Jimma University

School of Graduate Studies

Jimma Institute of Technology

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Highway Engineering Stream

Assessment on the Impacts of Road Geometry and Route Selection on Road Safety: A case study on Mettu-Gore Road

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Highway Engineering.

By: Alamirew Mulugeta Tola

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ABSTRACT

Traffic accident becomes a growing problem globally. Currently traffic accident is one of the problems on Mettu-Gore road. This study assessed the impacts of bad geometry and route selection on road safety and setting out the possible safety countermeasures: with particular focus on Mettu-Gore road.

To meet the objectives of this research, the researcher has given attention to collect accident data, road data, traffic data, and geographical and land use Maps from Mettu and Gore town police commission, ERA (Ethiopian Roads Authority), Ethiopian Mapping Agency, and field observations. Identification and prioritizing of accident Hot-Spot locations were done by using ArcGIS and the results respectively showed that; "Arat-kilo" square in Mettu town, "S-curve" geometry in Gore town, "Bechano and Gagi", and "Sor-bridge" area are among the prioritized accident Hot-Spot locations. Geometric characteristics of the existing road were evaluated according to design standards specified by ERA, 2013 for safe governing values of the Geometric parameters.

Thus, all defective segments of the road due to Geometric characteristics were identified and marked to their existing locations on the digitized Map of the road in order to assess the contributing factors of Geometric characteristics specifically, on the accident-intensive prone locations of the road. Moreover, the study confirmed that on the identified accident Hot-Spot locations bad Geometry and route selection such as; radius of a curve and gradients are the main factors causing road safety problem thus, affecting the socio-economy of the towns.

Upgrading safe alternative routes and roundabout, clearing obstructions from visible sight lines at curves, construction of transverse ramps and fencing guard rails, and provision of traffic signal and signs are among the major recommended safety counter-measures of the study for the accident Hot-Spot segments of the road.

***Key words:** AADT, Accident, Grade, Radius of a curve, Sight distance, and Superelevation.*

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ACRONYMS

AACRA	*Addis Ababa City Road Authority*
AADT	*Annual Average Daily Traffic*
AR	*Accident Rate*
CSR	*Complete Spatial Randomness*
DC	*Data Collector*
ERA	*Ethiopian Road Authority*
ESRI	*Environmental System Research Institute*
GIS	*Global Information System*
HSIS	*Highway Safety Information System*
I/A/B	*Ilu Abba Bora*
JIT	*Jimma Institute of Technology*
Lat.	*Latitude*
Long.	*Longitude*
LW	*Lane Width*
LOS	*Level of Service*
RSDP	*Road Sector Development Program*
RTA	*Road Traffic Accident*
TIN	*Triangulated Irregular Network*
WHO	*World Health Organization*
UNECA	*United Nation Economic Commission for Africa*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

It is difficult to imagine of a situation where transport does not play a vital role in the life of an individual. It is logical and accepted to say that of all modes of transportation, road transportation is easily accessible to people. That is because of its advantages of flexibility, most competitive price, and door-to-door operation while compared to other modes of transportation. In Africa over 80 percent of goods and peoples are transported by roads, where as in Ethiopia road transport accounts for over 90 percent of all the Inter-Urban freight and passenger movement in the country (Haile, 2014).

"Road crashes are a worsening global disaster destroying lives and livelihoods, hampering development and leaving millions in greater vulnerability". (World Disaster Report, 1998).

Road traffic accidents (RTAs) constitute major health, economic, and developmental challenges of developing countries, especially adversely affected sub Saharan African Countries (Chen, 2009). In 1999, for instance, 750,000-880,000 people died in road traffic crashes of which, about 85% of these occurred in developing countries (Downing, Jacobs, Aeron-Thomas & Sharples, 2000) and in 2002 an estimated 1.2 million people were killed in road traffic crashes (WHO, 2009; UNECA, 2009); 90% of the traffic crashes occurred in low and middle income countries of which Sub-Saharan countries had faced the highest fatality rate (28.3 per 100,000 population), which is substantially higher than any continent in the world (Peden et al, 2004).

In economic terms, road traffic accidents have negative impact on the gross national product of different countries. For instance, according to World Health Organization, the cost of road crash injuries is estimated at roughly 1% of gross national product in low-income countries, 1.5% in middle-income countries, and 2% in high-income countries (WHO, 2004). Thus, RTAs are influencing social, economic, and politics all over the world. The loss of lives, damage to property, and the sorrow it leaves in human mind are profound though the degree varies (Peden et al, 2004). Geographically, 35% to 70% of all crashes occur in urban areas and urban road networks contribute to a significant proportion of countries' national road traffic crash problem (Downing et al, 2000). These make traffic accident the third major killer next to HIV/AIDS and TB (Peden et al, 2004).

