rainy season which ultimately alter much of the sub-grade properties. Thus, the pavement in reaches where the slope curvature is concave possibly pavement is more susceptible to distress and distortion. However, in addition to slope curvature other factors may also be collectively responsible in contributing for pavement distress.

5.1.7 Relationship Between Structural Lineament and Pavement Condition

Structural Lineament affects everything on the surface, including all natural landforms and human made features. Symptoms of lineament include cracks in highways and building slabs, and failures along flood protection levees.

Table 5.8 –Relation of Slope Aspect with Pavement condition

No	Slope Aspect	ROAD STATUS																
		Total Slope Aspect COUNT	Total Slope Aspect percentage%	**Poor**				Total Poor		**Good**						Total Good	Ratio, Poor/Good
				Very poor		Poor				Fair		Good		Excellent			
				Count	%	Count	%			Count	%	Count	%	Count	%		
1	-1 - 0 Flat	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0.00
2	0 - 79 (N)	2327	11	1	0	1039	26	1040		1287	16	0	0	0	0	1287	0.81
3	79 - 119 (NE)	4746	22	1395	37	0	0	1395		2635	33	0	0	716	43	3351	0.42
4	119 - 159 (E)	2350	11	2350	62	0	0	2350		0	0	0	0	0	0	1	2350.00
5	159 - 199 (SE)	6283	30	53	1	1249	31	1302		1248	16	2863	79	870	53	4981	0.26
6	199 - 239 (S)	1082	5	0	0	0	0	0		1082	14	0	0	0	0	1082	0.00
7	239 - 279 (SW)	3514	17	5	0	1702	42	1707		1747	22	0	0	60	4	1807	0.94
8	279 - 319 (W)	761	4	0	0	0	0	0		0	0	761	21	0	0	761	0.00
9	319 - 359 (NW)	44	0	0	0	44	1	44		0	0	0	0	0	0	1	44.00
TOTAL COUNT SUM = 21107		**21107**	**100**	**3804**	**100**	**4034**	**100**	**7838**		**7999**	**100**	**3624**	**100**	**1646**	**100**	**13269**	**0.59**

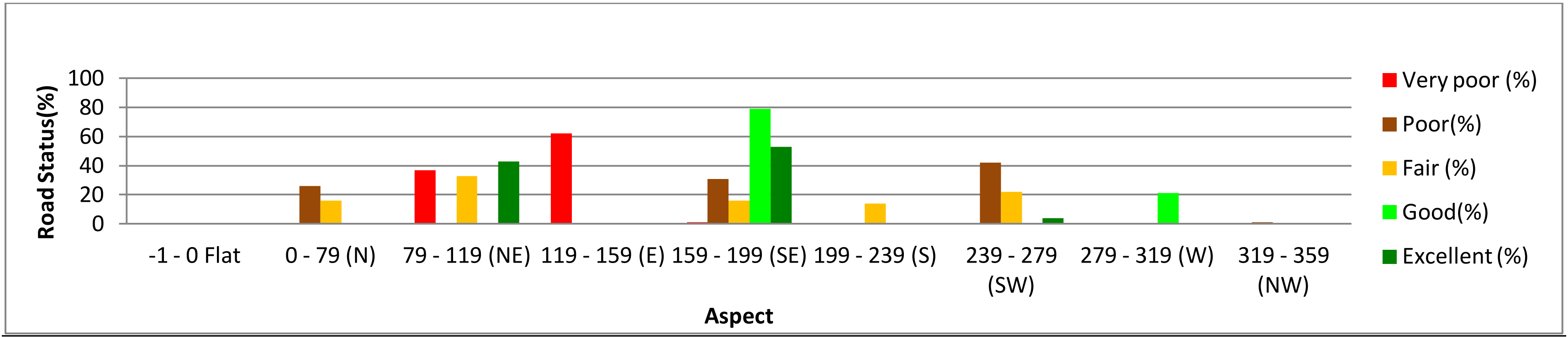

Fig 5.17 - Slope aspect versus Pavement Condition

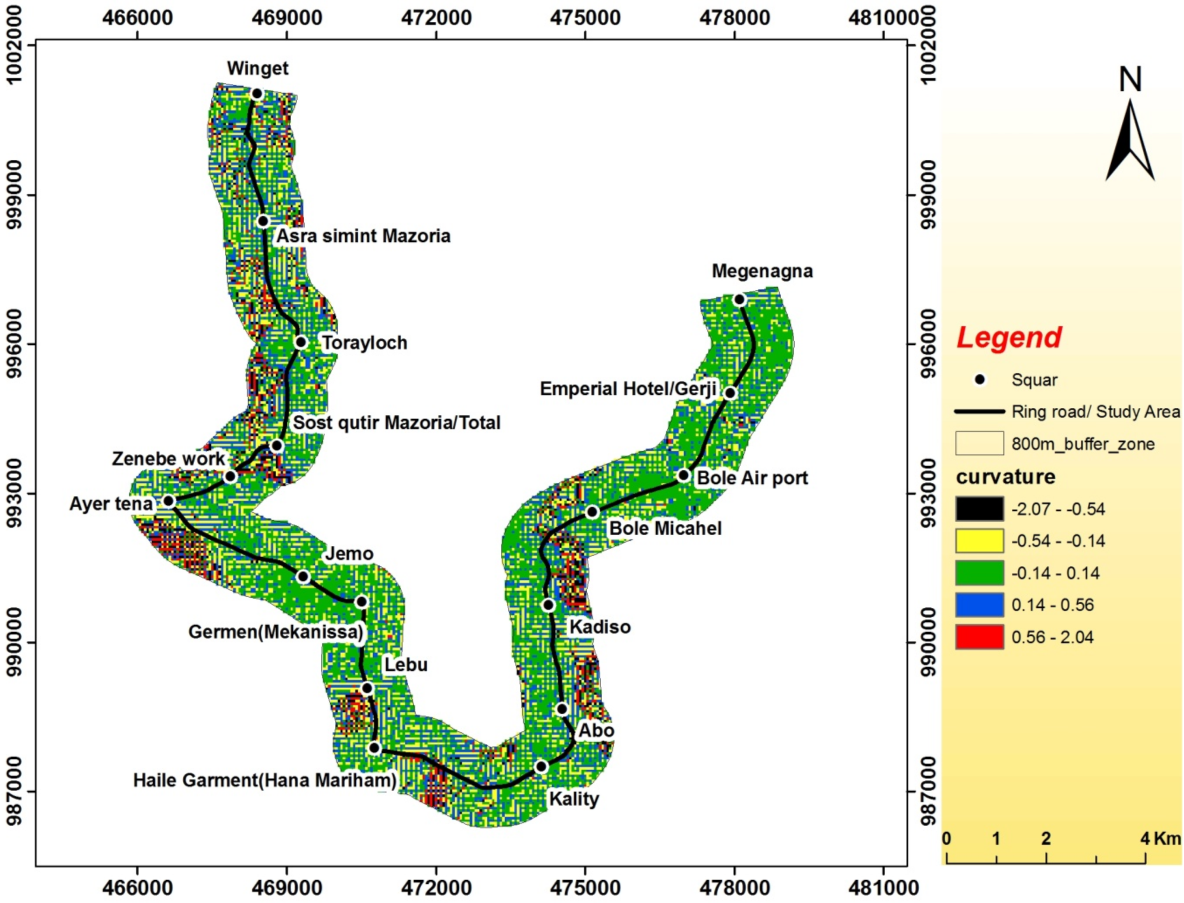

Fig 5.18 - Slope curvature map of the study area *(Source: Aster DEM 30m resolution)*

In the present study area, the locations and character of the lineaments with respect to approximate to pavement under present study area have been carefully mapped (Fig.5.20).

