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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

INVESTIGATION OF SOIL EROSION RESISTANCE ALONG ADAMA-ITEYA ROAD SECTION (CASE STUDY)

A Thesis in Geotechnical Engineering

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Investigation of soil erosion resistance along Adama-Iteya road Section (Case study)**' presented by **LEMMA HLEFOME KASSAY** , a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled "**Investigation of soil erosion resistance along Adama-Iteya road Section (Case study)**" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

Various studies have shown that the physical and chemical properties of soil are major cause of soil erosion and the formation of erosion gully.

This study was intended to investigate erosion resistance of the soil and cause of erosion gully along the Adama–Iteya road section. The assessment was achieved by conducting different physical and chemical laboratory tests on collected soil samples along the study area.

The test results of the soil along the study area shows that, it is highly susceptible to water erosion. Grain size of the soil in the study area is uniform and poor graded fine sand and silty soil. These soils are small in size compared to sands and do not bind together like clays and are subject to the most erosion.

The test result indicates that the soils along the study area are non plastic. The non plastic and cohensionless properties of the soil in the area is account for the formation of gully erosion. The maximum dry density values of the soil are generally low and it indicate that the natural deposits are loose and account for the high void ratio and the high void ratio of the soil will generate high flow velocities, high seepage pressure and account high internal erosion potential.

The chemical test results of the soil samples along the study area shows it has contain relatively high percent sodium concentration and it will be easily eroded.

An integrated approach including watershed management strategies, Construction of ditches (concrete or masonry) at appropriate locations and filling the gully with high plastic reddish clay soil, and a long term re-vegetation strategy are recommended for mitigation and controlling soil erosion and gulling in the study area.

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m: meters

asl: above sea level

ºC: Degree Celsius

S-1: per second

m3: metric cubic

ha: hectare

mm: millimeter

USC: unified soil classification

LHS: left hand side

RHS: right hand side

E: Easting

N: Northing

Km: Kilometer

Cu: Coefficient of uniformity

PI: plastic index

LL : Liquid limit

PL : Plastic limit

NP: Non Plastic

MDD: Maximum Dry Density

OMC: Optimum moisture content

%: percentage

Na : sodium

Ca : calcium

Mg :magnesium

K : potassium

SAR: sodium adsorption ratio

CHAPTER-I INTRODUCTION

1.0 Background

Road is an important infrastructure for the economic development of country like Ethiopia. The construction and maintenance of roads in Ethiopia are often challenged by fragile geological conditions and dynamics of geological and morphological processes. In developing countries like Ethiopia, development of rural road infrastructure is a major priority for reducing rural poverty (World Bank, 1994).

Ethiopia allocated significant budget for road construction. However, due to limited design knowledge of geotechnical properties of the area, different road construction projects are failed before expected design life.

Soil erosion is physical movement of soil particles from one location to another, primarily due to forces of water or wind (Ofomata, 1985). The most common types of water erosion are sheet, rill and gully erosion.

Sheet erosion is soil movement from rain drop splash resulting in the breakdown of soil surface structure and surface runoff (Hudson, 1983); it occurs rather uniformly over the slope and may go unnoticed until most of the topsoil has been lost.

Rill erosion results when surface runoff concentrates forming small well-defined channels. In many part of the country, particularly on steep cultivated land,pronounced rilling is abundant (Barber,1984). Rill erosion is present on gentle slopes with deep sediments, and may also be found in direct association with gully systems. Rills can also be found on coarser soils, and are particularly abundant when a coarse soil is overlaying a fine grained and less permeable one. Rills give rise to the development of gullies.

Gully erosion is an advanced stage of rill erosion and rill erosion is an advanced stage of sheet erosion. Gully channels carry water during and immediately after rains and as distinguished from rills, gullies cannot be obliterated by normal tillage (Hilborn, 1985).

The Soil Conservation Society of America defines a gully as “a channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains; it may be dendritic or branching or it may be linear, rather long, narrow, and of uniform width" (SCSA 1982). Gully erosion occurs when water concentrates to form big furrows with a steep head-cut wall. They may also occur when run-off volume from a sloppy terrain increases sufficiently or increase in flow velocity as to cut deep holes along its path.

Gully erosion is due to unsustainable farming practices, path and road construction, poorly constructed drainage system, it takes place when excessive surface run-off flowing with high velocity and force, detach and carry soil particles down the slope. They may also occur when run-off volume from a sloppy terrain increases sufficiently or increase in flow velocity as to cut deep holes along its path. The problem of gully erosion grows as interconnecting system of gullies spread across the land surface. Gully processes are sometimes neglected because they are difficult to study and control. This is why studies in gully processes and their modeling are scarce. Gully erosion occurs virtually in all parts of the country but it is most devastating in the area of poor erosion resistant soil, like that of Adama-Iteya road section. The development of gully has caused extensive damage to the environment and infrastructure in the study area.

The main causes of gully erosion in the study area include inappropriately termination of the storm drain and concentrated runoff from the road system flow to the poor erosion resistant soil. In this regard, Pathak et al. (2006) stated that inadequate drainage systems for roads such as small number of culverts and insufficient capacity of road ditches are some of the causes of gulling.

Efforts made in recent times to address situation regarding gully erosion by government has not been successful probably due to the fact that inadequate studies were carried out before remediation and control measures were undertaken. In order to adequately address the problem of the area, the geotechnical properties of the area must be adequately studied. The geotechnical properties of the area must be known so that appropriate biophysical measures can be taken to address the problem.

The unstable nature of the material along the study area has accounts; a series of points on the gully wall will slump in various part of the gully. This in turn will cause and results in further widening of the gully and the deposition of higher volume of sediment at the downstream of the gully creating further environmental degradation and loss of valuable properties and land resources. The critical threshold for the initiation and development of gullies in different environment in terms of geotechnical characteristics use need to be identified. Once these are done, adequate remediation measures can be undertaken. Preventing gully formation is much easier and more economical than treating the already formed gully. It is therefore very important to identify the causes and extent of gully development in order to carryout effective remediation and control of their spread.

1.1 Problem statement

It is reported that some of newly constructed roads in Ethiopia have shown premature failures due to geotechnical related failures such as erosion gully problem, where huge amount of resource was allocated for the construction of roads. This shows that, newly constructed roads are not long lasting and do not give intended purpose and thus entail an increased amount of maintenance and road users cost that directly affects the economy of the nation. Conducting researches relating to the subject matter is crucial in order to improve performance of road construction in such area and to provide appropriate prevention and mitigation measure to minimize problem.

Researches (Osadebe and Akpokodje, 2007), (Hudson, 1996) and (Shestha 2002) show that physical and chemical characteristics of soil are main factors that affect erodibility nature of soil and formation of erosion gully.

This study was, therefore, made to evaluate the effect of soil factors, such as physical and chemical characteristics of soil, for the formation gullies along Adama-Iteya road section.

On the other hand, once the gully has formed it is difficult to control and the treatment measure will be an expensive. Therefore, in addition to seeking for cause of erosion gully along Adama-Iteya road section, alternative appropriate and economical remedial measures are recommended. Thus, this study was made with this intention.

1.2 Research objective

The overall objective of this study is mainly focused on investigations of erosion resistance of the soil and cause of erosion gully along the Adama–Iteya road section. Besides, it will recommend appropriate mitigation measures for the problem

Generally, the main objective of the study includes;

- to identify distribution and geometrical description of erosion gully along Adama –Iteya road section.
- to assess major cause of erosion gully problem along road.
- to examine the consequence of erosion gully on the newly constructed Adama-Asala Asphalt road.
- to suggest possible treatment and control remedial measures

1.3 Research organization

This research has eight chapters. The first chapter is the introductory part which highlights project background, objective and scope of the research. The second chapter focues on literature review of the research. The third chapter concerned about describing general description of the study area. Methodology for the investigation is thoroughly discussed in chapter four. In the fifth chapter, the detailed field geotechnical studies work are discussed in detail. Analysis and evaluation of field survey and laboratory test results are discussed in the sixth chapter. In chapter seven, Treatment mitigation measure of the study area are thoroughly discussed. Conclusions and recommendations are discussed in chapter eight.

CHAPTER-II LITERATURE REVIEW

2.0 Introduction

Various studies (Emerson (1959), Valentin. (2005)., Poesen (2005), Igwe, C. A. (1999), Rode (1962), Simonson (1959), Asadu (1983)) have been conducted on physical and chemical properties of soil. In general the main objectives of the researches were to understand in a better way the soil factor is one of the major cause of soil erosion and evaluate the effects of erodible soil on the performance of road infrastructure.

Among the various studies conducted on cause of soil erosion, many were concerned on investigation of the physical and chemical properties of soil are major cause of soil erosion. This was due to the fact that soil factor is a prime cause of soil erosion and formation of erosion gullies. Likewise, it has been addressed that, the properties of soil influence to a larger extent than other causes of soil erosion.

The research herein concentrates on erosion resistance of soil and the cause of gully formation along Adama-Iteya road section based on different field and laboratory test analysis. The assessment on the subject matter was achieved by conducting different physical and chemical tests on sample collected along the study area.

In this chapter, cause of soil erosion and review of researches conducted on the physical and chemical properties of soil are major cause of soil erosion and gully formation will be discussed.

2.1 Process of soil erosion and Gully formation

Soil erosion generally refers to detachment and transportation of soil material from the place of origin by water, wind, ice or gravity and deposition to another places.

According to Lakew & Belayneh (2012), erosion can be classified in to two categories:

- Geological Erosion – natural erosion
- Accelerated Erosion – caused by mankind

Geological type of soil erosion is a natural phenomenon and happens without the intervention of human being. When the soil removal to that of soil formation is compared, it is not critical to consider geological erosion as that of accelerated erosion.

Accelerated (manmade) soil erosion is defined as rapid removal of soil brought about by the intervention of man in the process of earning livelihood. When soil is bare of its natural protective vegetation because of human intervention, the soil is exposed directly to the abrasive action of the elements of erosion mainly wind and water. Erosion due to water is a significant contributor for soil erosion.

The process of water erosion starts with rainfall. Raindrops which do not touch plants will have the splash effect, defined as the impact of raindrops on the soil surface. Soil aggregates are smashed and their particles thrown in all directions. From the surface, water can infiltrate the soil through pores, as long as they are not saturated. Excess water moves as overland flow ("runoff") down slope and detaches additional soil particles. When runoff is evenly distributed, sheet erosion occurs.

Water usually tends to concentrate along the lowest parts of a soil surface and forms small channels called rills. Overland flow that concentrates in channels leads to the formation of rills and gullies.

Rills are usually small and can be easily removed by tillage. Rill erosion is much more easily noticed than inter rill erosion. If unchecked, rills may extend into the subsoil resulting in gully erosion. Another cause of gully erosion is an increase in flood flow, which may be caused by deterioration of vegetation in a catchment, and the concentration of flow in roads, footpaths, poorly maintained cutoff drains, waterways and cattle tracks, etc.

As mentioned by Miller et al., 1997, cited in Girma (2005) below, erosion by water is classified as raindrop splash erosion, surface flow or sheet erosion,and channelized- flow erosion.

a) Rain drop splash erosion

Rain drops fall with an approximate speed of 914 cm/s. When raindrops strike bare soil, they beat it into flowing mud, which splashes as far as 60 cm high and 150 cm away. The soils most readily detached by raindrop splash erosion are fine sands and silt. Coarser particles are not shifted about as much because of their greater volume and weight. Most soils of finer texture, such as clays and clay loams, are not readily detached because of the strong forces of cohesion that keep them aggregated (Girma, 2005). The following are some of the basic principles for splash erosion:

- Soil splashing is resulting from the impact of water drops directly on soil particles.
- If a rain drop strikes a land covered with thick blanket of vegetation, the drop breaks into a spray of clean water- it then slowly finds its way into soil pores. But if it strikes bare soil, considerable splashing occurs
- The falling drops break down soil aggregates and detach soil particles and the fine materials from the soil are removed, less fertile sands and gravels remain behind.
- The principal effect of splash erosion is to detach soil and transportation of the detached soil takes place after wards.
- The number and size of drops and the velocity of drops determine the impact of raindrops per unit area. Large drops may increase the sediment carrying capacity and the velocity of raindrops, on the other hand, is affected by its size, height of fall, wind velocity and air resistance.
- It has been observed that a single raindrop may splash wet soil as much as 60cm high and 150cm from the spot where the raindrop hits.
- Continuous bombardment in a rainstorm by millions of raindrops causes damage by beating the bare soil into a flowing mud.

Factors affecting the direction and distance of soil splash are: presence of wind, land slope, Soil surface conditions (vegetative cover and mulches). Generally, splash erosion is the worst form of water erosion as it gives a start for the other forms of erosion.

(b) Surface flow erosion (sheet erosion)

Runoff water is responsible for much soil erosion, moving the soil particles by surface creep, saltation (movement of wet and supersaturated soil downhill by a rolling or dragging action), valuation (results when turbulent water causes soil particles to hop or skip in water as they move downward), and suspension (movement of smaller particles carried by moving water without touching the soil surface) (Miller 1997)

(c) Rill Erosion

According to Herweg (1996),rill erosion is defined as the removal of soil by runoff water with the formation of shallow channels that can be smoothed out completely by normal cultivation. Rills develop as a result of concentration and flowing of runoff water along the slopes through small finger-like channels. The soil eroded from upland areas comes from these small channels, called rills, and from inter-rill areas between them.