In Ethiopia, the situation has been worsened as the number of vehicles has increased consequently due to increased traffic flow and conflicts between vehicles and pedestrians (Guyu, 2013). Despite government efforts in the road development, road crashes remain to be one of the critical problems of the road transport sector in Ethiopia (UNECA, 2009). Losses of many lives and destruction of property are the consequences of road traffic accidents every year. The Country has experienced average annual road accidents of 8115 over the past 11 years (CSA, 2000/01-2010/11). Currently, the financial estimation of property damage (excluding human deaths and injuries), is more than 15 million Ethiopian birr annually on average (CSA, 2000/01-2010/11). According to UNECA (2009), the rate of traffic accident death in 2007/08 was 95 per 10,000 motor vehicles, which put the country on the extreme high side of the international road safety scene (UNECA, 2009). Moreover, in the same year, the police report revealed that 15,086 accidents caused results the losses of 2,161 lives, and over 82 million Birr, equivalent to US$7.3 million estimated cost of property damaged. (US$1 =11.34 Ethiopian Birr).Also, up to 2005/06, traffic accidents and fatalities increased at 17 % and 10 % per year respectively although there is a decreasing trend in this respect. There were 2.84 per 100,000 population's that had road accident fatalities in the same year (UNECA, 2009).

Consequently, Mettu-Gore road which is found in Ilu Abba Bora zone of Oromia region is the major area where accidents and traffic safety problems are observed.

Therefore, understanding the contribution of road geometry and route selections on road safety on Mettu-Gore road and identifying *black spots* has paramount importance to implement remedial safety procedures for these severer problems. In light of these, in this research it is tried to assess and avail information on the problematic segments of the road due to bad road geometry and route selection.

1.2. Statement of the problem

Nowadays, it is normal to see safety problems on Mettu-Gore road after the upgrading of the main road from gravel to pavement. The observed accident rate is increasing from the traffic opening of the upgrading. Geometry and route selection were the main contributing factors for those problem on the road in addition to other factors.

For instance, a place locally named “Arat-kilo” square is a segment with an observed geometric and route selection problems.

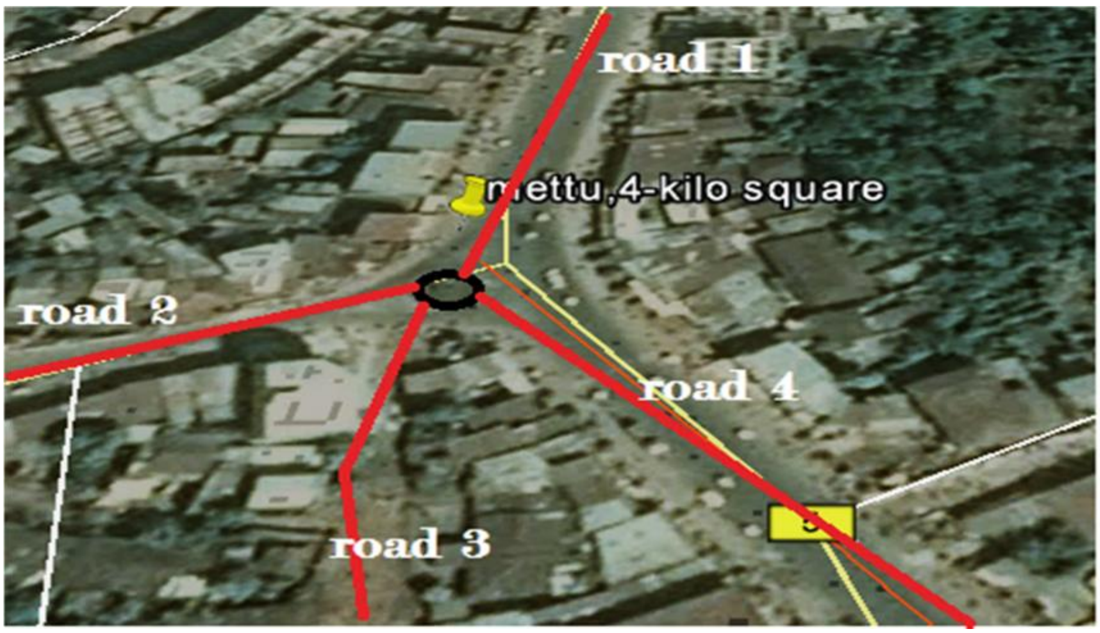


Figure 1.1: Image of Arat-kilo, Mettu (Source: Google Earth)

As it is shown in the image, the place is geometrically identified as an intersection connecting four segments of the road i.e. Road-1 (the main road from Bedelle), Road-2 (road from Mettu University), Road-3 (local road joining the main road afterward) and Road-4 (the main road from Gore). This junction has a roundabout as shown in the image, but a roundabout with no rotary and a roundabout with small weaving length and width which makes difficult for track trailers to rotate. Vehicles passing “Arat-kilo” square never permitted to rotate the roundabout. For instance vehicles coming from road-1 passes without approaching and without rotating a roundabout and all the junction forming road segments do the same. This makes higher opportunity of car-to-car collusion since vehicles from road-1 and road-4 are meeting at a junction.