It is diffecult to make overlayed analyses of the fault line with respect to the pavement condition.The structural linaments have shown in the figure 5.20 are extracted from a satellite imagery map which have not any detail information about the lineaments and also the lineaments coulde not identified on the land surfacial and quntify the extent and the orentation. Therefore, it is better to discussed the structural lineaments parmeter using qulitatively asseaement than overlay spatial analysis like as the previous parameters. Generally, as it can see the figure 5.20 that most of those geological linaments have overlaid on the poor pavement status. Thus, it mighte be a good corelation is present for pavement condition and area affected by lineaments.

Table 5.9-Relation between slope curvature and Pavement condition

No	**Curvature**	**ROAD STATUS**															
		Total Curvature COUNT	Total Curvature percent%	Poor				Total Poor	Good							Total Good	Ratio, Poor/Good
				Very Poor		Poor			Fair		Good		Excellent				
				Count	%	Count	%		Count	%	Count	%	Count	%			
1	-2.07 - -0.54 (Convex)	2326	11	0	0	1039	26	1039	1287	16	0	0	0	0	1287	0.81
2	-0.54 - -0.14	774	4	14	0	44	1	58	0	0	0	0	716	44	716	0.08
3	-0.14 - 0.14	6946	33	1440	38	0	0	1440	3883	49	761	21	862	52	5506	0.26
4	0.14 - 0.56	9308	44	2301	60	1249	31	3550	2829	35	2863	79	66	4	5758	0.62
5	0.56 - 2.04 (Concave)	1753	8	49	1	1702	42	1751	2	0	0	0	0	0	2	875.50
TOTAL COUNT SUM = 21107		**21107**	**100**	**3804**	**100**	**4034**	**100**	**7838**	**8001**	**100**	**3624**	**100**	**1644**	**100**	**13269**	**0.59**

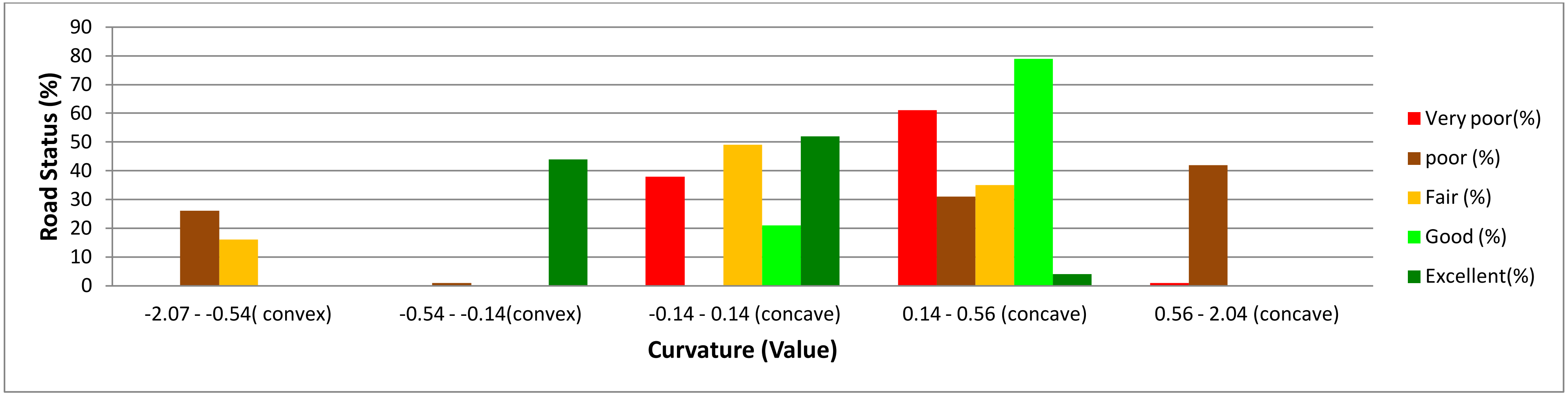

Fig 5.19 - Slope curvature versus Pavement condition

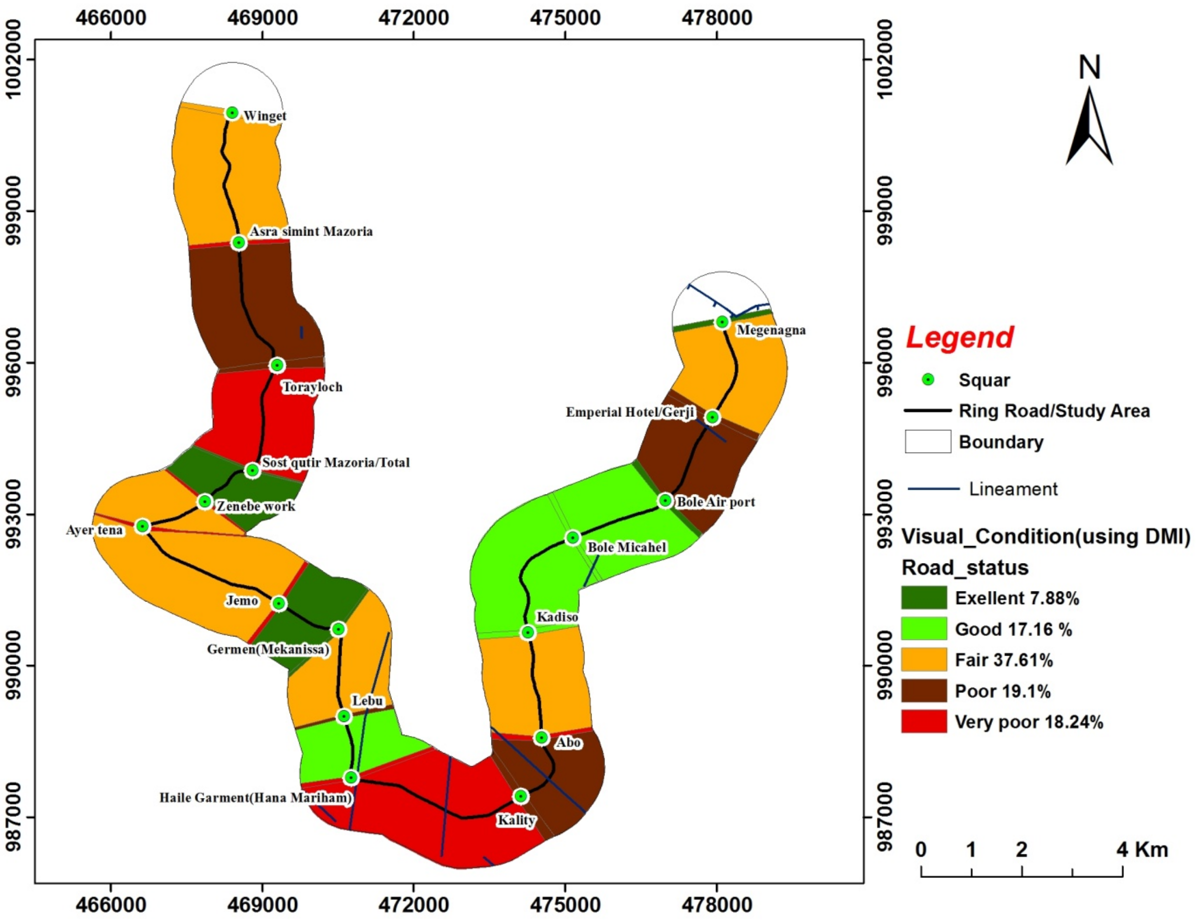

Fig 5.20 – Lineament overlaid on visual pavement condition map

5.2 Pavement Distress Suseptability Analysis

Once the inter-correlations among the seven parameters and road status using DMI were defined, pavement distress susuceptibility index is calcualted in ArcGis enviroments by summation of each parameters's rate weithed to 1. Then using raster calculation (Raster maths), each parmeters times by its rate and finally summation of all eights parameters which is called pavement distress index (PDI) as suggested by Lee and Min. (Lee and Min, 2001, as cited in Trufat, 2009)