The primary mechanism for soil detachment and transport from inter-rill areas is the energy resulting from raindrop impact while the primary for soil detachment for rill erosion is the distributed shear force on the rill channel boundary due to concentrated flow of runoff water.

During a rainfall event, flow is quickly concentrated in micro-rills, which in turn flows into larger rills and eventually discharge to anexisting channel system. The concentration of flow in rills increases the erosive power of the flow resulting in increased soil detachment from the rill channel boundary (Evans 1993).

(d) Stream Bank Erosion

Stream erosion is the scouring of soil material from the stream bed and cutting of the stream banks by the force of running water. Stream bank erosion is often increased by the removal of vegetation, overgrazing, or tillage near the banks. Scouring is influenced by the velocity and direction of the flow, depth and width of the stream, soil texture and alignment of the stream (Floyd, 1965). Rivers and streams often meander and change their course by cutting one bank and depositing sand and silt loads on the other.

(e) Gully Erosion

Gully erosion is the erosion process whereby water concentrates in narrow channels and over short periods removes the soil. Gully erosion produces channels larger than rills. As the volume of concentrated water increases and attains more velocity on slopes; it enlarges the rills into gullies.

Gully can also originate from any depression such as cattle trails, footpaths, cart tracks and traditional furrows and indicates neglect of land over long period of time (Lemly, 1982).

Some gullies may be formed as a result of tunnel erosion, also known as piping. Tunnel erosion develops particularly where the soil is highly sodic. Runoff water passes through cracks and macrospores (mole channels, termite holes etc.) and on reaching the slowly permeable sodic subsoil, it moves laterally as sub-surface flow. Clay dispersions (as a result of high sodium content) may occur along the flow lines and lead to the formation of tunnels. Eventually, the roof of the tunnel may collapse and a gully is created (Hoque, 1979)

The gully channels carry water during and immediately after rains and distinguished from rills, gullies cannot be obliterated by normal tillage. The Soil Conservation Society of America defines a gully as “a channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains: it may be dendritic or branching or it may be linear, rather long, narrow and of uniform width”.

The rate of gully erosion depends primarily on the runoff producing characteristics of the watershed, soil characteristics, alignment, size and shape of the gully and the slope in the channel.

2.2 Factors affecting gully formation

According to Hamelmal, 2005, the rate and magnitude of erosion gully is mainly depend on the following four factors:

2.2.1 Rainfall intensity and runoff

Both rainfall and runoff factors must be considered in assessing water gully erosion problems. The loss of soil is closely related to the impact of raindrops on the soil surface to separate down soil aggregates and disperse them. The energy of the raindrops influences the kind of soils that are detached.Lighter soil materials can be easily removed by raindrop splash and runoff, but larger and denser materials require raindrops with higher energy. Soil movement is usually high and easily noticeable during short-duration and high-intensity thunderstorms. As indicated in (Hudson ,1996), less intense and long lasting rainfall should not be misinterpreted as being not capable of moving significant amount of soil when compounded over time. Runoff depends on rainfall intensity and infiltration capacity of soil. It can occur when rainfall intensity exceeds the rate of infiltration; as a result, the excess water cannot be absorbed into the soil so it forms surface runoff. The amount of runoff can increase if infiltration is reduced due to soil compaction, saturation, crusting or freezing.

2.2.2 Soil erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion,based on the physical characteristics of each soil.The physical factors which affect erodibility of soil are aggregate stability, particle size distribution, base minerals, organic carbon content, clay mineralogy, infiltration capacity, pore size, pore stability, moisture holding capacity of soil, topographic features and management of the land ((Hudson, 1996 and Shestha, 2002). Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have greater resistance to erosion. Loam-textured soils tend to be less erodible than silt and very fine sand. Tillage and cropping practices that lower soil organic matter levels, cause poor soil structure, and result an increases in soil erodibility.

2.2.3 Slope gradient and length

Generally, soil erosion by water increases as the slope of a field increases. Soil erosion by water also increases when the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with high erosion potential, due to increase in the velocity of water, which permits a greater degree of scouring (carrying capacity for sediment).

2.2.4 Vegetation / Crop cover

Soil erosion potential increases if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash. Plant and residue cover tends to slow down the movement of surface runoff and allows excess surface water to infiltrate.The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent,and quantity of cover.The effectiveness of any crop,management system or protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. Soil erosion potential is affected by tillage operations,depending on depth, direction, timing of plowing, type of tillage equipment and number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing erosion.

2.3 Road construction and erosion problems

Gully erosion is probably the most serious form of water erosion, it is highly affect several infrastructure i.e, bridges, roads and settlements.For roads and streets, ditches are used for collecting surface runoff along roadsides and uses to a diversion for preventing water from reaching the road.

Off-site effects of gully erosion include siltation of rivers and reservoirs. Gullies can be defined as “relatively permanent steep-sided water courses which experience ephemeral flows during rainstorm” (Morgan, 1995).

Gully erosion is most prevalent type of water erosion as it dissects the fields, impedes tillage operations, damaging infrastructure and restricts free movement of traffic. Many rural communities in the Ethiopian are located more than 25 km away from any road. As part of the development strategy, many feeder and rural access roads were built recently to increase the accessibility of these areas. However, it has observed that the construction of these roads is one of the cause of formation of gully (Chadhokar, 2000) due to artificial drains and increased catchment area. In the East African Moeyersons (1991) monitored and analyzed progressive gully formation after road construction in Rwanda. Montgomery (1994) indicated that, the main causes of gulling after road building are overland flow concentration by the establishment of artificial drains and increased catchment area. (Liuelseged, Amare and Awdengest, 2014) assessed the impact of road construction on the formation and development of gullies, particularly along the Hadero Tunto-Durgi road that was built between 2006 and 2008 in Southern Ethiopia. Along a 42km long road in Kenya, incipient gullying was observed down slope of 54 % of the culverts compared to 22 percent of the drifts,this is explained by the fact that drifts conform more to the natural hydrological conditions (Jungerius, unpublished work ,1999).

In Kenya, (Dunne ,1982) and (Dietrich ,1982) show that rural roads and footpaths in a densely populated area cover about 2 percent of a catchment’s area, but provoke 25% to 50 % of total soil erosion in the country.

According to Mitiku (2002), the formation and development of gullies have been analyzed after the construction of the Mekelle-Adwa road in 1993 to early 1994. During the first rainy season, farmers observed important gully initiation on their lands just down slope of culverts and outlets of lateral road drains.

2.4 Gully category

The simplest classification system of gully type is based on gully depth: Small gully <1m; medium gully 1–5 m; and large gully >5 m. The size of gully, however, often reflects its stage of development rather than the size of water flow. Besides, gully has also categorized based on the flow rate and drainage area is as follws : Small gully has flow rate of <0.3 m3/s and drainage area of < 5ha; medium gully has flow rates ranges 0.3–2.0 m3/s and drainage area ranges 5-40ha; large gully has flow rate >2.0 m3 /s and drainage area >40ha (Pathak et al., 2006).

Table 2.1. Gully classification based on depth and drainage area.

Gully classes	Gully depth (m)	Gully drainage area (Ha)	Flow rate m3/ s
Small gully	1	5	0.3
Medium gully	1-5	5-40	0.3-20
Large Gully	>5	>40	>2

Sources: Pathak, et al: August 2006

2.5 Identification of soil susceptible to erosion gully.

Various studies (Obi & Asiegbu, 1980; Akpokodje et. al 1986; Ezechi, 1987, Okagbue & Ezechi 1987; Okagbue, 1988, Okoli, 1991, IDRC/CRDI (1998) have shown that the initiation and propagation of gully erosion in southeastern Nigeria is mainly influenced geotechnical properties of the soil. The studies revealed that the areas that are prone to severe gully erosion have very specific geotechnical properties that favour gully erosion. These soils are characterized by:

(a) high silty and fine sand content and low fines,

(b) low dry density ,

(c) low plastic soil and ,

(d) high percentage of sodium concentration.

The textural properties of these deposits, to a large extent, determine their responses to the erosive action of surface runoff. Hudec et al. (1998) described the results of gradation analysis and measurements of the dry bulk density, dispersivity and moisture content of samples from the main geological units, which are susceptible to gullying. Gradation analysis of the Nanka silty sand, Ajali silty sand soil and silty sand shows that they are all strikingly uniform. The combined percent passing curves for size analyses of the units follow closely similar trends. The coefficient of uniformity (D60/D10) shows relatively minor variation in size distribution, in the size range of silty to fine sand.

The degree of dry density and the presence of interstitial and intercalated mudstone of the main sand and sandstone units also have a bearing on their susceptibility to gully erosion (Hudec et al., 1998). The amount of sodium concentration (Na+) has direct correlations with the rate of gully formation: the higher amount of sodium concentration in the soil is account for greater the rate of gully formation (Aitchison and Wood (1965); Ingles and Wood(1964); Rallings, (1966))

2.6 Gully erosion control measures

The result of Akpokodje (1998), Nnamdi (2008) and Ekeocha (2010) study revealed that, gully control measures that have been applied for the management of gully erosion in the southeastern Nigeria regions has been grouped into two categories, namely:

(a) control/curative and

(b) Preventive measures

a. Curative/Control Measure

The basic philosophies behind the curative/ control measure are to:

- prevent run-off from reaching the gullies as much as possible and
- enhance the stability of slopes.

The methods reduced both the quantity and velocity of flood water in the gullies and this in turn, leads to significant reduction in the erosive power of the gully flood waters. The most commonly used structures are:

- interceptor open drained or canals
- catch pit or soak-away pit and
- underground drainage pipes

b. Preventive Measures

Preventive measures are usually easier and cheaper to execute. The preventive concept is aimed at encouraging all practices that prevent erosion while discouraging all those practices or conditions that either initiate or accelerate gully erosion. It emphasizes correct land-use practices.However, for them to be effective,they require the mobilization and active participation of all the people that are either directly or indirectly connected with.

CHAPTER-III GENERAL INFORMATION

3.1 Location and accessibility

The study area lies in south eastern Oromia regional state along Adama-Asala road section particularly between Sodera junction (i.e,which is 113km from Addis Ababa) up to Iteya town (which is about 135km from Addis Ababa).

The UTM Coordinate of Adama town is, Easting 529836.5 and Northing 943512.6 and UTM coordinate of Iteya town is Easting 524967.4 and Northing 899695.9 (Fig.3.2).

Figure 3.1 Location map of the study area

Figure 3.2 Location Map of the study Area (scale 1:250, 0000)

The erosion gully problem is mainly located adjacent to newly constructed Adama-Asala asphalt road, it is very dangerous to the newly constructed Adama-Asala road.

3.2 Geological formation of study area

The study area is found in south central part of the country at the verge of the Eastern Plateau and the Main Ethiopian Rift system. The area is found making the shoulder of the rift from the east direction with an elevation of ranges from 1600m to 2000m amsl. The erosion gully hazards are mainly observed starting from Sodera junction up to Iteya town.

The main features of this area include flat morphology with frequent appearance of greyish silty sand soil. Erosion gully hazards become evident near to the Adama-Iteya road side.

The geological formation of the study area is mainly covered by quaternary sediments of lacustrine origin. Lacustrine beds are interbedded with pliopleistocene. Lacustrine beds are mostly redeposited volcanic sand and tuff with calcareous material and diatomite. According to Mohr.(1966) at the beginning of the Quaternary an ancestral lake which was almost certainly continuous from south to Awash basin to the north existed until it shrinks to the smaller ones by late Pleistocene tectonic movements. As observed during the site investigation, the lacusrine deposit found in study area is greyish to whitish silty sandy soil. Moreover, gypsiferous and fossiliferous limestone of lacustrine origin is observed in study area.