Also this place may have been observed with a problem of vertical grade. Road-4 coming from Gore joining "Arat-kilo" square has an average grade of greater than 9% which may cause traffic accidents and road users discomfort near the junction due to high gradient. The figure below shows this road with rough vertical profile from Google earth.

Figure 1.2: Image of the road from Gore joining Arat-kilo square (Source: Google Earth)

So it is logical to think that the society of Mettu and Gore town would like to see this problems solved by making a deep study on the problems and coming up with a solution in correlation with ERA Road Safety Audit. Hence, ERA and local government need to assess the effects of bad geometry and route selection on road safety in the town. Additionally, the local government must have to collaborate with traffic polices in order to regulate the situation on the defective segments of the road. Otherwise, it would be practically impossible to have normal traffic flows in the road since the existing road is highly exposed to accidents and road user's comfort problem.

1.3 Research Questions

- ✓ Does the problem of geometry? And route selection exists on the road and what were there impacts on road safety?
- ✓ Where RTAs were highly occurred?
- ✓ What are the safety procedures need to be applicable on the *black spot* zones?

1.4. Objectives of the study

1.4.1. General Objective

- The general objective of the study was to assess the impact of road geometry and route selection on road safety.

1.4.2. Specific Objectives

To accomplish the stated general objective, the following specific objectives were compound:

- ✓ To check the existence of geometric and route selection problems on the road referring to ERA Geometric Design Manual and evaluating their impacts on road safety.
- ✓ To identify accident intensive prone (black spot) locations of the study area.
- ✓ To set safety procedures that are applicable in the study area.

1.5. Significance of the Study

No significant studies were undertaken to show the effects of road geometric design and route selections on road safety and identification of black spot areas on Mettu-Gore road. Hence, the current study has the importance of

- ✓ Adding knowledge on the gap created with safe geometric design and As-built Mettu-Gore road.
- ✓ Setting applicable safety counter measures on the problematic segments of the road due to bad geometry and route selection.
- ✓ Offering information regarding the basic cause of road traffic accidents on Mettu-Gore road and on the locations of accident intensive prone.

- ✓ Providing policy makers, researchers, institutions etc. with adequate, and reliable data so as to implement feasible and appropriate safety solutions to reduce the road traffic accidents.

1.6. Limitation of the study

For the sake of making the research manageable, this study has been limited in scope, time, and coverage areas since the contributing factors to road safety touches a lot area and wider perspective. Accordingly, to conduct the research on the causes of Road traffic accidents and identification of black spots on Mettu-Gore road would be comprehensive and it needs a huge amount of money and long progress. Hence, the study has been limited to road safety problems due to bad geometry and route selection on Mettu-Gore road and setting out safety procedures that are applicable on the identified accident intensive prone locations. Moreover, the researcher has considered very limited representative of sample respondents in interviews in order to supplement the data collected from document reviews. Besides, possible efforts were exerted to overcome the above constraints and to accomplish the desired work successfully.

1.7. Organization of the study

The Study is comprised of five Chapters. The first chapter presents background of the study, objectives of the Research, significance of the Study, limitation of the Study, and organization of the Study. The second chapter comprises review of related literature, review of literature mainly dealing with different citations of journal articles, books, brochures, reports, strategies, guidelines, and other similar sources employed to support this research. Chapter three is on research methodology, study design, data collection sources and type of data analysis. Chapter four consists of data analysis and data interpretations of the Study. Chapter five consists of the conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

The literature reviewed in this report focuses on the objectives presented in Chapter 1. The literature search was performed using libraries and Google's search engine. The key words used are: accident, grade, horizontal and vertical alignment, road safety, and sight distance.

2.2. Global accident statistics

It is a fact that over millions of people are killed each year due to road traffic accidents. Every day, thousands of people are killed and injured on road by traffic accident. It is the leading cause of death, disabilities and hospitalization, sever socioeconomic costs, across the world. In 2002, an estimated 1.18 million people died from road traffic crashes: an average of 3,242 deaths per day (WHO, 2004). The WHO Global Burden of Disease study, predicts the following changes from 1990 to 2020 G.C. (Source: WHO, 2004)

- ✓ Road traffic injuries will rise in rank to sixth place as a major cause of death worldwide.
- ✓ Road traffic injuries will rise to become the third leading cause of DALYs lost.
- ✓ Road traffic injuries will become the second leading cause of DALYs lost for low-income and middle-income countries.
- ✓ Road traffic deaths will increase worldwide, from 0.99 million to 2.34 million (representing 3.4% of all deaths).
- ✓ Road traffic deaths will increase on average by over 80% in low-income and middle-income countries and decline by almost 30% in high-income countries.
- ✓ DALYs lost will increase worldwide from 34.3 million to 71.2 million (representing 5.1% of the global burden of disease).