The pavement distress susceptibility mapping is performed using the interpreted pavement distress index. After considering of several classification techniques, the index value are classified by natural breaks and grouped in to five classes; such as very high, high, moderate, low and very low (Fig 5.21). A natural break is one of the automated classification methods in ArcMap. It identifies break points by picking the class breaks that best group similar value and maximize the difference btween classes.

5.2.1 Verification of Susceptibility Analysis with Visula Survey Map (DMI)

Verification is performed by routine comparison the existing visual survey map (DMI) with the new susceptibility map. The Susceptibility classes, which were classified based on DMI, are compared with that of the degree of distress. The validation results show satisfactory agreement; the correlations rate of all classes are either above or nearly 1, to indicate sensible correlation (Table 5.10). It is also provide that the interpretation of the PDI classification is more or less reasonable. However, better results can be obtained further if the rate of parameters were weighed to their respective influence.

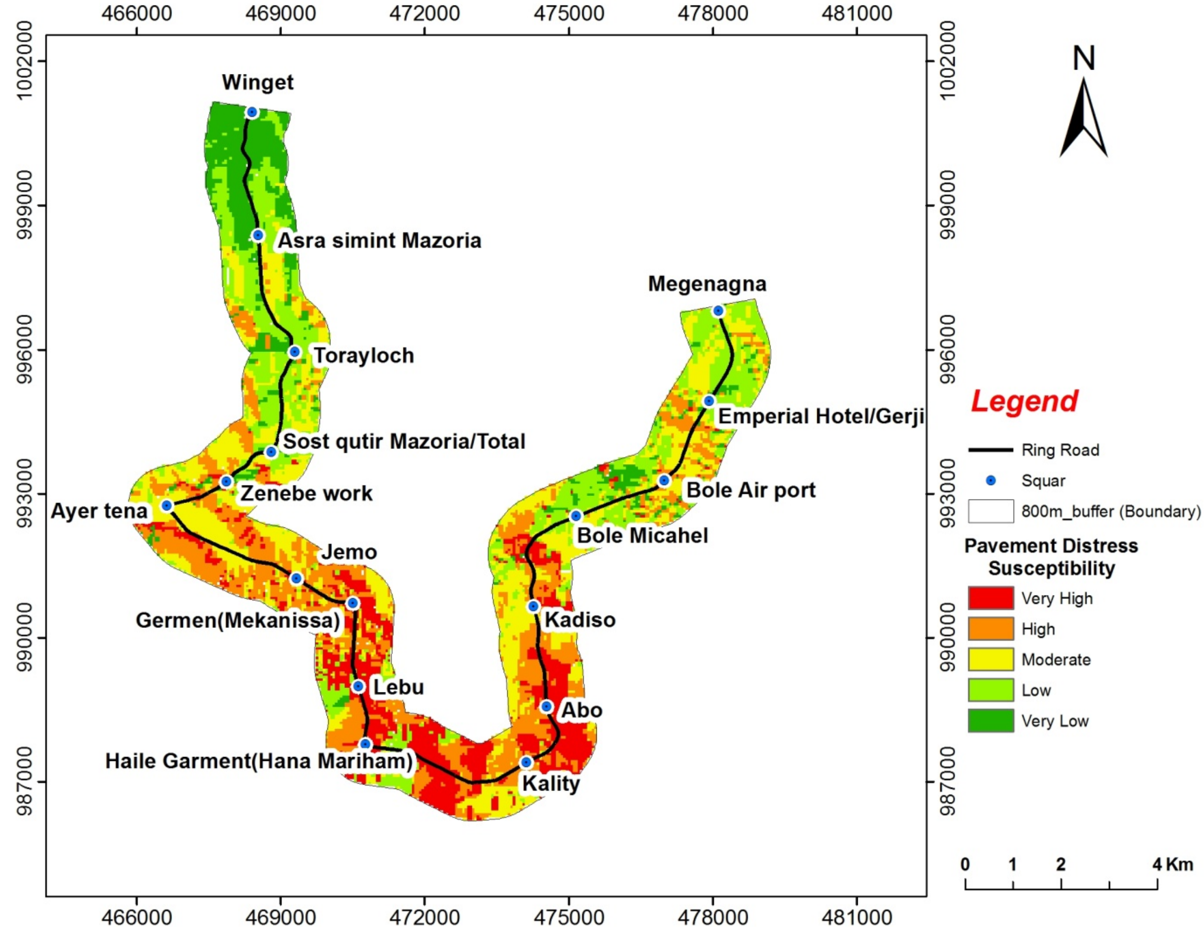

Fig 5.21 - Pavement Distress Susceptibility Map of the study area

Very high, high and moderate pavement distress show high to moderat probablity while low and very low pavevent distress show rather slight low from average probablity. Beside , very high and high susceptblity covers 39.6 % of the whole area. The moderate susceptibility covers 27.7% of the whole area. Finally the low and very low susceptibility covers 32.7% of the whole area. It is noted that the comparision of pixel and area coverage show slightly variation,which supposedly explained by pixel-area conversion in GIS systems.

Table 5.10- Pixel count and area coverage comparision of pavement disstress susceptibility map with that of DMI(Distress manifestation index map)

Map	Susceptibility Map			Pavement distress (delineated Visual survey), DMI			
Class	Pixel count	Area (km2)	ratio (%)(a)	Pixel count	Area (km2)	ratio (%)(b)	Correlation (b/a)
Very High	3223	8.1	15.40	3834	9.59	18.2	1.18
High	5067	12.67	24.20	4025	10.06	19.1	0.79
Moderate	5799	14.5	27.70	7978	19.95	37.8	1.36
Low	4730	11.83	22.59	3620	9.05	17.2	0.76
Very Low	2115	5.29	10.10	1650	4.13	7.8	0.77
Total	20934	52.39	100	21107	52.78	100	1

5.3 Overall Pavement Distress Condition and Possible Causative Factors

During the present study overlay analysis in GIS environment was performed where pavement distress condition map was overlaid individually on various causative factors maps, in the present case mainly Engineering Geological factors were considered. Based on analysis relative influence of various sub-classes of each causative factor on pavement distress condition was assessed. Thus, based on the results following is summarized;

- There is a good correlation between perennial streams and pavement distress. In case of Perennial streams as the pavement condition improves from poor to excellent the percentage coverage of perennial streams decreases. On the other hand seasonal streams show reverse trend as the pavement condition improves from poor to excellent percentage coverage of seasonal streams increases.