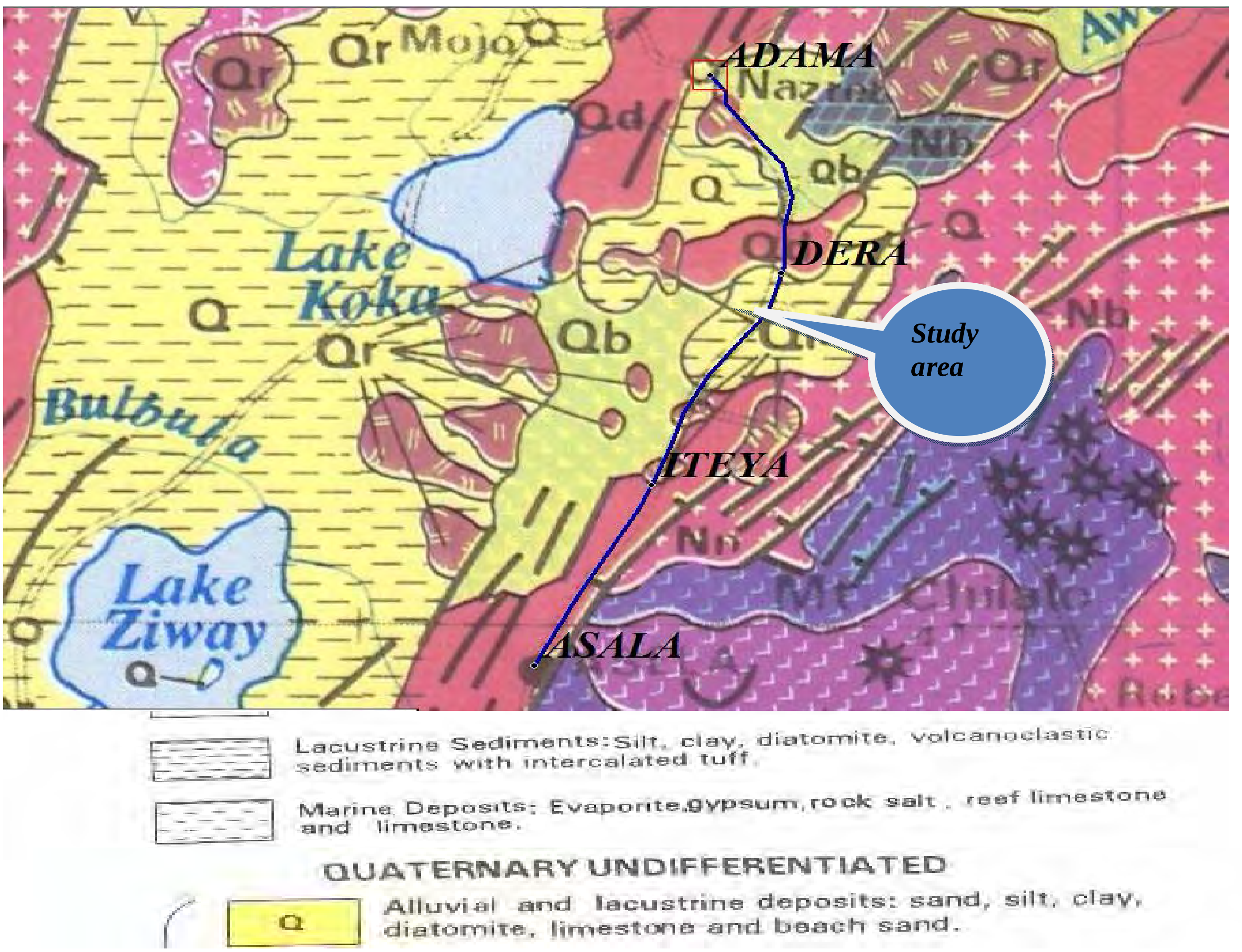


Figure 3.3 Geological f of the study area

3.3 Topography of the study area

The study area is characterized by more or less uniform topography which is straight and flat topography nature. Geomorphologically, the study area lies in an elevation of ranges from 1600m in north to 2000m in the south. The slope is generally flat at the surrounding area.

The study area contains few streams and most of which are small and seasonal type and are tributaries of Awash Melka River. The Awash melka river is one of the biggest river draining to the study area.

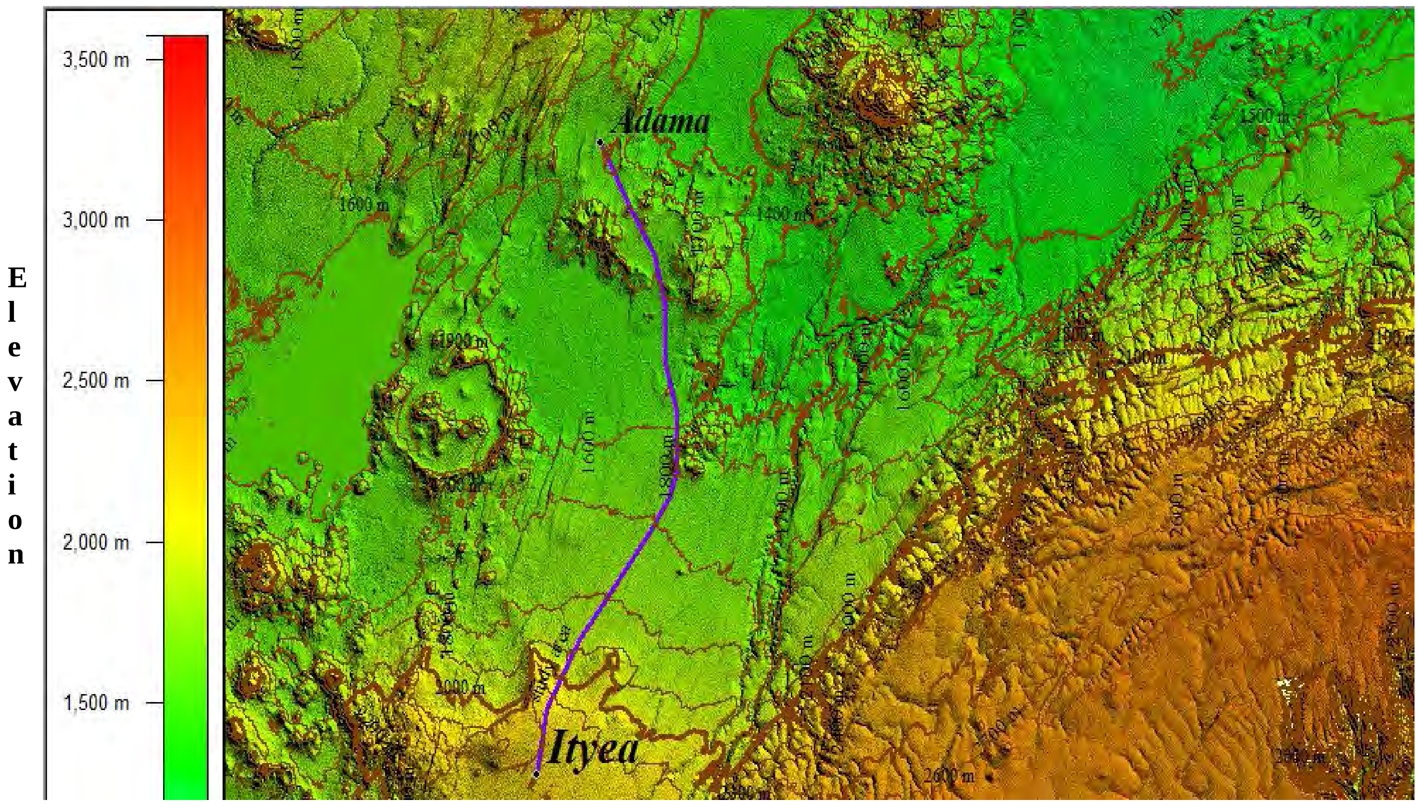


Figure 3.4 Terrain classification of the study area.

3.4 Climate of the study area

The system of climatic classification of National Atlas of Ethiopia was used to classify the climatic condition of the study area.The climate along the study area is mainly dependent on distribution of rainfall and variation of temperature. Based on Mean Seasonal Precipitation and Mean Seasonal Temperature variations,three seasonal periods are commonly known in Ethiopia.These are named as “Bega”, “Belg” and “Kiremt” and occur in months of October - January, February- May and June - September, respectively.

The National Atlas of Ethiopia (1984) system includes five major categories which is based on Temperature/Altitude Relationships which are.

“Wirch”; above 3300 m a.s.l. (mean annual temperature below 10ºC).

“Dega”; 2300 – 3300 m a.s.l. (mean annual temperature between 10 to 15ºC).

“Weina-Dega”; 1500 – 2300 m a.s.l. (mean annual temperature is between 15 to 20ºC).

“Kola”; 500 – 1500 m a.s.l. (mean annual temperature between 20 to 30ºC).

“Berha”; below 500 m a.s.l. (mean annual temperature between 30 to 40ºC).

From the above classification, the study area mainly falls within the Weina-Dega climatic zone, as the altitude of the alignment mainly lies 1500 – 2300 m a.s.l.

CHAPTER-IV METHODOLOGY FOR INVESTIGATION

4.0. Introduction

Geotechnical investigation on the gully sites are performed by different approaches and methodology. The approaches and methodology carried on the gully sites include field survey and laboratory tests. Besides, geotechnical mapping of the area are conducted in order to get better understanding of geotechnical hazards level of the area.

The following methodological scheme is conducted during detailed study of the area. During the field study, different methods were applied and the subsequent work was completed at different stages of study these are;

- preliminary works,
- detailed field works,
- laboratory investigation works and,
- report writing.

4.1. Preliminary works

During the preliminary work, collections of the available information from various reports and related papers were done. Physiographic information, geological data, regional geological structures and different literature were referred. The topographical maps of the 1:250,000 scale was used for the detailed analysis of study area. Besides, detailed engineering design of the Adama-Asala road project was also referred.

4.2 Detailed field work

The field work was carried out after the compilation of preliminary work. Firstly, it focused on confirming the information collected during the preliminary work. After that, the detailed investigation was performed, which includes the following.

Reconnaissance survey: During the investigation, geotechnical reconnaissance survey was made along the study area to confirm the location of erosion gully hazard section .

Detailed geotechnical investigation: detailed geotechnical investigation covers the following specific studies:

a) measurement of gully size;

b) field identification of the soil;

c) representative disturbed soil samples; and

d) identify and checking other possible factors affects soil erosion of the study area.

a) Measurement of gully size:

The equipment like, hand GPS and meter were used during field investigation period inorder to located and measure gully area. The depth and width of all erosion gullies were measured along the study area. The location of all gullies were identified by hand GPS and the data were plotted on the map. Besides, slope of the gully and drainage pattern also note down.

b) Field identification of the soil:

The geological and earth map were referred during the field study. The lithological characteristics were identified and analyzed along in all erosion gully area and on exposure gully bed. During field investigation, the formation of soil such as colour, drainage or moisture condition, textural type and presence of chemical have been visually identified.

Besides, the engineering properties of soils in the study area were noted down within 50m interval along erosion gully section. The soil type, lithological formation, slope of the road and seepage conditions, etc were the major properties of concern.

c) Representative disturbed soil samples:

To determine engineering properties and to assess the erodiablity nature of the soil on the gully area, representative disturbed samples were collected by digging test pits at each gully location. Test pits are excavated up to 1.0 m depth on the gully bed and gully wall at different location. The test pitting and sampling furnish not only laboratory indication of the character of the soil, but also help to identify the thickness and character of the overlying materials if any.

Table-4.1 location of test pits.

Gully sites	Station	Depth (m) from top surface.
Gully site1	5+200	1.5m
Gully site 2	8+650	2.0m
Gully site 3	9+700	3.0m
Gully site4	15+150	3.0m
Gully site5	23+100	3.0m
Gully site6	30+000	1.0m
Gully site7	33+000	3.5m
Gully site8	35+200	4.5m
Gully site9	36+800	4.5m
Gully site10	38+500	9.0m
Gully site11	41+500	6.0m

d) Identifying and checking other possible factors affecting soil erosion in the study area;

The necessary equipment and documents like, hand GPS and topographical map, etc. were used during the field study to check other possible factors affecting soil erosion. The drainage characteristics along the study area were analyzed and identified.

4.3. Laboratory investigation

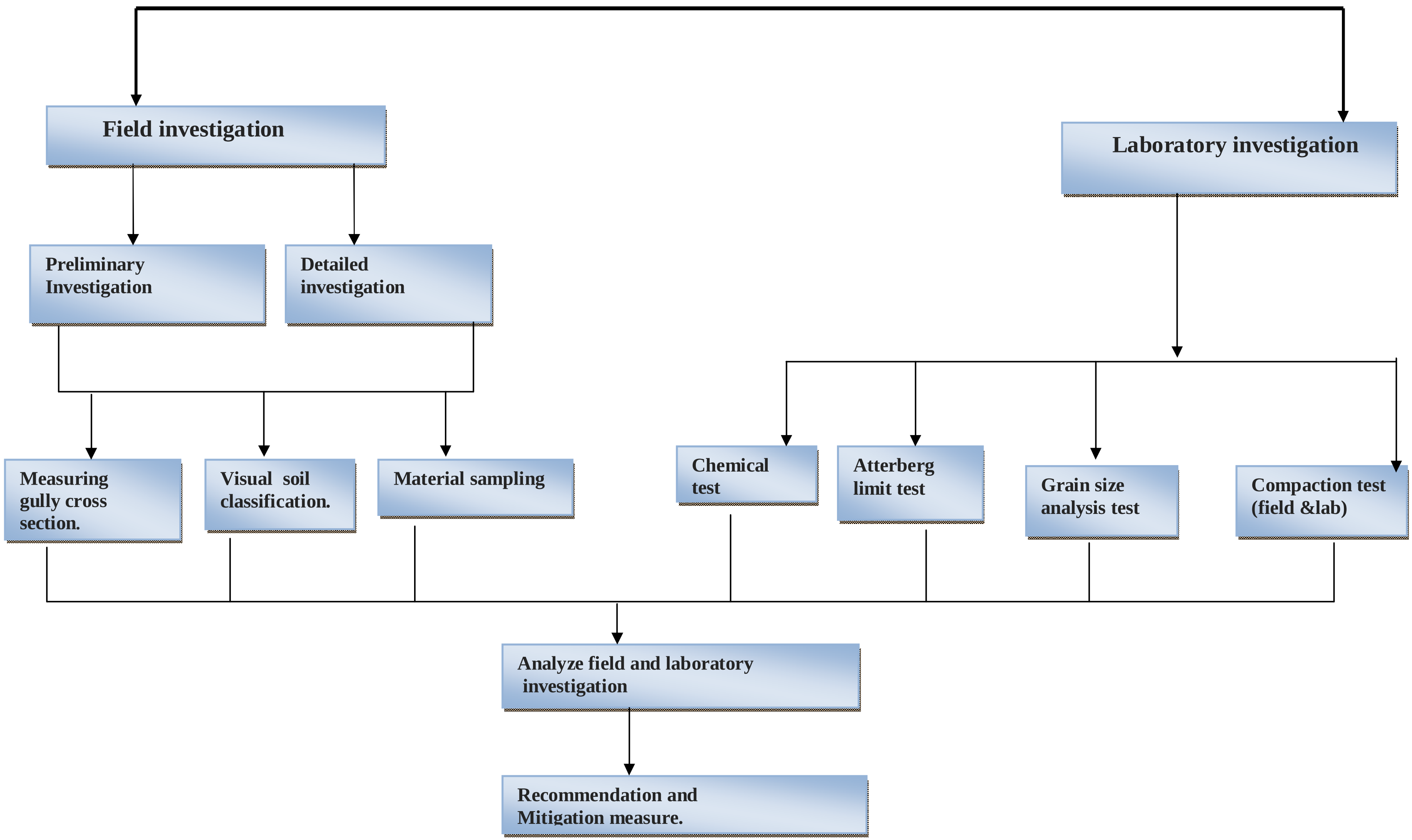
After the completion of the field work, laboratory investigation work were performed on all the collected disturbed soil samples at the gully sites in order to achieve the following tasks;

- to evaluate erosion resistance of the soil,
- to Identification of Soil type;
- to preparation of erosion gully hazard maps ;
- to analysis of test results;
- to provide appropriate mitigation measure.