In the world, nearly half (46%) of all RTA involve pedestrians, motorcyclists and cyclists (vulnerable) road users (WHO, 2004). The economic consequences due to RTAs have been estimated 1% of GNP in developing country, 1.5% in countries in economic transition, and 2% in highly motorized countries (WHO, 2004). In 2004, (WHO) RTAs were the 9th leading cause of death and the study forecasts that at current rates by 2030, the RTAs will rise to 2.4 million death each year and will be the third leading cause of death overtaking diabetes and HIV.

According to WHO, 2008 study on Global Burden of Disease, in 2004, RTAs injures affect all age groups, but their impact is most striking among the young. The features of on people are descended. RTAs have become the second leading cause of death worldwide for age 5 to 14 year the leads cause of death for the age's 15-29 years, and the third leading cause of death among the people whose is age 30 to 44 (WHO, 2008).

Men, women, or children walking, biking, or riding to work, school, playing in streets or setting out long trips are never having guarantee to reach destinations or to return home safely (WHO, 2004).

In 2005, World Health Organization (WHO) reported that traffic accidents had taken the second leading cause of death for the people whose age is 5 to 14 next to lower respiratory, the first cause for death of people whose age is 15 to 19, and the third leading cause of death for the people whose age is between 30 to 40 next to HIV/AIDS and Tuberculosis. World health organization reported that in 2000, l.26 million deaths occurred worldwide (20.8 per 100,000 people). From this, 90% of deaths is in low middle-income countries with south East Asia and Africa. In 2010, from the esteemed 1.24 million lives were lost as the result of RTAs, of which 80 % was in middle-income countries where 27 % of the world's population lives, but where only half of the world-registered vehicles are owned and driven (WHO, 2012).

In Africa, Ethiopia has been found one of the countries with the highest rate of fatalities per vehicle of accident in the world .According to the Ethiopian Government reports, at least 70 people die in every 10,000 vehicle- accidents per year.

2.3. Conceptual frame work on factor that cause Road safety problem

The causes of traffic accidents are: road geometry, the driver, the road user, vehicle, and environmental factors. According to Ruman, K.(1985), studies from the American and British reports; accidents occurred 57% due to driver factor, 27% due to combined roadway and driver factor, 6% combined vehicles and deriver factor ,3% a combination of the road, drivers, vehicles ,2% vehicle factor ,1% combined of vehicle and road user factor. Road network in Africa is expanding fast, and similarly maintenance standards are improved resulting the safe standard of the road. However, in Ethiopia, due to lack of trainings on the subject area, contribution of roads and environment to traffic accidents are underestimated.

A lot of literature founds that to address the problem of road traffic accident rate estimation, and the identification various causes of this accident rate.

Joshua and Garber (1990) applied multiple linear and Poisson regression in order to estimate road accident rates using AADT and geometric independent variables. Jones and Whitfield (1991) used Poisson regression with data from Seattle to identify the daily characteristics (traffic, weather, etc.) which affects accident rates. Miaou et al. (1992) applied Poisson regression on traffic data from 8779 miles of roadway from the Highway Safety Information System (HSIS) to establish quantitative relationships between road accident rates and highway geometric characteristics. Their results indicate that a substitute measures for mean absolute curvature (radius of a horizontal curve) and mean absolute grade (tangent slope of vertical curve) are the most influential parameters of geometric characteristics on road safety.

The effects of road geometry and route on accident rates are an ongoing argument amongst academic researchers and transportation bodies. Much road safety audit report recommends that road geometric characteristics affects road safety in addition to ‘driver error’. For example, French DoTs have shown that consistent road geometry and appropriate signaling ease the task of the driver therefore dramatically reducing the risk of driver error. As a result, many road authorities have recommended the removal of unnecessary bends and the lengthening of curves, thus easing the demands of the driver.

However, British transportation design reports do not agree with the suggestion of road geometry being a major issue involved in accidents rates. A number of studies carried out by British transportation bodies on rural roads aiming to correlate personal injury and accident rates with horizontal curvature and suggest that accident rates are unlikely to be affected by moderate changes in road design parameters. These studies estimate road layout as a contributing factor in only a small number of accidents. Furthermore, the effects of layout parameters such as gradients, sight distance in combination with horizontal curvature were necessary in order to show slight increases in accident rates. Thus reflecting the influence of factors other than road layout.