  The surface Flow direction towards and along the side of the pavement is more related to pavement distress condition. Indeed, it is logical and reasonable that when the Flow direction is towards and along the side of the pavement it may result into saturation of pavement layers which ultimately may result into pavement distress.

  The average depth to groundwater table in the study area is relatively at great depth (17.65 m to 66.2 m) and thus, groundwater has not contributed towards any kind of pavement distress or deteriorations in the study area.

- With regards to Rocks and soils present in the study area probably alluvial, colluvial and lacustrine (Black cotton) soils are more related to pavement distress than the residual soils and other rock units present in the study area.

- With respect to terrain slope factor a good correlation was found between “High Slope class” and the pavement distress condition. This correlation may further be explained with a fact that High slope provide more gradient to pavement and traffic movement over high slope gradients may expert static and dynamic loads for relatively longer durations due to slow movement. Thus, the pavement structure in such high slope gradient reaches will be more prone for distress and deterioration.

- Elevation class “2,100 - 2,194 m” is the lowest elevation class in the study area and strongly related to the pavement distress. All other elevation classes, other than “2,100 - 2,194 m” are higher elevation classes and do not show any relation to poor pavement distress. It may be inferred from this that high elevated areas have better surface drainage than the low elevated area and perhaps for this reason the lowest elevation class “2,100 - 2,194 m” show better correlation with pavement distress condition.

- From the slope aspect overlay analysis it is found that where the pavement in the study area is falling over the slopes inclined towards East or North-West directions are more susceptible to distress and distortion.

- With respect to slope curvature it is deduced from the analysis that Concave curvature class has a good correlation between curvature and pavement distress condition. The concave curve is curved inward and might accumulate surface water during rainy season which ultimately alter much of the sub-grade properties. Thus, the pavement in reaches where the slope curvature is concave possibly it is more susceptible to distress and distortion.

- Fig. 5.20 has shown that most of structural lineaments are overlaid on the poor pavement status. Thus, it shows a good corelation with pavement condition.

- With regards to relative contribution of various causative factors on pavement distress it may be noted from Table 5.11 and Fig. 5.22 that ‘Surface Water Flow directions’ show a positive relation with pavement distress and is probably most important in terms of order of importance. In contrast Elevation, slope terrain, Aspects and Curvatures shows similar relation with pavement distress and have less contribution on pavement distress.

Table 5.11- The most and the least influencing factors with their general orders

No	Engineering Geological Parameters	Road Status							Ratio/Rate Poor/Good
		Poor		Total Poor	Good			Total Good	
		Very poor Total Count	Poor Total Count		Fair Total Count	Good Total Count	Excellent Total Count		
1	Surface Water Flow directions	11517	2878	14395	3837	1918	960	6715	**2.14**
2	Engineering geology	6229	3942	10171	5595	2543	2797	10937	**0.93**
3	Streams Flow	532	233	765	464	209	395	1068	**0.72**
4	Slope	3806	4034	7840	7999	3624	1644	13268	**0.59**
5	Elevation	3836	4025	7861	7978	3619	1649	13247	**0.59**
6	Aspects	3804	4034	7838	7999	3624	1646	13269	**0.59**
7	Curvature	3804	4034	7838	8001	3624	1644	13269	**0.59**

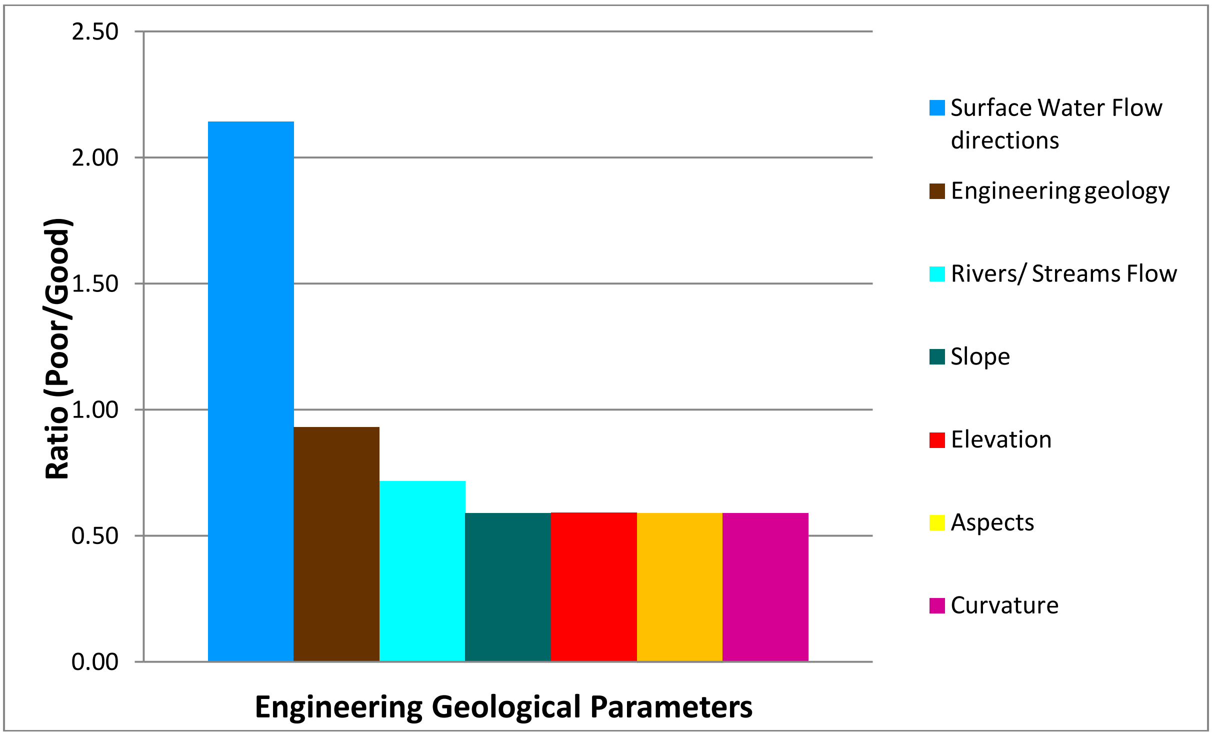

Fig 5.22 - The order of influencing geotechnical parameters on the road status

During the present study the overlay analysis has facilitated in understanding quantitatively the relative impact of each causative factor sub-class on pavement distress. The analysis made to know the relative impact of causative factors on pavement distress was on individual causative factor basis. However, the causative factors may have a combined effect on pavement distress and analysis is practically not possible to assess such combined effect of these causative factors on pavement distress condition. Also, there may be other factors which may be responsible for pavement distress such as; traffic loading, climate, inappropriate pavement design, construction deficiencies etc.. During the present study only the causative factors related to engineering geology were considered. Though the information obtained is on individual causative factor basis but this information is vital in deciding most suitable rehabilitating method for pavement condition improvement. The detailed alternative rehabilitation options are discussed in the following chapter.

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Chapter 6 PAVEMENT DISTRESS REHABILITATION

6.0 Preamble

The present chapter presents a detailed description on Pavement distress rehabilitation methods that may be employed for pavement maintenance. It has already been discussed in literature review chapter that pavement distresses can be classified as being caused either by traffic loads or non traffic load factors, including design, construction, poor-durability materials, drainage, geological, geotechnical and climatic factors. Such classification helps to determine appropriate maintenance and/or rehabilitation alternative.