4.4. Report

After the completion of the field work and laboratory investigation, the detailed analysis of the cause of erosion gully along the study area are identified .Besides, possible remedial measures were included in the report.

Figure 4.1 Flow chart of methodology



CHAPTER-V FIELD GEOTECHNICAL INVESTIGATION

5.0. Introduction

The geotechnical studies of the erosion gully along the Adama-Iteya road section were carried. The study includes the detailed investigation and evaluation of geotechnical conditions of the alignment material along corridor of study area. The geotechnical studies are mainly confined to the description of the material formation along alignment, hazard assessment and preparation of geotechnical hazard maps.

5.1 Parameters of causes of soil erosion

Soil erosion generally is caused by several factors working simultaneously or individually to detach, transport and deposit soil particles in a different places other than where they were formed. The resultant effects of this phenomenon are deep cuttings and ravine which dissects the entire land surface. These are very common all over the study area. It is well established fact among earth scientists that a number of environmental factors as well as pedological parameters influence the extent of soil erosion where ever it occurs globally. Although man has helped in reshaping and preserving the earth surface, yet man has also helped in causing instability of equilibrium in the natural ecology and hence the rapid spread of environmental problem such as soil erosion.

Giordano (1991) showed that road infrastructure is one of the factor encouraging soil erosion ,which creates excessive water runoff side of bare land.

In classical modelling works on soil erosion prediction and estimation, works by Renard (1997) and Igwe (1999) have identified that topography/relief, rainfall and soil factors are the main agents that affect the formation of erosion gully.

The effect of these agents on the formation of erosion gully along Adama-Iteya road section is thoroughly presented in the subsequent section.

5.1.1 Role of topography.

Hudson (1996) state in simplest term, steep land is more vulnerable to water erosion than flat land for reasons that erosive forces, splash, scour and transport, all have greater effect on steep slopes. Soil erosion and gully formation is function of steepness of the slope. The amount of soil erosion have always been proportional to the steepness of the slope.

However, according to terrain classification of the study area, Adama-Iteya road section is mainly classified as flat to rolling topography. Thus, the cause of the soil erosion and gully formation in the study area will not be due to topography of the area.

Photo 5.1 Typical topography nature of the area (flat topography)

5.1.2 Influence of rainfall

The rainfall distribution of study area is generally normal however, it is short and intensive.The annual rainfall recorded in study area is ranges from 700mm to 900mm. The Rainfall often comes between month of July and last till September. Besides, due to global climate change, sometimes rainy period is unduly prolonged while in other time their onset may be delayed.

Short and intensive rainfall has contributes significantly cause to the erosion of the soil. Rainfall erosivity is the potential ability of rain to cause erosion. Obi and Salako (1995), reported that intensity and energy of the rainfall are likely to be closely linked with erosivity.

Accordingly, it is confirmed that the intensive nature of the rainfall has easily detach soil along the study area and eventually form erosion gully.

5.1.3 Influence of soil factor (erodibility nature of the soil)

The erodibility of the soil is defined as the vulnerability or susceptibility of the soil to erosion. Igwe (1999), remarked that the physical and chemical properties of the soil are main factors that affect erodibility of the soil. In the study area, it is evident from the nature and long weathering history of the parent soils, loose fine sand and silty soil texture are dominate soil formation found in the area ,this soil formation is most erodible type since it is small in size compared to sands and do not bind together like clays.

Besides, the soil in the study area has contain relatively higher percent of sodium concentration than other four metallic cations and hence, excessive leaching will occur and the situation worsen.

Generally, the inherent properties of the soil combine with physical forces of rainfall in the area are main factors to be created erosion gully in study area.

Photo 5.2 physical nature of the soil

Photo 5.3 physical nature of the soil

5.2. Identification of erosion gully sites

Eleven (11) erosion gully site have been identified at different location along the study area. The physical natures of each gully site have been described in the subsequent section.

Erosion Gully site-1 (km 5+000 - km 5+ 300)

The erosion gully is located at the outskirt of Adama has an offset of 5m on LHS along Adama-Asala road. The terrain of area is almost flat and it is slightly covered by few vegetation and shrubs. The UTM coordinate of the gully stie-1 is E532518.697 and Northing 938263.799.

The soil types found in this gully area are alluivial & lacustrine formation, which is yellowish to brown silty sand soil and it is classified as SM group as according to USC system. The depth of the gully in this stretches reaches up to 1.5m and it widths is about 3m. The gully is inactive and of low hazard level and it is triggered due to improper rain surface water.

Photo 5.4 Actual condition of gully site -1

Erosion Gully site-2 (km 8+600 - km 8+750)

The erosion gully in this section is found at adjacent to both sides of the road (i.e,an offset of 2.0m). The slope of the road alignment is almost flat and the area is covered by few vegetation and shrubs. The UTM coordinate of the gully area is E534305.802 and Northing 935427.742.

The soil types found in the area is alluivial & lacustrine formation of brown silty sandy soil and it is classified as SM group according to USC system. The average depth of the gully reaches up to 2m and its width is about 2.5m and it is categorized as medium gully. The length of gully has extends to 150m and has low level hazard. The gully has trigger due to improper surface rain water management.

Currently, the erosion gully has less effect on the existing asphalt road however; there will be problem in the future if it is not protected well.

Photo 5.5 Actual condition of erosion gully site -2

Erosion Gully site-3 (km 9+600 - km 9+800)

The erosion gully in this section of the road is located an offset of 2m at right hand side of the road. The wangi sugar cane farm is found at the LHS of the road. The slope of the road alignment is almost flat. The UTM coordinate of the erosion gully is Easting 534694.302 and Northing 934456.490

The soil types found in the area are lacustrine & alluivial formation of light brown silty sand soil. The soil found at the gully area is classified as SM group as according to USC system. The depth of the erosion gully has reached up to 3.5m and its widths is about 4.5m ,which is an active gully. The length of erosion gully extends up to 200m and it is very near to the road and it is dangerous to the existing asphalt road. The possible cause of erosion gully is improper management irrigation water of sugar cane farm and surface runoff water.

Currently, newly constructed protection Gabion wall in this gully site has totally failed.

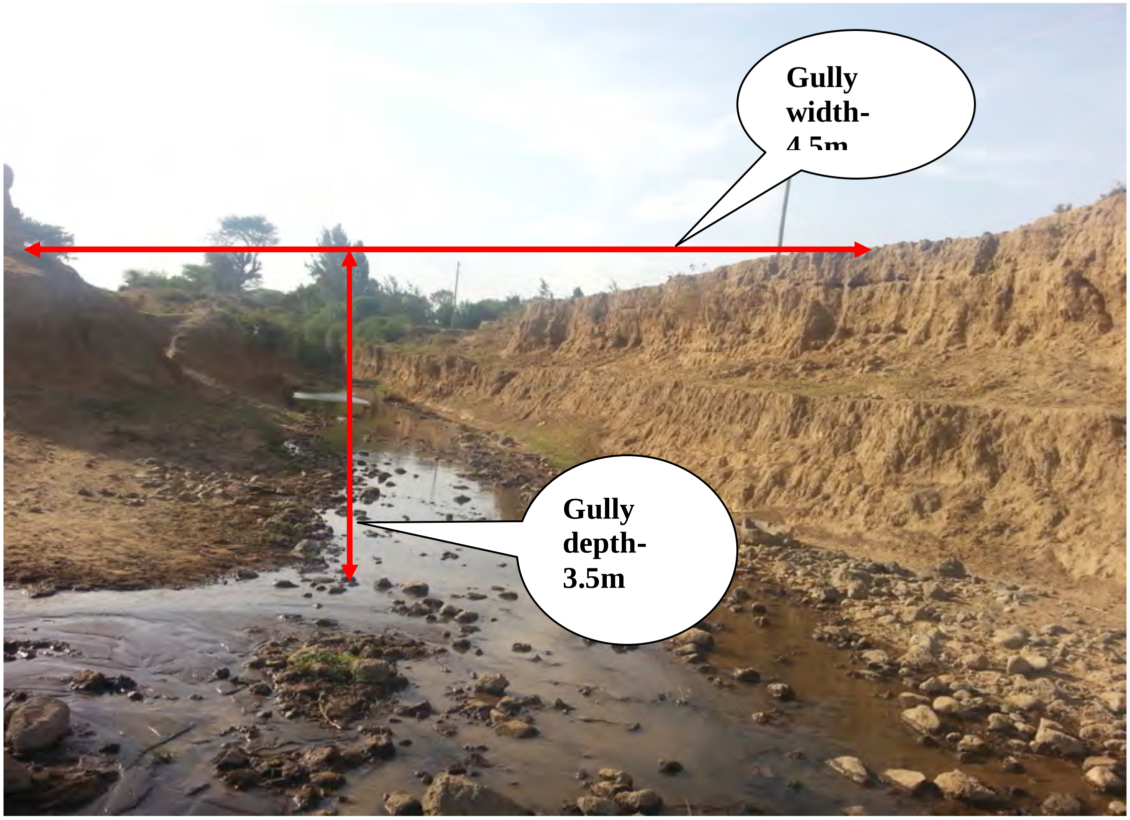


Photo 5.6 Actual condition of erosion gully site-3

Erosion Gully site-4 (km 15+000 - km 15+300)

The erosion gully on this section of the road is located at left hand side of the road (LHS) has an offset of 2m. The gully has developed due to improper management of irrigation water canal of wangi sugar farm. The UTM coordinate of the erosion gully is E535315.904 and Northing 929056.327.

The length of gully has 300m, which is very close to the road and thus dangerous to the existing asphalt road. The soil of this section is classified as SM according to USC system. The slope of the road alignment is almost flat. Awash river is located 2km far from the gully site i.e,at Km 17+400.

The depth of erosion gully has reached up to 3.5m and its widths is about 3.5m, which is relatively an active and of high hazard level. The soil types found in the area are lacustrine & alluivial formation of light brown silty sandy soil .