Although the French transportation body has opposing views as to whether or not road geometry is a significant cause of road accidents, it is widely accepted in literature that elements of road geometry such as horizontal curvature are a significant contributing factor to accident rates. This is illustrated in early work by researchers Cairney P. & McGann, A. (2000), Persaud, B, AR Retting and Lynon, C. (2000) and Torbic, D. J. etal (2004) who all report increases in crash rates as a result of road curvature. In a report by Cairney et al (2000) on the relationship between crash risk and rural highways in Australia, the authors conclude that single vehicle crashes increase as curvature increases particularly at curvatures below radius lengths of 200m. Furthermore, Persaud et al (2000) reported a similar trend in crash rate increases on curved roadways in America. These studies also argue that crashes on bends tended to be more severe than that of straight roadways, with results of up to three times the amount of fatalities occurring on road bends. In addition, road reports by Torbic et al (2004) present similar approximations of accident rates in their Guide for Reducing Collisions on Horizontal Curves. The authors reported a crash rate for horizontal curvature is three times than that of straight/tangent sections of roadway and approximate that 76% of fatal crashes are single-vehicle run-off-road collisions related to road curves.

Due to the relatively small sample size, conclusions drawn from the accident data can be inconclusive due to statistical noise. However, examining the aforementioned reports from larger populations and transportation bodies helped reduce the rarity of such data and provided a better understanding of crash rates with respect to curvature. For example, findings by Torbic et al (2004) were the result of analyzing up to 43,000 fatalities in 2002 alone, a number that would take a country the size of Ireland over 200 years to amass (based on a current average of 189 fatalities per year).

By examining the 'relationship' between the roads geometric elements and contributing factors to road safety further findings can be derived. Variations can be seen in accident rates when road elements like shoulder width and lane numbers are changed supporting further the argument that road geometry characteristics do affect road safety. For example, studies by Othman, S., Thomson, R. & Road, S.N. (2009) suggests that curves with high accident rates can be improved by restricting lane changing maneuvers. Ahmed 2011 supports this argument by stating that sites with higher degrees of curvature, wider medians (narrow barrier used to separate opposing traffic flows) and increases in lane numbers are factors for lowering crash rates. However, the same study by Ahmed also suggests that the degree of curvature is negatively correlated with crash risk, supporting previous research by Stewart and Chudworth (1990). These studies suggest that the sense of danger along sharp curves may increase the drivers alertness, thus decreasing accident rates by causing the drivers to be more cautious with their speed.

And it is convenient to examine the theoretical foundations for further description of road geometric elements and their contributing factors to road safety.

2.4. Effects of road Geometric elements on road safety

Road geometry refers to the physical features of the road itself. This includes the surface of the road, its width, whether it is straight or curved, flat or sloping, and clarity of the division between the road and the area next to the road.

2.4.1. Horizontal Alignments

2.4.1.1. Radius of a curve

Most of the past Studies show that accidents often occur at curves. Ding jianmei & Pei yulong (2000) reviews from the study of Shenda Freeway that accident rate and curve radius have a close relationship. This means, accident rate reduces as the radius of the road increases; and the curves with the same or similar radius are safer than with different radius. A small radius, which is inserted into long and straight line, is dangerous, and the study conclude that modification of horizontal alignment is one of the effective countermeasures for highway accidents.

All being equal, crashes are more likely to occur on highway curves than on tangents (straight sections of road). Glennon (1987) quotes results which suggest that the average crash rate for curved road segments is three times that of tangents, and the average single vehicle's, run off road crash rate is four times higher. Moreover, curved road segments have higher proportions of severe wet road and icy road crashes.

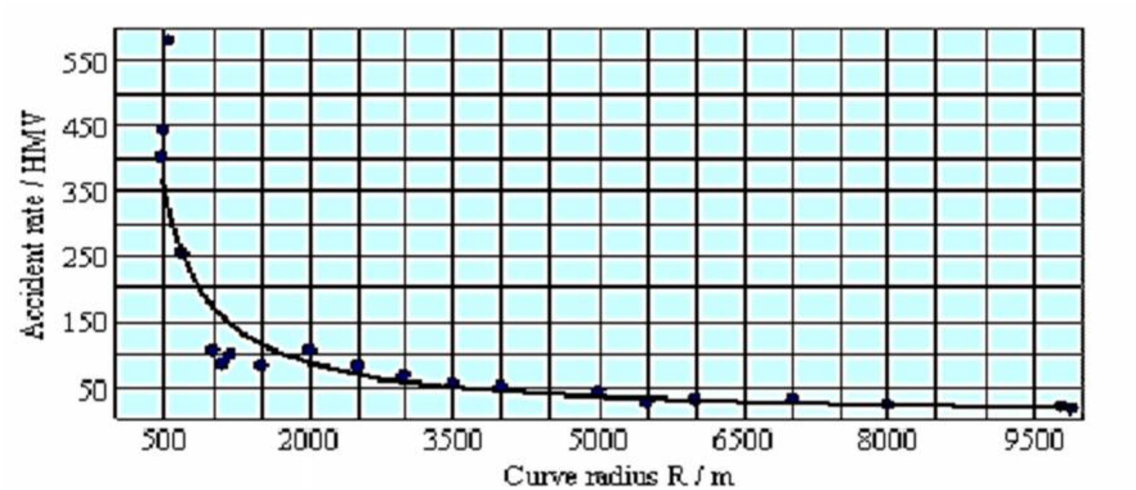


Figure 2.1: Relationship of accident rate and curve radius (Source: Ding jianmei & Pei yulong, 2000 study on Shenda Freeway in China)