One of the major challenges being faced by pavement engineers is that how to select the optimal repair strategy for a flexible pavement that is aging and exhibiting distress. This selection process can be relatively straight forward if the cause of the pavement distress is known. Unfortunately, finding the cause of the distress is often complex.

Pavements deteriorate as a result of a combination of several factors. The primary mechanisms of asphalt concrete (flexible) pavement deterioration are environmental (such as; aging and oxidation) which is non traffic factor and traffic loading related effects.

Load associate distresses which result in to the development of structural distresses are generally caused by overloading, high traffic repletion, high tire pressure and underestimated traffic loads. The types of distress categorized in this group are alligator cracking, corrugation, edge cracking, potholes, rutting and slippage cracking. However, in the present study traffic loading parameters were not considered and attempt was made mainly to study the relative influence of non-loading engineering geological factors on pavement distress condition.

None traffic associate distress are mainly caused by climate (environmental forces) and engineering geological associated factors. Environment condition, structural weakness, method of construction, quality construction material and also lack of maintenance will further aggravate all types of distress. The types of distresses categorized in this groups are bleeding, block cracking, joint reflection, line cracking(Longitudinal/transversal), potholes, patching of climate/during swell cause distress, weathering, raveling, shoving, shoulder drop off, depression and swell (Fikir Alebachew,2005).

Pavements which are left to deteriorate without timely maintenance treatments are likely to require major rehabilitation and reconstruction much sooner than those which are properly maintained. There are many techniques and treatments available for the rehabilitation, the same will be discussed in the later sections of this chapter.

In the present study pavement distress was assessed based on the causative factors which are related to non traffic loading. The causative factors which were considered for analysis are mainly engineering geological factors such as; Rock and soil type, Geological formations, Surface drainage and groundwater, elevation, slope, aspect, curvature and Fault lines. It was believed that these causative factors might be significant factors which might have directly or indirectly contributed for the pavement distress in the study area. Further, a detailed visual survey was conducted to know the pavement condition and by utilizing standard Distress Manifestation Index (DMI) pavement was classified into various homogeneous classes as; Very poor, poor, Fair, Good and Excellent. Thus, the analysis was carried out to analyze the possible impact of various causative factors on pavement distress so that this quantitative information may be utilized to evolve proper maintenance and/or rehabilitation alternative.

Further, the common definition of pavement performance is the serviceability history of the pavement. Performance may be quantified by the area under the curve of serviceability versus time or traffic. This is illustrated in Fig. 6.1. For the purpose of life-cycle cost analysis of pavement design, maintenance, or rehabilitation alternatives, it is important to estimate the performance of the different alternatives under consideration (Hall et al, 2002).

6.1 Pavement Distress Rehabilitation

Rehabilitation is defined as a structural or functional enhancement that produces substantial extensions in service life, by substantially improving pavement condition and ride quality. Addis Ababa City Roads Authority (AACRA, 2004) had annual expenditure of around 300 million Birr for road construction and maintenance. Out of which more than 30 million Birr was expended for pavement maintenance and rehabilitation. Yet it is difficult to quantify very well the initial and long-term effects of different maintenance and rehabilitation treatments on pavement performance

The following issues are related to the effects of maintenance and rehabilitations;

- The relative effectiveness of different maintenance and rehabilitation treatments in producing immediate improvements in pavement condition

- The relative effectiveness of different maintenance and rehabilitation treatments in producing long-term changes in pavement condition (Fig. 6.2), and
- Finally, the influence of the causative factors on pavement distress condition that were analyzed and presented in Chapter 5 such as; Rock and Soil coverage, Geological formation, Surface drainage, Elevation, Terrain Slope, Slope Aspect, Curvatures and structural setup (fault line). All these factors, in addition to other factors need to be considered during pretreatment condition on the effectiveness of different maintenance and rehabilitation methods.

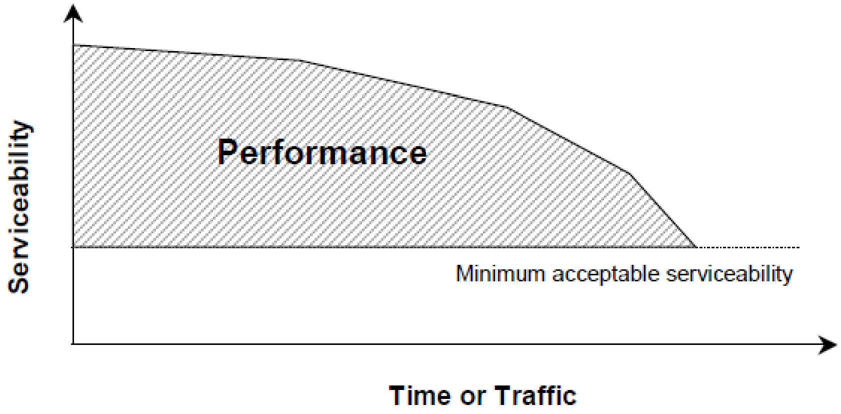

Fig 6.1 - Pavement performance quantified by the area under the serviceability curve *(Source: Hall et al, 2002)*

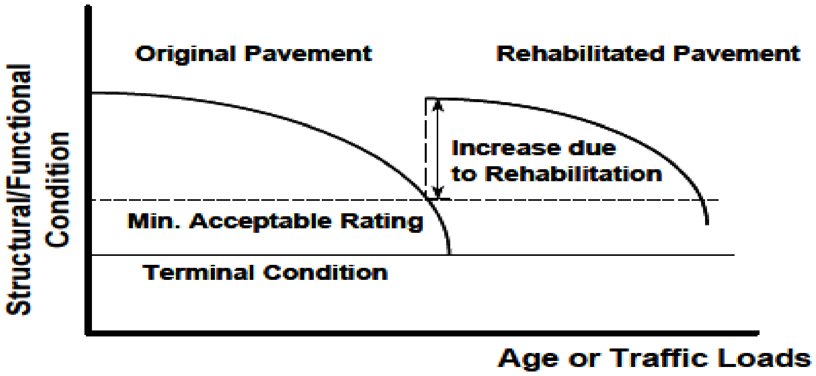

Fig. 6.2- Increase in pavement life due to effective rehabilitation (*Source:* ACPA, 2002)

Following steps should, in general, needs to be followed while proposing the appropriate maintenance and rehabilitation method:

- The maintenance and rehabilitation method need to be evolved after a thorough data analysis on various causative factors and their possible effects on pavement distress.

- Causes of distress can generally be grouped into three broad categories namely; load associated climate /durability associated and drainage /moisture associated.

- Severity and extent of damage are governing criterions to choose appropriate maintenance and/or rehabilitation option.

- Preliminary pavement thickness design can be reviewed on some typical sections of pavement to check and decide for the necessity of structural strengthening or complete reconstruction.

In the present study joint overlay spatial GIS analysis between visual pavement distress condition and various engineering geological causative factors has clearly shown good correlations between various factor classes and pavement distress.

In general, the various pavement distress types observed in the present study area can be grouped into three classes; disintegrating type distresses, distortion type distresses and cracking type distress. Thus, based on the type of distress and possible responsible causative factors appropriate maintenance and rehabilitation method has been identified.