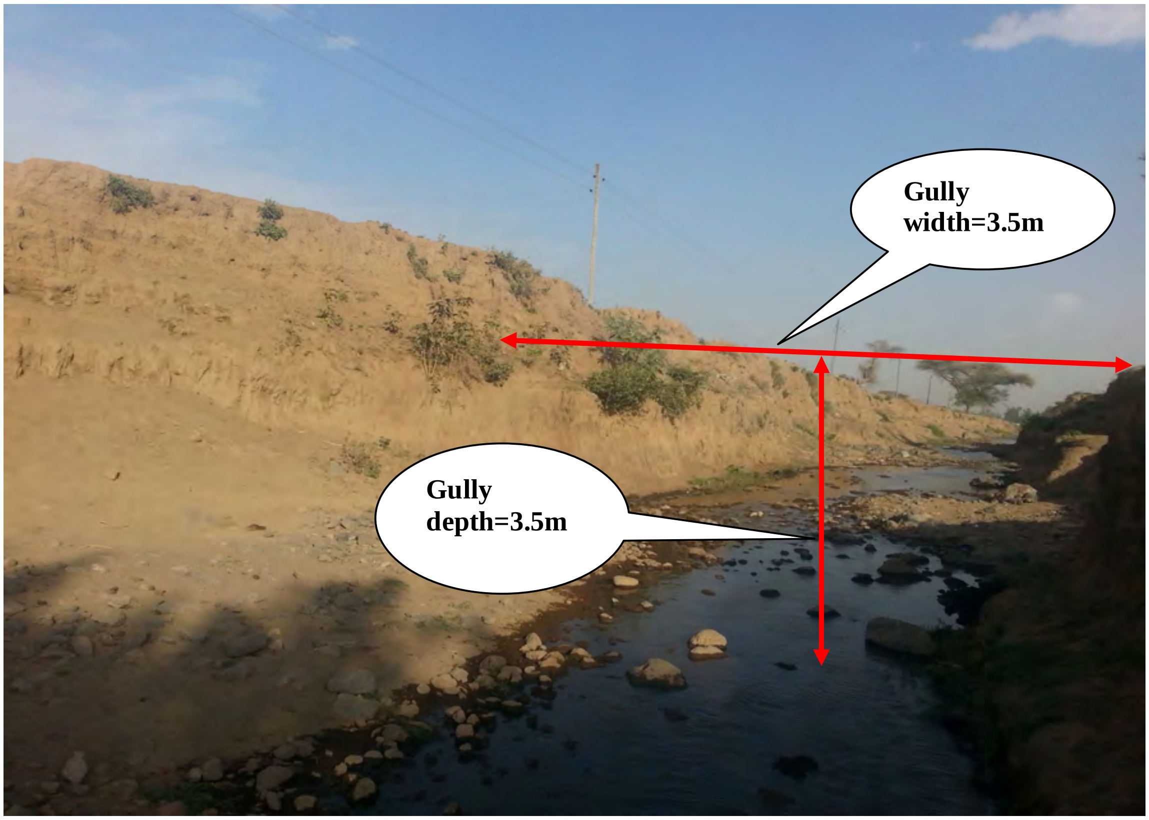


Photo 5.7 Actual condition of erosion gully site-4

<u>Erosion Gully site-5 (km 23+000 - km 23+200)</u>

The erosion gully in this section of the road is located on left hand sides of the road (LHS) has an offset of 1.5m. The gully has developed due to improper surface rain water management. The UTM coordinate of the erosion gully is E536209.456 and Northing 921373.721. The length of the gully is 200m and it is very close to the road and it is dangerous to the existing asphalt road. The soil type in gully site is lacustrine & alluivial formation of light brown silty sandy soil and it is classified as SM according to USC system. The slope of the road alignment is almost flat. The depth of the gully is reach up to 4m and its widths is about 3m, it is relatively an active and high hazard level.

Currently, the newly constructed protection Gabion wall at the side of the gully is starts to fail since the foundation is very loss and it is not embedded well.

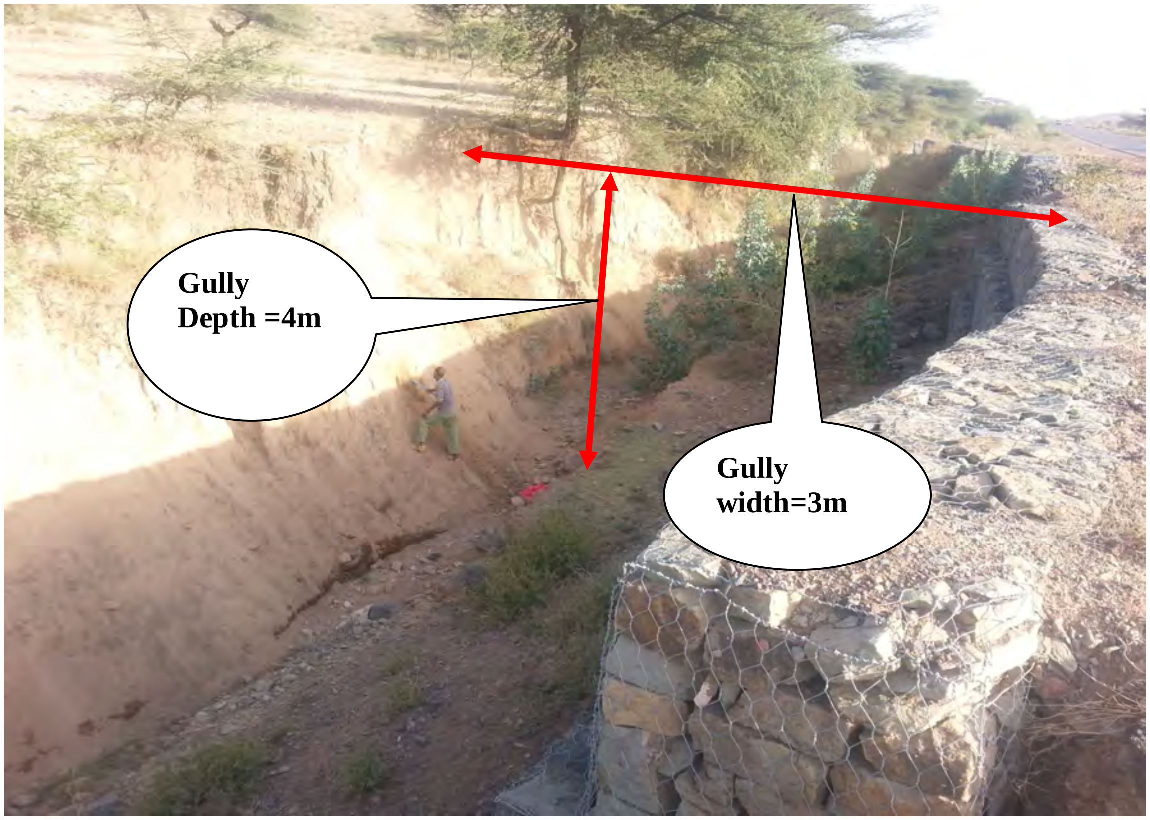


Photo 5.8 Actual condition of erosion gully site-5

<u>Erosion Gully site-6 (km 29+700 - km 30+700)</u>

The erosion gully in this section of the road is located on both side of the road. The gully in this section of the road is very minor and has an average depth of 1m and width of about 1m.The gully is developed due to improper surface rain water management. Besides, during construction period, it was not properly provided concrete or masonry ditch along the road stretch. The length of the gully extends to 1km and currently, it has less hazard level on the existing asphalt road.

The soil types found in the area are lacustrine & alluivial formation of whitish silty sandy soil and it is classified as ML according to USC system. The slope of the road alignment in this section ranges from flat to rolling. The UTM coordinate of the erosion gully is E533528.800 and Northing 915429.656

Photo 5.9 Actual condition of erosion gully site-6

Erosion Gully site-7 (km 32+600 - km 33+600)

The gully site is located very close to farm and cultivated land. The erosion gully in this section of the road is located on the left hand side of the road and is very close to the existing asphalt road. Thus, it is very dangerous to road. Similarly, formation of gully in this area of the road is associated to improper surface rain water management i.e, during construction period it was not provided appropriate concrete or masonry ditch along the side of the road. The length of the gully extends to 1km. The soil types found in the area are lacustrine & alluivial formations of greyish to whitish silty sandy soil and it is classified as ML according to USC system. The slope of the road alignment in this section ranges from flat to rolling. The depth of the gully reaches up to 4m and it widths is about 3m.

Currently, well developed erosion gully has significant affect on the newly constructed asphalt road thus, it is necessary to protected or rehabilitate the gully as early as possible. The UTM coordinate of the erosion gully is E531809.683 and Northing 912872.835

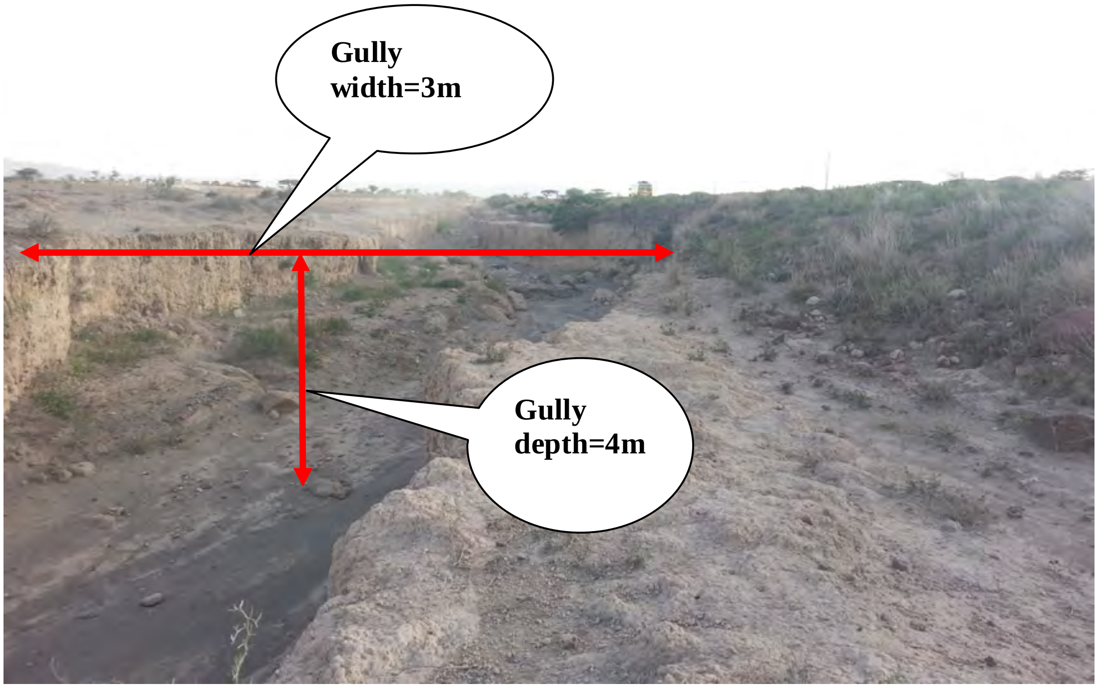


Photo 5.10 Actual condition of erosion gully site-7

Erosion Gully site-8 (km 35+000 - km 35+300)

The erosion gully in this section of the road is located on left hand side of the road (LHS) at UTM coordinate of E530245.867 and Northing 910961.896. Similarly, the cause of erosion gully in this area is mainly associated with improper surface rain water management i.e, during construction period it was not provided appropriate concrete or masonry ditch along the side of the road. Gully erosion within this section of the road has an average length of 300m. The soil types found in the area are lacustrine & alluivial formations of greyish to whitish silty sandy soil and classified as SM according to USC system. The slope of the road alignment has rolling topography. The depth of erosion gully reaches up to 5m and its width is about 3m.

Currently, the erosion gully will greatly affect the newly constructed asphalt road and away from it if immediate remedial measure is not provided the problem will worse.

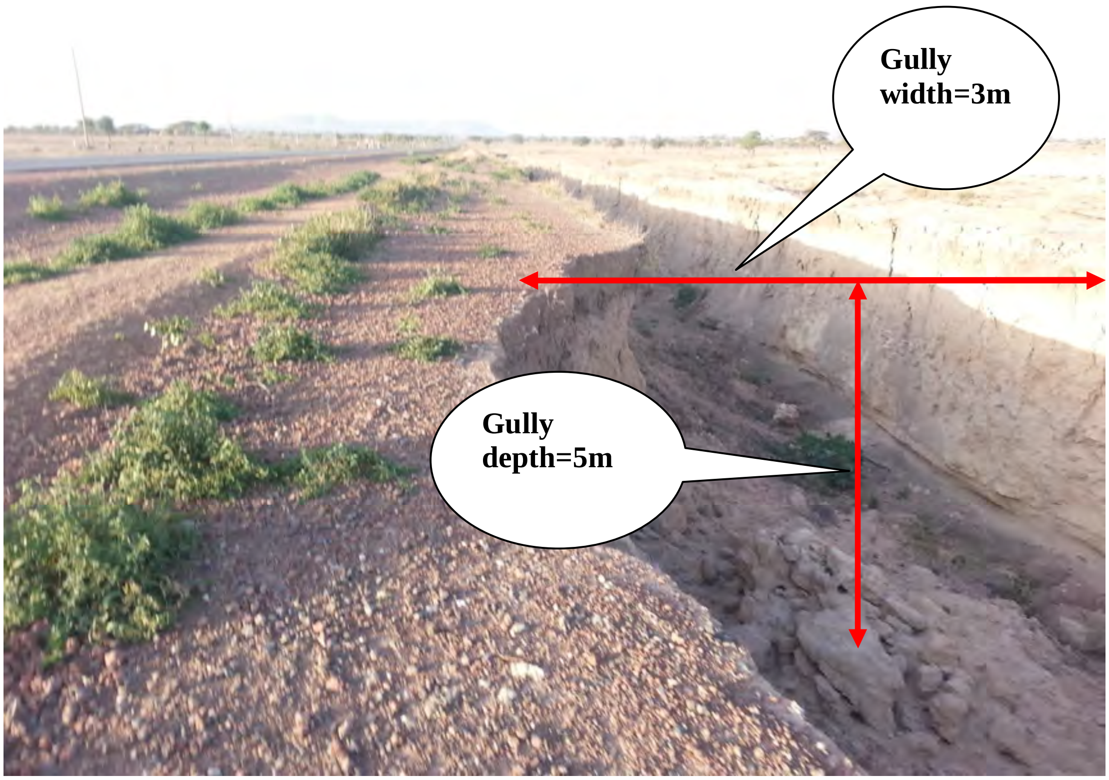


Photo 5.11 Actual condition of erosion gully site-8

Erosion Gully site-9 (km 35+800 - km 37+400)

The erosion gully in this section of the road is located on the left hand side of the road (LHS) and has UTM coordinate of E526341.532 and Northing 905731.702. Similarly, the cause of the gully in this area of the road is associated with improper surface rain water management i.e, during construction period it was not provided appropriate concrete or masonry ditch along the side of the road. Gully erosion present within this section of the road has an average length of 1600m. The soil types found in the area are lacustrine & alluivial formation of greyish to whitish silty sand soil and classified as SM according to USC system. The gradient of the road alignment in this section has rolling topography. The depth of the gully reaches up to 5m and its width is about 3m.