Getu (2007) reviewed that generally sharp curves result high accident rate than more gentle curves, especially below 20 m radius rate of accident is increasing. Curves themselves decrease the sight distance a head, so a wide curve followed by a sharp curve may lead to inappropriate speed as the sharp curve will be concealed by the previous curve. Drivers also tend to enter curves too fast when the curve follows a long section of straight road as the driver has built up speed on the straight section (Dietze, Ebersach, Lippold, Mallschutzke, & Gatti, 2005).

Sarbaz Othman & Robert Thomson (2009) studied the effect of the curvature on the accident rate and summarized that accident rate decreases with increasing radius of curves, for both right and left curves. Higher road traffic accidents have occurred on left turn curves than right turn. Road sections with left curve and radius less than 100 meter have two times accident rate as compared to right curve radius less than 100 meter. In addition, road section with left curve radius of less than 100 m has accident rates that are four times as high as those on section with curve radius greater than 500 m.

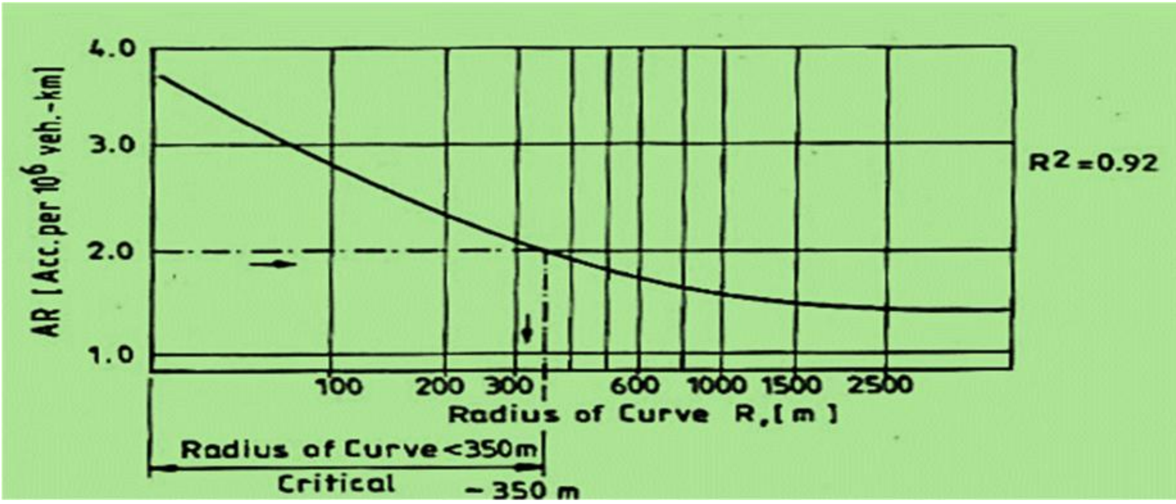


Figure2.2: Relative accident rate on curvature change rate and radius of curve (Source: Iyinam, A.F., 1997)

2.4.1.2. Deflection angle

According to studies by Ding Jianmei & Pei Yulong of at Shenda, freeway small angle or deflection leads to steep curves to drive and unfavorable to traffic safety. Figure 2.3 shows accident rate vs. deflection degree.