6.2 Methods of Maintenance and/or Rehabilitation

Major maintenance methods to be applied for non-load associated distresses comprises the following: crack sealing, skin patches, partial and full depth patches, pothole patching, surface sanding, surface treatments, fuel resistant seals or overlays, or porous friction course (Fiker Alebachew, 2005).

Maintenance of disintegrating type of distresses

Disintegration type distresses are characterized by the breaking up of a pavement into small loose fragments. This includes the dislodging of aggregate particles. If not repaired at its early stage, it can progress until the pavement requires complete reconstruction (Fiker Alebachew, 2005).

The two common types of disintegration type of distress observed in the present study area are ‘potholes’ and ‘raveling’. In terms of proportion ‘potholes’ and ‘raveling’ covers ***44%*** of the total distress type in the study area. With regards to maintenance and rehabilitation measures these may be repaired either by simple seals or deep patches.

(i) Potholes Maintenance

Potholes are “bowl–shaped holes of various sizes in a pavement resulting from localized disintegration under traffic movement impact”. They can start with a small crack that lets water in and weakens the road’s base, or a small area of raveling that goes up to full depth, or a whole bunch of potholes can occur overnight in an alligator cracked area of a thin pavement. Poor soils, poor drainage, too thin an asphalt surface, poor compaction, and poor pavement maintenance can all lead to potholes (Blades and Kearney, 2004).

In the present study area the total number of potholes, with varied dimensions, is 140 in number and out of total distress type’s potholes account for 41.3%. The relative large proportion of potholes in the study area clearly shows that the drainage of the pavement is not appropriate, particularly in those areas of pavement where potholes are present.

A perusal of Table 6.1 indicates that the distribution of pothole with respect to surface drainage system is mainly concentrated in those sections of pavement where the surface water flow is towards the road. Further, majority of potholes are associated with ‘Low slope’ and ‘Flat’ slope terrain. Here, this correlation is logical to understand because ‘Low slope’ and ‘Flat’ slope terrain facilitate retention of surface water which may result in to peeling of asphalt aggregate resulting into potholes. During the present study above mentioned correlations were found to be significant though, there may be other factors which may be responsible for the development of these potholes; such as; in appropriate asphalt thickness or poor asphalt mixing or construction deficiencies in pavement layers etc. However, while making a choice for most appropriate rehabilitation measure the possible causative factors for the development of these potholes may be taken into consideration. Low slope and Flat areas has shown prominent relation with development of potholes besides, surface drainage is also related to potholes. Thus, it is necessary that in Low slope and Flat areas proper drainage must be provided so that any future development of such potholes can be minimized. Besides, for existing potholes following rehabilitation measure can be followed.

For best results, all materials for filling potholes must meet appropriate and approved standards. Proper preparation and backfilling are very important. This can be done using asphalt cutter, jackhammer, chisel and other hand tools. The sides of cut surface have to be vertical. The base materials should be replaced with equal or better material than that removed or with bituminous material. The hole should be primed before placing and compaction of the bituminous material. It is advisable to overfill drainage should be considered during the rehabilitation/ maintenance (Fiker Alebachew, 2005)

Table 6.1 – Summary of relation between causative factors and pavement distress type

No	Engineering Geological Parameters	Distress Types (Total Joint pixels Counts)							
		Ph	Shov	Rut	Dep	CC	Del	Rav	Lc
1	**Surface water flow direction**								
	Flow toward & along the road	82	25	36	15	10	7	5	3
	Flow away & along the road	58	41	14	11	13	14	5	0
2	**Rock and soil units**								
	Residual soil	41	15	11	6	7	9	3	0
	Alluvial soil	4	1	2	0	0	1	0	0
	Colluvial soil	0	0	0	0	0	0	0	0
	Lacustrian soil	69	36	28	13	12	7	6	3
	Rock high strength	0	0	0	0	0	0	0	0
	Rock medium strength	22	12	9	2	4	3	1	0
	Rock very high strength	4	1	0	1	0	1	0	0
3	**Rivers/Streams types**								
	Seasonal streams	3	0	2	1	0	1	0	0
	Perennial streams	3	0	0	0	0	0	0	0
4	**Slope terrain**								
	0 - 2 (Flat)	52	22	16	5	7	7	2	2
	2 - 4 (Low slope)	44	22	16	11	7	12	5	1
	4 - 7 (Medium slope)	27	8	14	3	5	2	2	0
	7 - 11 (High strength)	4	0	2	1	1	0	1	0
	11 - 22 (Very high strength)	0	0	0	0	0	0	0	0
5	**Elevation (Altitude)(m)**								
	2100 - 2194 (lowest)	29	13	15	1	4	2	0	2
	2194 - 2266	22	12	9	6	2	1	2	1
	2266 - 2341	36	25	13	8	5	3	2	0
	2341 - 2438	43	19	9	8	9	6	3	0
	2438 - 2581(highest)	10	0	1	1	3	9	3	0
6	**Aspect**								
	-1 - 0 Flat	9	3	6	1	1	0	1	1
	0 - 79 (N)	16	5	8	2	2	2	0	1
	79 - 119 (NE)	16	6	5	3	1	2	0	1
	119 - 159 (E)	17	12	4	2	2	3	1	0
	159 - 199 (SE)	19	7	9	3	3	3	2	0
	199 - 239 (S)	20	7	7	5	3	2	1	0
	239 - 279 (SW)	25	9	6	1	4	1	2	0
	279 - 319 (W)	14	11	3	6	1	2	0	0
	319 - 359 (NW)	3	3	2	1	1	0	1	0
7	**Curvature**								
	-2.07 - -0.54(convex)	0	0	0	0	0	0	0	0
	-0.54 - -0.14(convex)	5	1	3	0	1	0	0	1
	-0.14 - 0.14 (convex & concave)	127	67	34	15	20	17	8	2
	0.14 - 0.56 (concave)	5	1	3	0	2	0	0	0
	0.56 - 2.04 (concave)	0	0	0	0	0	0	2	0

Abbreviations: PH-Pothole, SHOV-Shoving, RUT-Rutting, DEP-Depression, CC-Crocodile crack, DEL-Delamination, RAV-Raveling, LC-Longitudinal Crack

(ii) Raveling Maintenance

In the present study area the total number of raveling which were observed and recorded are 10 in number. It covers 2.95% of the total number of distress types in the study area. Raveling surfaces usually require a surface treatment that can be looked upon as corrective or preventive maintenance. The type of surface treatment can be selected depending on the extent of damage and nature of traffic.

Since the number of raveling as observed and recorded in the present study area is very less (2.95% of total distress) it is difficult to establish some correlation between this distress type and the causative factors. A perusal of Table 6.1 shows some sketchy relationship of raveling with curvature and lacustrian soil.

Maintenance of distortion type of distresses

Distortion type of distresses is characterized by a change of the pavement surface from its original shape. Lack of proper compaction, excessive fines in the mix, too much asphalt, swelling of underlying courses, or settlements are the major causes of distortion type distresses (Uzarowski and Bashir 2007).

In the present study area major distortion type of distress that were observed and recorded are; Rutting, Shoving, Depression, and Delamination. The distortion type of distress accounts for 48.37% of the total distress type in the study area.