Currently, the erosion gully will greatly affect the newly constructed asphalt road and away from it if immediate remedial measure is not provided the problem will worse.

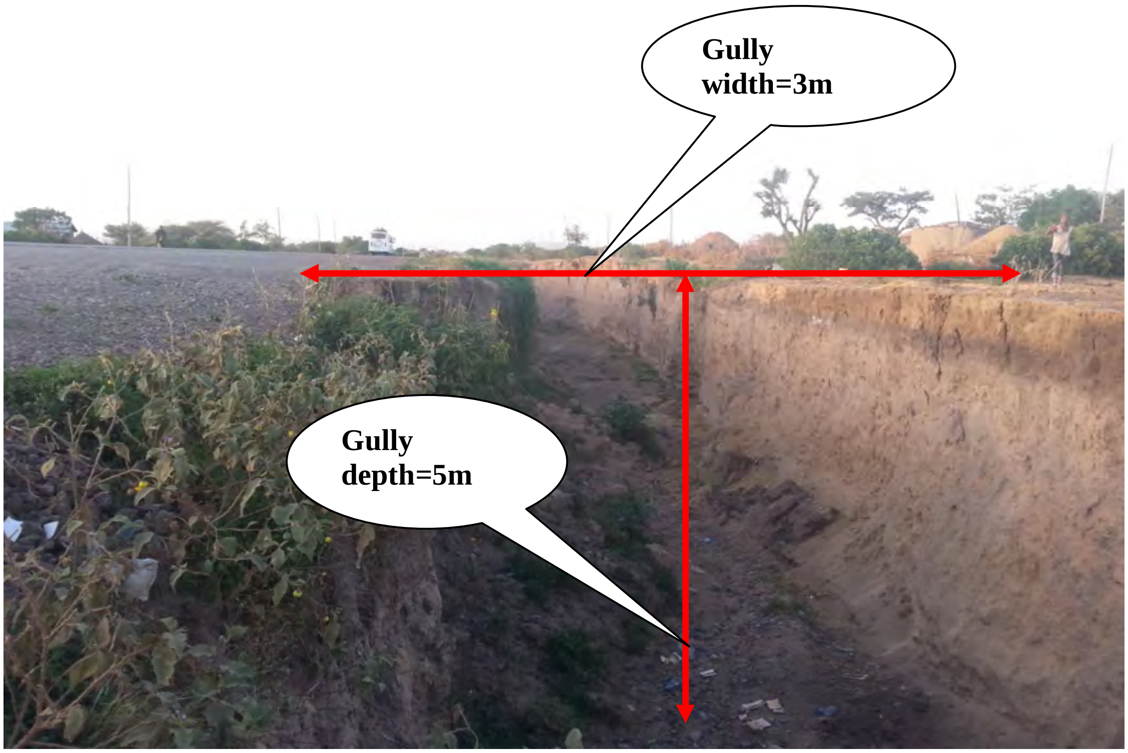


Photo 5.12 Actual condition of erosion gully site-9

Gully site-10 (km 38+200 - km 39+100)

The erosion gully in this section of the road is located on the left hand side of the road (LHS) and has UTM coordinate of E528439.437 and Northing 908266.671.The development of gully in this area is mainly associated to improper surface rain water management i.e, during construction period it was not provided appropriate concrete or masonry ditch along the side of the road by considering erodiablity nature of the soil. The average length of the gully has extends to 900m. The soil types found in the area are lacustrine & alluivial formation of yellowish to whitish silty sandy soil and it is classified as SM according to USC system. The slope of the road alignment in this section is rolling topography. The depth of the gully in this stretches reaches up to 10m and it widths is about 3.5m.

Currently, the erosion gully in this section of the road has greatly affected the newly constructed asphalt road and even the road cracks due to lack of lateral support thus, it needs immediate remedial measure on the erosion gully hazards in this section of the road. Besides, the village near to the gully area is also susceptible to land failure.

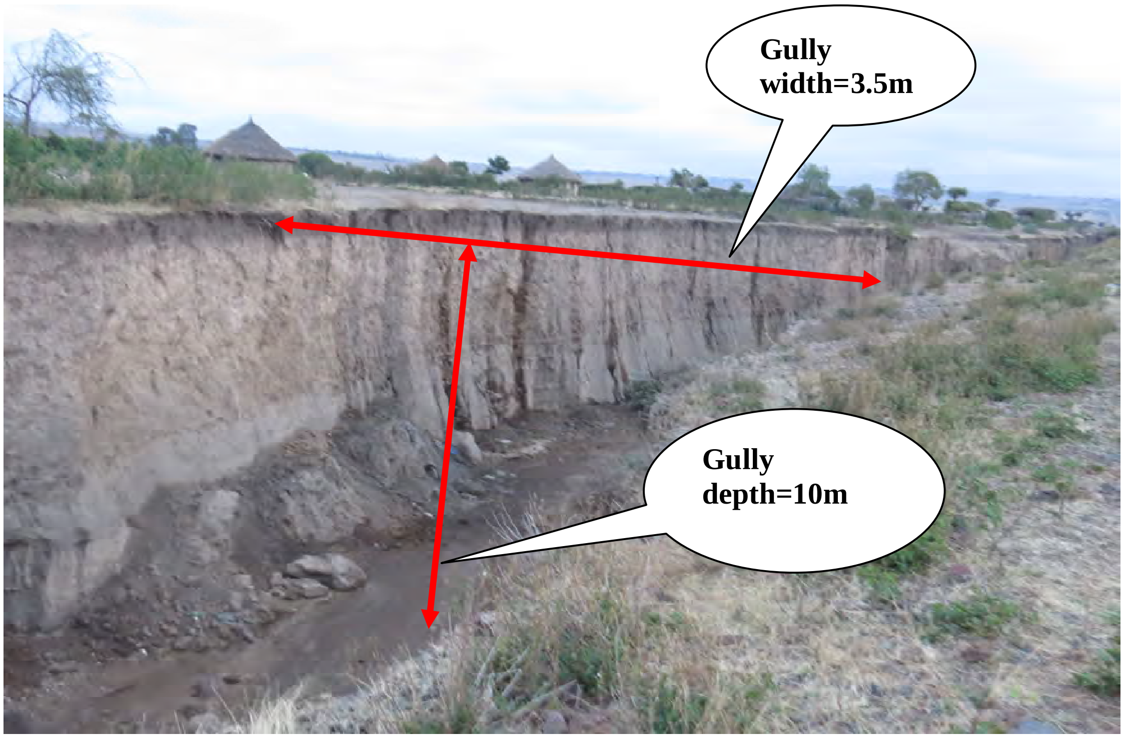


Photo 5.13 Actual condition of erosion gully site-10

Photo 5.14 Road starts to fail because of erosion gully.

Photo 5.15. Settlement near to the gully area susceptible to land failure.

<u>Gully site-11(km 41+000 - km 42+200)</u>

The erosion gully in this section of the road is located on left hand side of the road (LHS) and has UTM coordinate of E524802.098 and Northing 900206.895.The main cause of the formation of gully in this area is due to improper surface rain water management i.e, during construction period it was not provided concrete or masonry ditch by considering characteristics soil. The length of Gully erosion in this section has an average of 1200m. The soil types found in the area are lacustrine & alluivial formation of yellowish silty sandy soil (Tuff (Ash)).

The soil is classified as SM according to USC system. According to the terrain classification, the road alignment has rolling topography. The depth of the gully reaches up to 7.0m and its width is about 4.5m. Currently, the erosion gully has greatly affected the newly constructed asphalt road thus it needs immediate remedial measure on the erosion gully hazards.

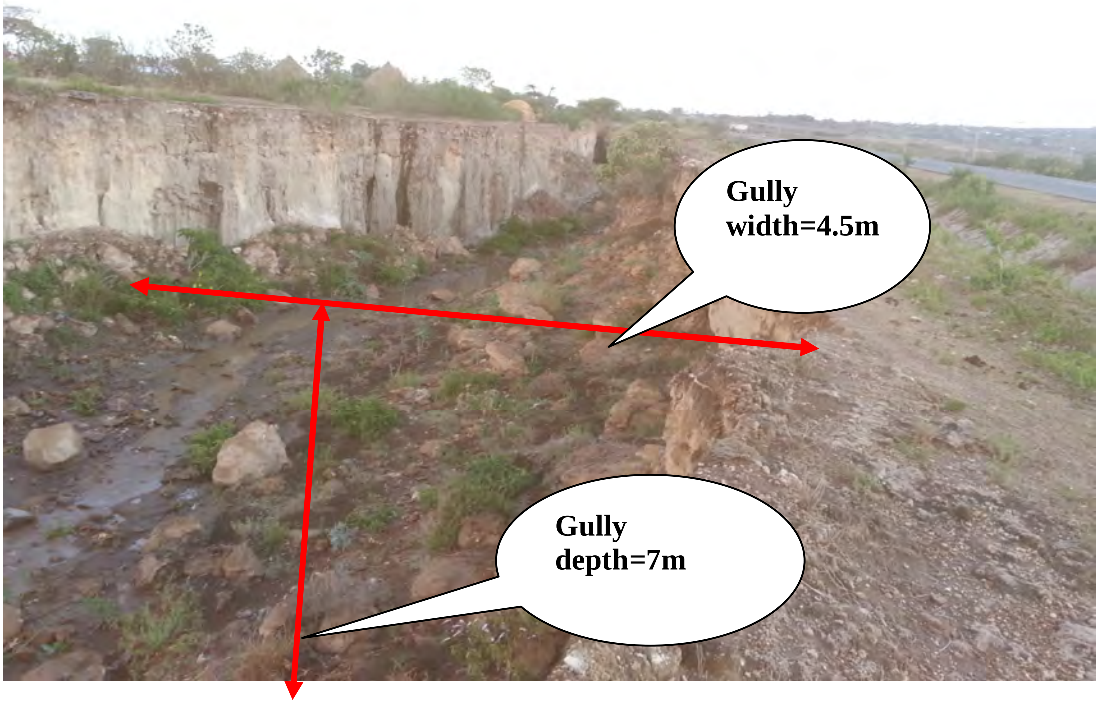


Photo 5.16 Actual condition of erosion gully site-11

CHAPTER-VI TEST RESULTS ANALYSIS AND EVALUATION

6.0 Laboratory tests and analysis

All the collected materials were submitted to the Beza consulting engineers Plc central laboratory for grain-size analysis test, Atterberg limit test, compaction test and chemical test.

6.1 Grain-size analysis

The distribution of different grain sizes affects the engineering properties of soil and it is one of the main tests to identify the erodiablity nature of the soil. The permeability and water holding capacity has totally depends on distribution of grain sizes of the soil matrix.

Samples collected from the study area were tested for sieve analysis test and hydrometer test. The hydrometer test analysis is important for evaluation of erodiablity nature of the soil since, it determine effective diameter (D10) of the soil and coefficient of uniformity (Cu) of the soil. Dissection

6.1.2 Results and discussion on grain-size analysis

Eleven (11) soil samples have been collected from all gully sites in the study area and it was analyzed for grain size distribution of the soil (i.e, sieve analysis and hydrometer analysis), in order to evaluate the erodiablity nature, permeability and water holding capacity of the soil.

Table-6.1 Percentage of grain size analysis of the gully sites.

Station from Adama town	**Gully site**	**Material classification.**			
		%Clay <0.002mm	**%Silty** 0.075mm-0.002mm	**%Fine sand** 0.4mm-0.075mm	**%Medium sand** 1.7mm-0.4mm
5+200	Gully site-1	4.00%	44.00%	32.00%	15.00%
8+650	Gully site-2	3.70%	37.30%	32.00%	18.00%
9+700	Gully site-3	6.00%	38.00%	31.00%	18.00%
15+150	Gully site-4	4.00%	36.00%	30.00%	20.00%
23+100	Gully site-5	2.00%	43.00%	30.00%	19.00%
30+000	Gully site-6	6.00%	44.00%	30.00%	12.30%
33+000	Gully site-7	3.00%	52.00%	21.00%	18.20%
35+200	Gully site-8	5.00%	40.00%	26.00%	20.00%
36+800	Gully site-9	6.00%	29.00%	40.00%	20.00%
38+500	Gullysite-10	4.00%	21.00%	55.00%	16.00%
41+500	Gullysite-11	2.10%	22.90%	45.00%	28.00%

The grain size analysis result of Table 6.1 shows that erosion gully sites 1,2.3.4,5,6,7 and 8 have high proportion silty soil than fine sand soil ,whereas erosion gully sites 9, 10 and 11 have contain more proportion of fine sand than silts. Besides, from the detailed grain size analysis it can be concluded that, there is very strong correlation between gully size and grain size proportion, where the large gully area is located on high percentage of fine sand soil area at gully site 10 and gully site 11.