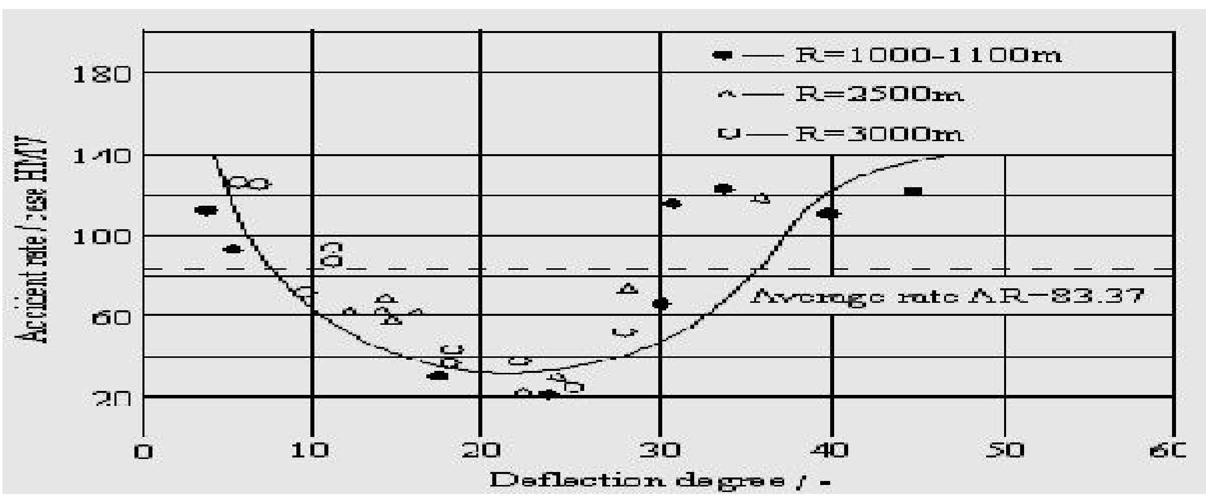


Figure 2.3: Relationships of accident rate and deflection angle (Source: Ding jianmei & Pei yulong, 2000)

According to the above graph, when angle of deflection varies from 0^o to 45^o, accident rate decreases with angle of deflection increasing to minimum level 7^o, and then less or equal to 7^o of deflection angle increases rate of accident with increasing of deflection angle. Getu (2007) reviews that section with curvature of 5 to 10 degrees is twice higher than a section with degree of deflection 1 to 5.

2.4.2. Vertical alignments

2.4.2.1. Vertical curvature

Crests affect sight distance, which means that drivers cannot perceive information about the road ahead and slow down if this is necessary (Fildes & Lee, 1993). Sags or dips affect sight distance at night, as headlight have a restricted vertical range (Dietze et al., 2005). Vertical alignment can alter the perceived width of a road’s horizontal curves, marking them appear less sharp than they actually are when superimposed on sag vertical curve (Hassan & Easa, 2003).

2.4.2.2. Grade

Steeper grades are generally associated with higher crash rates. For example, Roy Jorgensen (1978) suggested that both crash rate and severity increase with gradient, and both upgrade and downgrade. Organization for Economic Cooperation and Development (1976), Hillier, and Wardrop (1966) reached a similar conclusion, but suggested that downgrades were the greater problem. Hoban (1988) concluded that steep grades above about 6 per cent are associated with a higher crash rate.

The Interactive Safety Design Model Crash Prediction Module uses a value of 1.6% increase in crashes with every 1% increase in grade (Harwood, Council, Hauer, Hughes, &Vogt, 2000). However, this model does not take account the sign of the grade as one direction will be travelling up and the other down, and the crash livelihood is calculated for both directions in a segment. Dietze et al (2005) cite some studies that showed an increase risk of crashes on downgrades, and some studies that showed a decreased risk of crashes on downgrades, and an increased risk on downgrades and an increased risk on upgrades. Recent research from Italy found an increased risk on downgrades and a decreased risk on upgrades (Montella, Colantuoni, & Lanberti, 2008, cited in Montella et al., 2008). Taylor et al (2002) found that the group of rural roads with the highest crash risk were very hilly and had lower speeds than other rural roads.

Chrisro J.Bener & Joster Maki (1999) review steeper grades increase the accident rates, and the accident rate in mountainous terrain is higher than in flat terrain. They summarize that the effects of vertical road alignment on accident are excessive speed, differential speed between vehicles and visibility difficulty for driver on crust curve.

Emergency braking distance downgrade is longer than that of braking distance upgrade. Due to this, more accident occurs at downgrade than upgrade. Safety measures was taken for the highway, accident rate was high on both upgrade and downgrades but significantly higher accident rate on downgrade than upgrade. After 1969, by increasing two directional lanes, remedial measures were taken to upgrade, and downgrade, and accidents are decreasing. Again, after installing a speed limit signs, the accidents get decreased and keep stable in absolve relatively. Sarbaz Othman & Robert Thomson (2009) studied the effects of grades on accident rates and reported that accident rate on downgrade is slightly higher than on upgrades, and upgrades have less effect on accident rate while accidents' rate increases with increasing downgrade.

2.4.2.3. Sight Distance

Sight distance means a distance required by drivers' to have a clear visibility of objects either moving or not above the roadway surface at a specified height. Getu (2007) reviews from studies in Sweden and concluded that increasing of sight distance results in decreasing of accident rate. Sight distance is particularly important for trucks since their poorer braking performance must be in part compensated by greater sight distance (Jarvis, 1994). Neuman and Glennon (1983), in a study of stopping sight distance found that different geometric conditions were associated with hazards. These were divided into three groups as follows:

- ✓ Minor hazards: tangent horizontal alignment, mild horizontal curvature (>600 m radius), mild downgrade (< 3 per cent);
- ✓ Significant hazards: low-volume intersections, intermediate horizontal curvature (300-600 m radius), moderate downgrade (3-5 per cent), structures;

- ✓ Major hazards: high volume intersections, Y-intersections, sharp curvature (< 300 m radius), steep downgrade (> 5 percent), narrow bridge, narrowed pavement, freeway lane drop, exit or entrance downstream along freeway.