(i) Rutting Maintenance

In total 49 ruts were observed and recorded in the present study area. In terms of its proportion rutting accounts for 14.45% of the total distress types in the study area. A perusal of Table 6.1 show that the parameters such as; surface flow direction toward the road, Lacustrian soil types, lowest elevation and the curvature are the most responsible causative factors which show good relation with rutting in the study area. Therefore, during the rehabilitation of rutting distress, above mentioned causative factors should be considered. Though, there may be other factors responsible for the development of these rutting.

It is necessary to repair such distresses by applying light track coat and spreading asphalt concrete in the channel since rutting can be aggravated and lead to major structural failures and hydroplaning (Uzarowski and Bashir 2007).

(ii) Shoving Maintenance

In total 69 shoves were observed and recorded in the present study area. In terms of its proportion rutting accounts for 20.35% of the total distress types in the study area. A perusal of Table 6.1 indicate that shoving is more associated with causative factors such as; Lacustrian soil types, aspect facing toward east and west, and curvature. Therefore, during the rehabilitation above mentioned factors should be given consideration for an effective rehabilitation measure. With these measures any future development of shoving in the pavement may be minimized. However, existing shoved areas can be repaired by using deep patch like for the alligator cracking (Uzarowski and Bashir, 2007).

(iii) Depressions Maintenance

In total 26 depressions were observed and recorded in the present study area. In terms of proportion, depression account for 7.67% of the total distress types in the study area. A perusal of Table 6.1 indicates that the distribution of depression type distress in the study area is more related with surface flow (direction toward the road), Lacustrian soil types, low slope terrain and curvature. For an effective rehabilitation measure/s above mentioned factors should be considered to minimize the possibility for future development of such depression type distress in pavement. However, for existing depression type distress in pavement following maintenance method may be employed.

Two or more layers of asphalt are required in the repair of deep depression. Filling the area by following the contour of depression is mostly mistakenly done. The correct way to repair a deep depression is to begin in the deepest part of the depression and place a thin layer, the surface of which, when compacted, will be parallel to the original pavement surface. Successive layers can be placed in the same manner (Uzarowski and Bashir, 2007).

(iv) Delamination Maintenance

Delamination is the localized loss of the entire thickness of an overlay. It is caused by the lack of a bond between the overlay and the original pavement. Delamination is usually confined to the wheel path area and takes several years after the overlay to become a serious problem. Once they occur, they are difficult to properly patch (Hall et al, 2002).

In total 20 delamination distresses were observed and recorded in the present study area. In terms of its proportion rutting accounts for 5.9% of the total distress types in the study area.
Although delamination type of distress is mostly associated with poor asphalt bond between overlay and underlying pavement layers still some correlation was observed (Table 6.1) between low slope terrain, highest elevation and curvatures (combination of convex and concave). Relation to some of these causative factors may have logical bearing on delamination distress. For instance, low slope terrain may be associated with poor drainage

condition and high abrasion stresses due to speeding vehicles which may result into delamination type of distress. Though there may be other factors also responsible such as; poor construction, inadequate design, in proper asphalt bond and its thickness etc. However, from engineering geological factors point of view low slope terrain, highest elevation and curvatures may be given due attention while considering the rehabilitation measure. The existing delamination type of distress can be maintained through following method.

Cleaning the old surface and applying a light asphalt emulsion tack coat will go a long way toward alleviating this problem. A tack coat is especially helpful when the overlay thickness is two inches or less (Hall et al, 2002).

Maintenance of Cracking Type Distress

Maintenance methods for cracking type of distresses mainly depend on the type of crack, which in turn is an indicator of the cause. In the present study area crocodile and longitudinal cracking was observed and recorded. These cracks in general cover ***7.38 %*** of the total distress type in the present study area.

(i) Crocodile cracks Maintenance

In total 23 crocodile crack type distress were observed and recorded in the present study area. In terms of its proportion crocodile cracks accounts for 6.79% of the total distress types in the study area.

A perusal of Table 6.1 indicate that the distribution of crocodile cracking is more related to causative factors such as; Lacustrian soil type, high elevation areas and the curvature (combination of convex and concave). It is a known fact that the cracking distress in pavement is mostly associated with overstressing of sub-grade or stresses within the pavement layers due to poor or inadequate design. These may indirectly be related to above causative factors also. To understand the possible effect of these causative factors on pavement cracking may require further elaborate study.

The maintenance of crocodile crack type distress should include removing the wet material and installing appropriate drainage. Full depth asphalt patching is necessary for having a strong and dependable repair. When necessary, temporary repairs can also be made by applying skin patches or aggregate seal coats to the affected areas to avoid any further damage to the pavement (Fiker Alebachew, 2005).

(ii) Longitudinal cracks Maintenance

Only three longitudinal crack type distresses were observed and recorded in the present study area. In terms of its proportion, longitudinal crack accounts for 0.59% of the total distress types in the study area. Longitudinal cracks are almost negligible in the study area. With such an insignificant proportion it is meaningless to establish correlation with the causative factors. However, a very sketchy relation was observed between longitudinal cracks and surface water flow direction and lacustrian soil types. For existing longitudinal cracks following maintenance method may be employed.

Longitudinal crack that are developed in an asphalt pavement as it ages and undergoes the thermal stresses associated with daily temperature cycles. Treatments for this type of distress are intended to prevent moisture intrusion and retard the rate of crack deterioration that occurs at the pavement surface (Hicks et al., 2000).

In the present study pavement distress was assessed based on the causative factors which are related to non traffic loading. The causative factors which were considered for the analysis are mainly engineering geological factors such as; Rock and soil type, Surface drainage and groundwater, elevation, slope, aspect and curvature. It was believed that these causative factors might be significant factors which might have directly or indirectly contributed for the pavement distress in the study area. However, there may be other factors responsible for pavement distress such as; inflation in design traffic loading, in appropriate pavement design, construction deficiencies, poor-durability materials, climatic effects etc. all these factors were not considered in the present study. Therefore, it is required that while considering the long term maintenance and rehabilitation of pavement distress all possible causative factors, those considered in the present study and those mentioned above, must be considered.

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Chapter 7 CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The present research study was carried out on Ring Road in Addis Ababa city of Ethiopia. The total length of the road is 33.2 Km. It was observed that almost *68.11 %* squares and 37.34 % of road spans in between two consecutive squares of ring road have distressed. Out of *68.11%* about 59.75% of squares have severely distressed. Similarly, out of 37.34 % spans of road almost 18.24 % have also severely distressed. Thus, keeping these facts in mind the present study was conceived with an objective to define the degree of pavement distress and to define and categorize the causes of pavement distress.

In order to achieve the objective of the present study systematic literature review was undertaken which includes previous studies, various standards manuals, research articles and online internet browsing. Thus, with this literature review a conceptual framework was developed and a feasible methodology for the present study was evolved.

In the present study to evaluate the condition of pavement two methods were applied for distress assessment. The first method, which was evolved during the present study, was Distress Density Method and other a standard method known as Distress Manifestation Index (DMI). The Distress Density Method is based on the number of distress per km of road length and it do not account for distress type, its location, its severity and density. Whereas, DMI method considers all pertinent information related to distress such as; type, severity, density etc. Thus, distress map was prepared by using DMI where based on the intensity of the distress, five homogeneous zones such as; excellent, good, fair, poor and very poor were defined. The percentage area coverage of distress type revealed pavement condition as; Fair (37.61%), Poor (19.1%), Very poor (18.24%), Good (17.16%) and Excellent (7.88%).