Generally, grain size of the soil in the study area is more or less uniform and poor graded fine sand and silty soil. This implies that the particle size distribution does not extend over a wide range without excess deficiency in any particular size and this character makes the soils is highly erodible.

Gradation analysis of the soil in all erosion gully area shows that they are all strikingly uniform and poor graded. The combined percent passing curves of the units follow closely similar trends. The coefficient of uniformity (D60/D10) of soil in most gully sites are less than 4 which shows relatively minor variation in size distribution (uniform size), in the size range of silty to fine sand soil. Besides, it has been observed and concluded that, very strong correlation between cause erosion gully and uniformity of coefficient material, where coefficient of uniformity of the material has less than 4 will be susceptible to erosion gully.

The soil along the study area are largely susceptible to gullying since it is covered with uniform size of silty to fine sand soil (D60/D10 less than 4%).

Generally, silt and very fine sand textures soil are the most erodible and is easily dislodge since they are small in size compared to sands and do not bind together like clays (ÓGeen et al. (2006) ,Wischmeier and Smith (1978), uiker et al. (2001))

Table-6.2 Uniformity coefficient of the soil on the gully sites

Gully sites	**D60**	**D10**	**coefficient of uniformity (D60/D10)**
Gully site1	0.14	0.04	3.5
Gully site 2	0.1	0.04	3.0
Gully site 3	0.15	0.04	3.75
Gully site4	0.16	0.04	4.0
Gully site5	0.15	0.04	3.75
Gully site6	0.08	0.028	2.8
Gully site7	0.1	0.03	3.3
Gully site 8	0.12	0.03	4.0
Gully site9	0.14	0.03	4.6
Gully site10	0.15	0.04	3.75
Gully site11	0.15	0.04	3.75

Where, D60 is the diameter of the soil particles for which 60% of the particles are finer, and D10 is the diameter of the soil particles for which 10% of the particles are finer.

6.2 Atterberg limit tests

The Atterberg limit test determines that moisture content at which the soil will flow under its own height. It defines boundaries of several state of consistency of plastic soil. It is used to determine plasticity of soil.

6.2.1 Results and discussion of atterberg limit tests

Disturbed soil samples were collected from gully bed and gully walls at various depths ranging from 1.0 metres to 9.0 metres. All gully wall profiles were examined and a total of eleven (11) disturbed soil samples were collected from erosion gully sites at the study area and packaged in polythene bags for laboratory analysis.

From the plasticity test results shown on table 5.3 below, all the soil samples from the various gully sites have clustered within the ranged from NP to 2.5%, which is categorized as non plastic or low plastic, hence they are cohensionless. Therefore, the non cohesive nature of the soils in the area account for the formation of gully erosion since water flows through the soil with ease and moves the soil particles down slope with increase in velocity of motion of the water.

Table-6.3 Summary of Atterberg limits test of soil samples from Gully sites

Gully sites	Station	Depth (m)	Liquid limit	Plastic limit	Plastic index (%)
Gully site1	5+200	1.5m	NP	NP	NP
Gully site 2	8+650	2.0m	NP	NP	NP
Gully site 3	9+700	3.0m	31.5	29.8	2.0
Gully site4	15+150	3.0m	NP	NP	NP
Gully site5	23+100	3.0m	NP	NP	NP
Gully site6	30+000	1.0m	24.1	21.6	2.5

Gully site7	33+000	3.5m	23.3	21.4	1.9
Gully site8	35+200	4.5m	34.5	32.8	1.7
Gully site9	36+800	4.5m	NP	NP	NP
Gully site10	38+500	9.0m	NP	NP	NP
Gully site11	41+500	6.0m	NP	NP	NP

Table 6.4: Plasticity indices and corresponding states of plasticity

S/N	PLASTICITY INDEX%	STATE OF PLASTICITY.
1	0	Non plastic
2	1-5	Slight
3	5-10	Low
4	10-20	Medium
5	20-40	High
6	>40	Very High

Generally, the soil along the study area are non plastic or low plastic range and they are cohensionless. Therefore, the non cohesiveness in the area accounts for the formation of gully erosion.

6.3 Compaction test

6.3.1 Laboratory compaction test

Laboratory density test shows maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. One of the major reasons for carrying out compaction test on soils is to increase soil strength and to prevent seepage of water through the soil. Thus, water content and dry density affect soil strength, which will increase when the soil is compacted to a higher density, and when the soil looses water, dries and hardens.

6.3.1.1 Results and discussion on laboratory compaction test.

Eleven (11) disturbed soil samples from erosion gully sites of the study area were analysed for laboratory compaction test. The compaction tests result shows that the optimum moisture content ranges from 13.2% to 19.5%, while the maximum dry density ranges from 1.40g/cm^3 to 1.54g/cm^3 .The maximum dry density values (MDD) are generally low because the soil is loose and thus susceptible to erosion.

The low values of the dry density indicate that the natural deposits are loose and account for the high void ratio. This high void ratio of the soil will generate high flow velocities, high seepage pressure and high internal erosion potential.

Therefore, the low maximum dry density of the soils in the area account for the formation of gully erosion since this high void ratio of the soil will create high internal erosion potential.

Table-6.5 Summary of compaction test of soil samples from erosion Gully sites

Gully sites	Station	Depth (m)	(MDD)	(OMC)
Gully site1	5+200	1.5m	1.54gm/cc	18.02%
Gully site 2	8+650	2.0m	1.43gm/cc	19.3%
Gully site 3	9+700	3.0m	1.52gm/cc	16.8%.
Gully site4	15+150	3.0m	1.485gm/cc	17.1%.
Gully site5	23+100	3.0m	1.46gm/cc	18.1%.
Gully site6	30+000	1.0m	1.48gm/cc.	16.4%.
Gully site7	33+000	3.5m	1.43gm/cc	14.4%
Gully site8	35+200	4.5m	1.54gm/cc.	17.2%.
Gully site9	36+800	4.5m	1.40gm/cc	13.2%.
Gully site10	38+500	9.0m	1.51gm/cc	10.0%.
Gully site11	41+500	6.0m	1.47gm/cc	16.0%.
Average			1.478gm/cc	16.04%
Min			1.40 gm/cc	10.0%
Max			1.54 gm/cc	19.3%

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6.3.2 In-situ density test

In-situ density test was conducted at five gully locations where the problem is severe namely erosion gully site-5,erosion gully site-7,erosion gully site-8, erosion gully site-10 and erosion gully site-11, in order to check the level of compaction of the soil.

The in-situ density test was conducted with sand replacement method, i.e. which involves excavating a hole in the ground, filling the hole with calibrated sand using the sand cone apparatus, and then determining the volume of the hole based on the amount of sand required to fill the hole. After determining the wet mass of the soil removed from the hole and dividing it by the volume of the hole, the wet density (bulk density) of the material is determined. To determine the moisture content of the soil collected from the hole, sample has sealed in airtight polythene bag, labeled and sent to the central laboratory.

The dry density is then determined from the natural moisture content and wet density using the following relation,

$$\gamma_d = \frac{\gamma_{wet}}{1+w}$$

Where,

$\gamma_d =$ Dry density,

$\gamma_{wet} =$ Wet density

$w =$ Natural moisture content

Finally the level/degree of compaction of the soil is computed as the ratio of the field dry density to the laboratory maximum dry density.

$$\text{Level Compaction} = \frac{\gamma_d}{MDD} * 100$$

From the detail analysis result shown in the Table 6.6 below, it can be seen that the values of the field dry density are generally lower than the values for the laboratory MDD. Accordingly, the average level compaction of the soil ranges from 72.3% to 78.83%.

Table-6.6 Summary of level of compaction test analysis

Gully sites	**Station**	**Field dry density**	**Maximum laboratory dry density**	**Level of compaction**
Gully site 5	23+100	1.151	1.46	78.83
Gully site 7	33+000	1.088	1.43	76.08
Gully site 8	35+200	1.195	1.54	77.60
Gully site 10	38+500	1.093	1.51	72.34
Gullysite 11	41+500	1.086	1.47	73.85

The field density analysis result on Table 6.6 shows that, erosion gully site 10 and erosion gully site 11 are less dense as compared to other erosion gully section and due to this; size of gully in the area is higher than other gully area.

Besides, it has been observed that very strong correlation exists between gully size and level of compaction material, where the large gully are located on low level of compaction section.

Generally, the level of compaction along the area is significantly low since soil deposition is not well compact and it is loose. Thus, formation of soil in the area is one of the causes of erosion gully.

6.4 Chemical tests

During the 1960's Australian researchers recognized the presence of exchangeable sodium as a main contributing chemical factor to erosive soil behaviour (Aitchison and Wood,1965; Ingles and Wood, 1964a; Rallings, 1966). The percent of sodium has been expressed in the following equation:

$$\textbf{Percent sodium} = \frac{Na}{TDS} \times 100$$

Where, $TDS = Na^{+} + Ca^{+2} + Mg^{+2} + K^{+}$

High sodium content soils are subject to having free salts and leached by seepage or water and it will be easily eroded.

In the last fifteen years, some researchers particularly in Australia and the USA have shown that erosive nature of soil is strongly dependent on the pore and eroding fluid compositions, type and amount clay ,which cannot be measured by the soil mechanics tests commonly employed by the civil engineer.

The type of pore fluid is quantified by the relative amounts of the calcium, magnesium and sodium ions and expressed as the sodium adsorption ratio (SAR).

$$SAR = \frac{Na+}{0.5(Ca+Mg)} \textit{ with unit of } mg/L$$

At normal salt concentrations, soils with more than 60% of their total salts being sodium are erodible soil. Soils with less than 40 % of their total salts being sodium are usually not erodible soil. Soils with 40 to 60 percent sodium are transition in erosive characteristics. (Paul C. Knodel,1991)

The currently accepted method of evaluating chemical influence on erosive behaviour soil is shown on figure below.

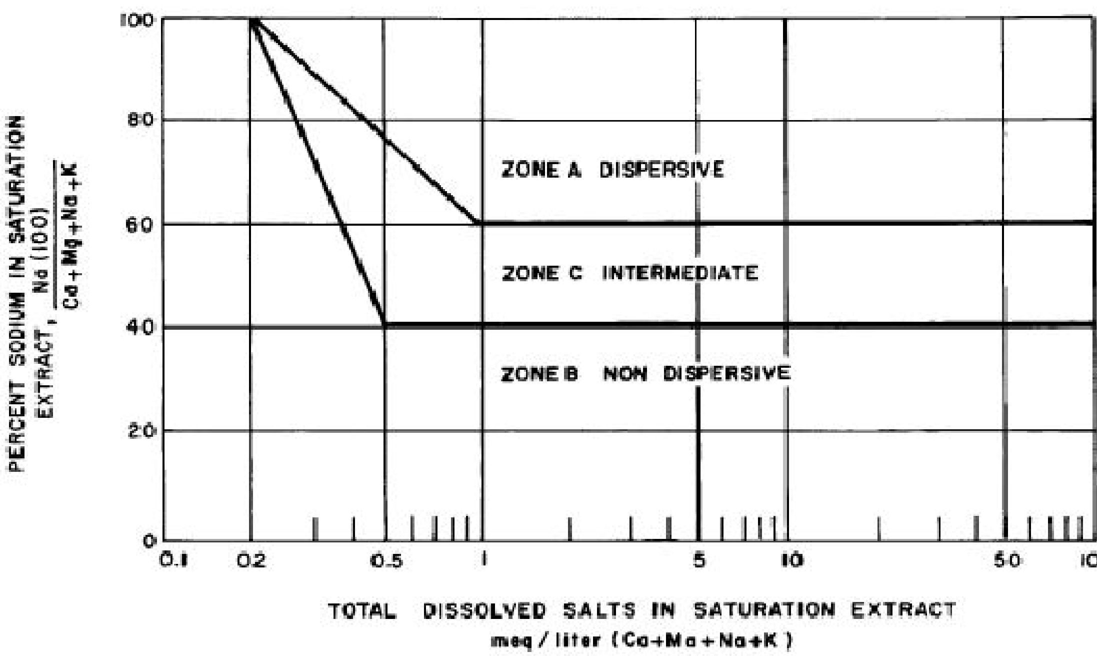

Figure-6.1, Erosive potential Vs TDS (Source; Paul C. Knodel, 1991)

6.4.1 Results and discussion on chemical test

Eleven (11) soil samples from erosion gully sites in the study area were collected and chemical tests on four metallic cations such sodium (Na), calcium (Ca), magnesium (mg) and potassium (K) have been performed in order to evaluate erosive nature of the soil regarding the chemical properties of soil. Chemical test result of all the collected sample from gully sites reveals that a percentage sodium (Na) is dominantly lies between 40%-60%, which is generally classified as Zone C intermediate erosive soil as shown in the figure 6.1 above.

Table-6.7 Summary of chemicals test of soil samples from Gully sites

Gully sites	**Station**	**Sodium (Na^+)**	**Cal-cium (Ca^{+2}),**	**Magnesium (mg^{+2})**	**Potassium (K^+)**	**TDS**	**% of sodium saturation**
Gully site1	5+200	33.2	31.5	10.5	5.7	80.9	41.03832
Gully site 2	8+650	33	29	9.5	4.6	76.1	43.36399
Gully site 3	9+700	31	27	8	5.5	71.5	43.35664
Gully site4	15+150	28	25	7.8	4.7	65.5	42.74809
Gully site5	23+100	34	29	11	6	80	42.5
Gully site6	30+000	24	27	8	3.1	62.1	38.64734
Gully site7	33+000	33	23	10	5	71	46.47887
Gully site8	35+200	28	21	6	3.1	58.1	48.19277
Gully site9	36+800	32	24	9	5.5	70.5	45.39007
Gully site10	38+500	36	23	7.2	3.4	69.6	51.72414
Gully site11	41+500	35	21	8.3	4.5	68.8	50.87209

Where, $TDS = Na^{+} + Ca^{+2} + Mg^{+2} + K^{+}$

The chemical tests were used to obtain degree of erodibity of the soil. From the summary of chemical test results shown in table 6.7, most of the soil samples from the gully sites along Adama-Iteya road section contain relatively high percent sodium concentration and hence it classified as Zone C, intermediate erosive soil.

CHAPTER-VII BIOPHYSICAL MITIGATION MEASURES

7.0 General

Stabilization of gullies involves the use of appropriate biophysical engineering measures. Once gullies begin to form, they must be treated as soon as possible, to minimize further damage and restore stability. There are a multitude of physical and biological techniques which can be applied for effective gully treatment. The combination of the two measures (biophysical approach) is the best and effective solution for gully control and gully rehabilitation for study area. The construction of physical structures will be followed by the establishment of biological measures. The natural regeneration which comes after the gullies are protected and enclosed should also be considered in the overall rehabilitation scheme.Therefore, attention must always be given to keeping the gully catchment well vegetated. If this fails, biophysical gully control measures which are executed with huge investment will fail as well. The choice of remedial measures also depend on the status of the gully whether young and actively eroding or mature and establishing naturally.Good engineering judgment is required while determining what measures to use and it would be a mistake to use expensive measures where more economical ones would do.

The gullies of the study area are unstable due to erosive nature of the soil thus; the remedial measures are based on the detailed engineering judgments and design.

7.1 Structural remedial measures

(a) Filling gullies by high plastic clay soil

Filling the gullies by high plastic clay soil is one of the best and economical remedial measures of the gully rehabilitation of the study area since it is abundant near the study area along the Iteya-Asela road section. The high plastic clay soil will normally stabilize non plastic silty sandy soil found in the gully area. Besides, it will also give full lateral support of the unstable gully wall. The Filling material should be properly compacted up to original level in order to provide good anchorage with in situ material. Generally, in the filling process the following needs to be considered:

a. the soil should be well compacted ;
b. the maximum thickness of compacted layer should be 200mm;
c. the compaction level should be above 95%;
d. the filling material should be high plastic clay soil;
e. the filling operation should be done before the rainy season; and
f. to protect it from erosion, growing crops should be planted or seeded immediately;

(b) Road side ditch (concrete or Masonry side ditch)

Road side ditches are used to intercept run-off and convey an adequate storm drain from carriageways and other areas. These ditches should be adequate capacity and shape for the design discharge. Ditches in the study area shall be constructed on the top of well compacted high plastic clay soil and it should be located where they can fully intercept the run-off flow from the natural catchments adjacent to the road.

Ditches shall be kept free of silt, debris, large amounts of vegetation, or any other material that restricts the flow of water. A complete cleaning shall be carried out at least once every year.

Joint separation is a common problem associated with concrete lined and masonry lined ditches. Once water gets under the concrete or masonry, the underlying soil is removed and deterioration may be rapid, so frequent inspection is vital (after any heavy rain) and fast repairs are necessary. If not immediately repair, it will cracks.

7.2 Vegetative control measures

Vegetative erosion gully control is an inexpensive and permanent protection. Grasses and vegetation slow down the velocity of the runoff and cause deposition of soils transported. Vegetation can be established in a gully by natural recovery or use of planting materials,where establishment of natural vegetation is too slow to cope with erosion.

The establishment of vegetation either naturally or artificially has to contend with a hostile environment. The type of planting material to be used should be seriously considered based on the specific situation of the gully. Besides, proper assessment of the soil and moisture conditions should be made in the gully area and gully offset zone.

Practically speaking, type of soil and hydrological characteristics of the area determined the type of species of grass, shrubs/bushes and trees to be planted.

Vetiver grass is one of the best species grass for erosion protection and it is unique in that it can thrive in arid and humid conditions, growing under some extreme soil,conditions and survives wide temperature ranges. This grass should be planted on both sides of the road side ditch

Vetiver grass has good morphological, physiological and ecological characteristics including its tolerance to highly adverse growing conditions.This provide a unique engineering tool for land stabilisation, soil erosion control and thus it is recommended erosion protection for study area ,Adama-Iteya road section.

Photo 7.1 Vetiver grass (Source; internet)

Photo 7.2 Vetiver grass for erosion protection (Source; internet)

Figure-6.2 biophysical mitigation measures recommends for erosion gully on study area.

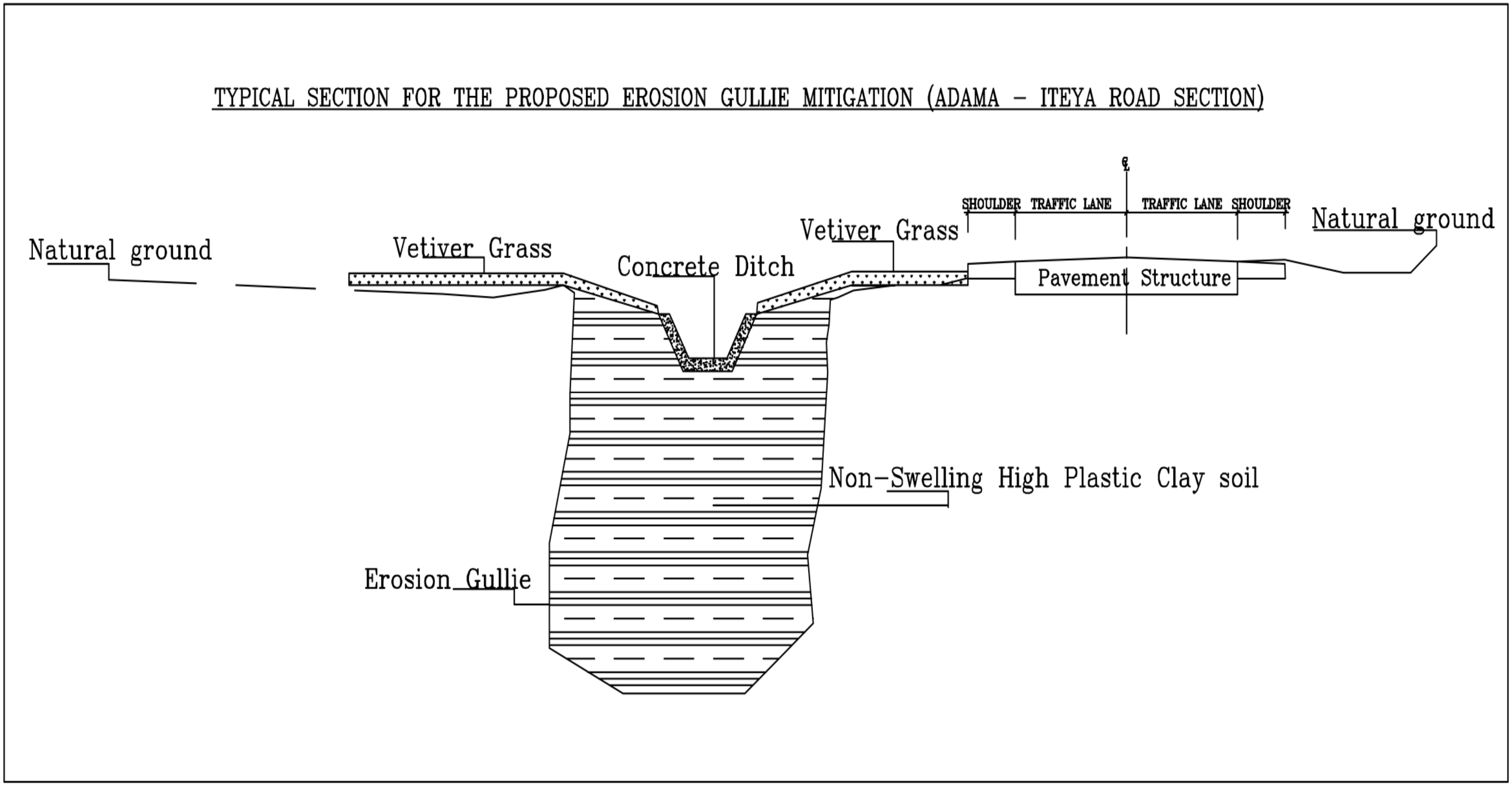

Table-6.7 Biophysical mitigation measure to be applied at each gully site

Gully site	Extent of hazard	Biophysical remedial measure considering actual site condition.
Gully site-1	Low hazard level	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ Planting Vetiver grass on both side of the road side ditch.
Gully site-2	Low level hazard	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch
Gully site-3	High level hazard	❖ properly divert irrigation water of wanji sugar farm ❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch
Gully site-4	high hazard level	❖ properly divert irrigation water of wanji sugar farm ❖ filling gully by high plastic clay soil up to original level;

		❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch
Gully site-5	High hazard level	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch
Gully site-6	Low level hazard	❖ filling gully by high plastic clay soil up to original level; ❖ planting Vetiver grass on both side of the road side ditch
Gully site-7	High Hazard level	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ Planting Vetiver grass on both side of the road side ditch
Gully site-8	high hazard level	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch
Gully site-9	High hazard level	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch

Gully site-10	High Hazard level	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch
Gully site-11	High Hazard level	❖ filling gully by high plastic clay soil up to original level; ❖ proper road side ditch is construction on the top of fill material; ❖ planting Vetiver grass on both side of the road side ditch

CHAPTER-VIII CONCLUSION AND RECOMMENDATIONS

8.0 Conclusion

Erosion resistance of soil along the Adama-Iteya road section has been studied. Besides, biophysical mitigation measure is recommended to control and manage gully erosion hazard in the area. In this research available geotechnical, morphological, meteorological, bio-resources and other pertinent data relating to the site have been investigated.

According to informants, erosion gully has formed immediately after the completion of Adama-Asela asphalt road project and the cause of the problem may by concentrated runoff flow from the road system to the less erosion resistance soil and gullies have been expanded continuously since that time. Besides, proper road side ditch (concrete or masonry) was not provided along the stretches considering the poor erosion resistance soil.

Based on the findings from the studies, the following conclusions were drawn:

- ❖ The erosion gully in the study area was initiated by improper termination of the storm drain of the area and concentrated runoff from the road system to the poor erosion resistance soil.
- ❖ The abrupt formation and expansion of the gully is due to the absence of appropriate side drainage facilities along the road side alignment, which is major gaps and limitation of ERA design manual where the manual recommends side drainage facilities only by considering the terrain and hydrological classification of the area .However, it should be considered the geotechnical properties of the material since it is one factors that determine erodiablity nature of the soil.
- ❖ The results obtained in this investigation so far, (Atterberg limit, sieve analysis, compaction test and chemical test) show that the soils in the study area are cohensionless, losses, erosive nature and non-plastic; hence the area is highly susceptible to water erosion.

- From the detailed sieve analysis, soil along erosion gully area is classified as SM and ML according to USC system.
- The gully erosion along the study area has depth varying from 1m to 10m, width varying from 1m to 4.5m and length has varying from 150m to 1600m.
- The size and extent of gully hazards at Gully site -10 and gully site -11 is higher than other gully sites since it has high erosive nature (i.e, the non plastic, low density ,high sodium saturation content and high fine sand proportion of the soil).
- According to the gully classification, most of the erosion gully sites are classified as medium to large.
- Most of the identified gullies are very close to the existing asphalt road and thus,it is dangerous for the existing Adama-Asela asphalt the road.
- Biophysical mitigation measure is recommended to control gully erosion hazard in the area

8.1 Recommendations

Erosion gully should be controlled and stabilized with properly designed mitigation measure so that it reduces expansion rate. Hence, careful attention in selection and designing should be given.

Arising from the conclusion the following recommendations can be made;

- It is recommended that, the erosion gully along the study area is mitigated by filling the gully with high plastic clay soil and planting Vetiver grass on both of the ditch. The borrow material for filling (high plastic reddish clay soil) is abundantly available near to the study area i.e, around Iteya town. Thus it is economical than any other stabilization measure.

- Proper termination of road side drainage structures (concrete or masonry ditch) should be provided, this may convey an adequate storm drain from carriageways and other areas. Ditches shall be kept free of silt, debris, large amounts of vegetation, or any other material that restricts the flow of water. A complete cleaning shall be carried out at least once every year.

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