Further, attempt was made to investigate and make an assessment of possible causes which might have contributed for the pavement distress and deterioration in the study area. It was found that pavement has suffered to various kind of distress such as; Pothole, Shoving, rutting, longitudinal cracks etc. With all such distress features, reasonably, about 37% of pavement status is poor or very poor within the study area. Thus, it becomes important to assess the possible causes which might have affected the pavement to such a deteriorated condition well before its designed life period. Investigation and assessment of the possible causes of pavement distress will not only help in pavement condition management but may also help in evolving possible rehabilitation methods.

It was believed that the distress or deterioration of pavement in the study area might have resulted due to combined effect of various inherent and external factors. For the present study mainly the engineering geological factors were considered these are; Rock and soil types, Drainage (Rivers, Surface flow direction, GW table and GW flow direction), Elevation (Altitude), Slope terrain, Curvature, Slope aspect and Structural lineaments of the area. All these factors might have interacted with the pavement, in due course of its performance, with relative varied impact in combination or significant effect individually.

In order to assess the relative influence of various causative factors on pavement distress, analysis was made in GIS environment. For this purpose overlay analysis was performed using various tools in ArcGIS. To know the relative contribution of each of the causative factors on pavement distress, Raster Calculator - a tool in Arc GIS, was used. Systematic steps were followed to analyze the relative contribution of each of the parameter on pavement condition (DMI).

Maps for each of the causative factors (Engineering geology, Drainage, Elevation, Slope terrain, Curvature, and Slope aspect) were prepared on same scale and similar projection system. Visual condition survey map prepared by using Distress Manifestation Index (DMI) and all factor maps were converted to Raster form with similar pixel size (50 x 50 m). Later, each of the causative factor maps was overlaid on visual condition survey map. By using Raster calculator total pixel count for each of the sub-class of causative factor falling within respective visual condition survey classes (very poor, poor, fair, good and excellent) was determined.

Further, ratio between poor and good pavement class for each sub-class of causative factors was determined. For convenience of computation very poor and poor visual condition survey classes were clubbed together to define “Poor status” of road. Similarly, fair, good and excellent visual condition survey classes were combined to redefine “Good status” of road. The ratio between “Poor status” and “Good status” defines the relative correlation of respective sub-class of a causative factor with pavement distress condition. It implies that if the ratio value is more than 1 the respective sub-class of a causative factor has relatively more impact on the pavement distress.

Based on analysis relative influence of various sub-classes of each causative factor on pavement distress condition was assessed.

There is a good correlation between perennial streams and pavement distress. In case of Perennial streams as the pavement condition improves from poor to excellent the percentage coverage of perennial streams decreases. On the other hand seasonal streams show reverse trend as the pavement condition improves from poor to excellent percentage coverage of seasonal streams increases. The surface Flow direction towards and along the side of the pavement is more related to pavement distress condition. The average depth to groundwater table in the study area is relatively at great depth (17.65 m to 66.2 m) and thus, groundwater has not contributed towards any kind of pavement distress or deteriorations in the study area.

Alluvial, colluvial and lacustrine (Black cotton) soils are more related to pavement distress than the residual soils and other rock units present in the study area.

With respect to terrain slope factor “High Slope class” and the pavement distress condition showed good correlation. High slope provide more gradient to pavement and traffic movement over high slope gradients may exert static and dynamic loads for relatively longer durations due to slow movement. Thus, the pavement structure in such high slope gradient reaches will be more prone for distress and deterioration.

Elevation class “2,100 - 2,194 m” is strongly related to the pavement distress. All other elevation classes are higher elevation classes and do not show any relation to poor pavement distress. It may be inferred from this that high elevated areas have better surface drainage than the low elevated area and perhaps for this reason the lowest elevation class “2,100 - 2,194 m” show better correlation with pavement distress condition.

Where the pavement in the study area is falling over the slopes inclined towards East or North-West directions are more susceptible to distress and distortion.

Concave curvature class has a good correlation between curvature and pavement distress condition. The concave curve is curved inward and might accumulate surface water during rainy season which ultimately alter much of the sub-grade properties. Thus, the pavement in reaches where the slope curvature is concave possibly it is more susceptible to distress and distortion.

Most of the structural lineaments are overlaid on the poor pavement status. Thus, it shows a good corelation with pavement condition.

With regards to relative contribution of various causative factors on pavement ‘Surface Water Flow directions’ shows a positive relation with pavement distress and is probably most important in terms of order of importance. In contrast Elevation, Slope terrain, Aspects and Curvatures shows similar relation with pavement distress and have less contribution on pavement distress.

During the present study the overlay analysis has facilitated in understanding quantitatively the relative impact of each causative factor sub-class on pavement distress. The analysis made to know the relative impact of causative factors on pavement distress was on individual causative factor basis. However, the causative factors may have a combined effect on pavement distress and analysis is practically not possible to assess such combined effect of these causative factors on pavement distress condition. Also, there may be other factors which may be responsible for pavement distress such as; traffic loading, climate, inappropriate pavement design, construction deficiencies etc.. During the present study only the causative factors related to engineering geology were considered. Though the information obtained is on individual causative factor basis but this information is vital in deciding most suitable rehabilitating method for pavement condition improvement. Finally, based on the relation between various causative types and pavement distress condition suitable rehabilitation and maintenance methods has been worked out.

7.2 Recommendations

The general recommendations based on the present study are;

- In order to avoid the deterioration of pavement and to achieve the required design period, there must be timely pavement maintenance. Most of the time damages are magnified if there are drainage problems. Hence, ditches, bridges and pipes should be cleaned and maintained frequently.

- Due consideration must be given to the possible causative factors before identifying and applying the maintenance and rehabilitation method to a specific distress type.

  In the present study it has been found that in general Surface drainage and their flow direction toward the road are the significant engineering geological factors which seem to be more related to pavement distress. Thus, these may be considered in addition to other factors related to traffic loading.

- From the present study it has been found that about 38% of the pavement alignment passes through expansive black cotton soil. Though it is obvious that all care must be taken in design and construction while preparing sub-grade in these sections still attention must be given during rehabilitation and maintenance of various pavement distresses in such sections with respect to expansive behavior of sub-grade soils.

- The lowest elevation area around Kality and Mekanissa are thick soil units as compared to high elevation area around Megenagna and Winget area. For proper maintenance and rehabilitation it may be required to remove thick soils in lowest elevation areas up to the desire depth and replaced by suitable selected aggregate material and may be compacted to maximum density.

- Majority of pavement distress type as observed in the study area are potholes (41.3%) which are more related to poor or in appropriate drainage in many parts of the study area. Thus, proper attention must be given to improve the drainage condition in the study area.

- A lot should be done on the falling weight data collection and analysis mechanisms in order to come up with better results. Responsible organizations like AACRA may arrange to develop a manual appropriate for maintenance and rehabilitation purposes.

Finally, the results and findings of the present study may be considered as indicative only as the present research study was carried out under the time, resource and financial constraints. All these constrain might have affected the quality of results and certain component of inaccuracy may not be ruled out. Traffic loading analysis would be mandatory before implementation of results and recommendations forwarded through the present study. The present study was focused only from engineering geological pint of view. The present study provides a general methodology to conduct similar studies on pavement rehabilitation and maintenance.

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