2.4.3. Cross section

The features of the cross-section of the pavement influences the life of the pavement as well as the riding comfort and safety. Of these, pavement surface characteristics affect both of these. Camber, kerbs, and geometry of various cross-sectional elements are important aspects to be considered in this regard. These include: lane width, median, shoulder width, and cross section type.

2.4.3.1. Lane width

Sarbaz Othman & Robert Thomson (2009) studied the influence of carriageway width on the accident rate and suggested that the accident rate decreases with increasing lane width greater than 5.8 m, and the carriageway width of 5.8 m has the lowest accident rate on one lane roads.

A study that was conducted by DeLuca (1985) in Miami-Dade, showed a significant increase in sideswipe crashes with the decrease in lane width. Another study conducted by Zegeer et al. (1981) found that wide lanes had accident rates 10 to 39% lower than those on narrow lanes. The study showed that heavy vehicles overtaking other heavy vehicles remain centered in their lanes only when lanes were 12 feet (3.6 m) wide or wider. Studying the effects of lane width on trucks, Joshua and Garber (1990) found that lane width has the greatest effect on the probability of a truck accident, and that the probability for a truck accident increases as lane width decreases.

On the other hand, the study conducted by Hauer (2000) attempted to show the link between lane width and safety. Accordingly, the first link is that the wider the lane, the larger will be the average separation between vehicles moving in adjacent lanes. This may provide a wider buffer to absorb the small random deviations of vehicles from their intended path .The second link between safety and lane width is that a wider lane may provide more room for correction in near accident circumstances.

National Association of Australian State Road Authorities (1988) quotes an Australian study where the sealed width on rural highways were widened from 4.9 to 5.5 m, and from 6.7 to 7.3 m, with a casualty crash reduction of 43 per cent. Transportation Research Board (1987) quote an American study where 2.7 m lanes on rural roads were widened to 3.3 m ,and 3 m lanes were widened to 3.6 m , with a serious injury crash rate reduction of 22 %.

2.4.3.2. Shoulder

Shoulders are needed for parking, stopping vehicles, and overtaking crossing vehicles. The width of shoulder on crashes is less conclusive. However, there is some evidence that crash rates reduce as shoulder width increases up to 3m. For example, an American study (Zegeer, Deen and Mayes, 1981) produced results which showed a 21 % reduction in crashes when a road with no shoulders over the shoulders had of 0.9-2.7 m in width provided.

The Chrisro J.Bener & Joster Maki A. (1999) making reviews study showed that shoulders wider than 2.1m have significance lower accident rate than those narrower than 2.1m, and according to other studies, roads without shoulder exhibit relative low accident rates, which are a one-lane earth roads where speed is very low.

Iyinam, A.F., Iyinam, S. & Ergun, M. (2000) studies tested the relationship between accident rate and shoulder width and showed that, as the width of a shoulder is increased, the number of accident is decreased .With respect to type of shoulder the Chrisro J.Bener & Joster maki (1999) reviewed from various studies that accident rates become high on roads with a wider lane and paved shoulder than on wide lane with a gravel shoulder with 2 to 2.1m wide.

2.4.3.3. Medians

The separation of opposing streams by a median leads to significant crash reductions. In urban areas, medians should ideally be wide enough to protect turning or crossing vehicles. National Association of Australian State Road Authorities (1988) reports a Victorian study where 42 km of 2-lane highway was replaced with a 4-lane divided highway, with a 30 % crash reduction. It also reported an Adelaide study, which compared crash rates for 4-lane roads having wide medians, narrow medians, and painted narrow medians with 4-lane roads without medians. Compared with the undivided roads, the others reduced the crash rate by 30% in narrow painted median, 48% in narrow raised median, and 54% in wide median.

This brief review of some of the existing literature suggests that a variety of traffic and design elements such as AADT, cross-section design, horizontal alignment, Vertical alignment, roadside features, speed limit, lane width (LW), and median width, affect road safety.

Relationships of road width, curvature and visibility will affect road safety. Generally more sensitive when considering these factors together the same as having a psychological effect on drivers and influences the choice on velocity. For example, widening the road alignment that was narrow and well alignment not be able to reduce accidents if the speed remains the same. However, speed is usually greater because of the sense of security, so that the rate increases the accidents. Super elevation improvement and repair the road surface is implemented isolation also has the same tendency to increase the rate of accident. Of safety considerations, condition assessment should be performed speed that may occur after any type of road repairs and checking the width lines, visibility and road surface are all satisfactory to raise the speed of thought. The selection of materials for lining the road to suit the needs of traffic and accidental slippage is no less important than the selection for the purpose of construction. The place that has a surface of low edge coefficient style will easily have an accident slippage than other similar locations that have high value.

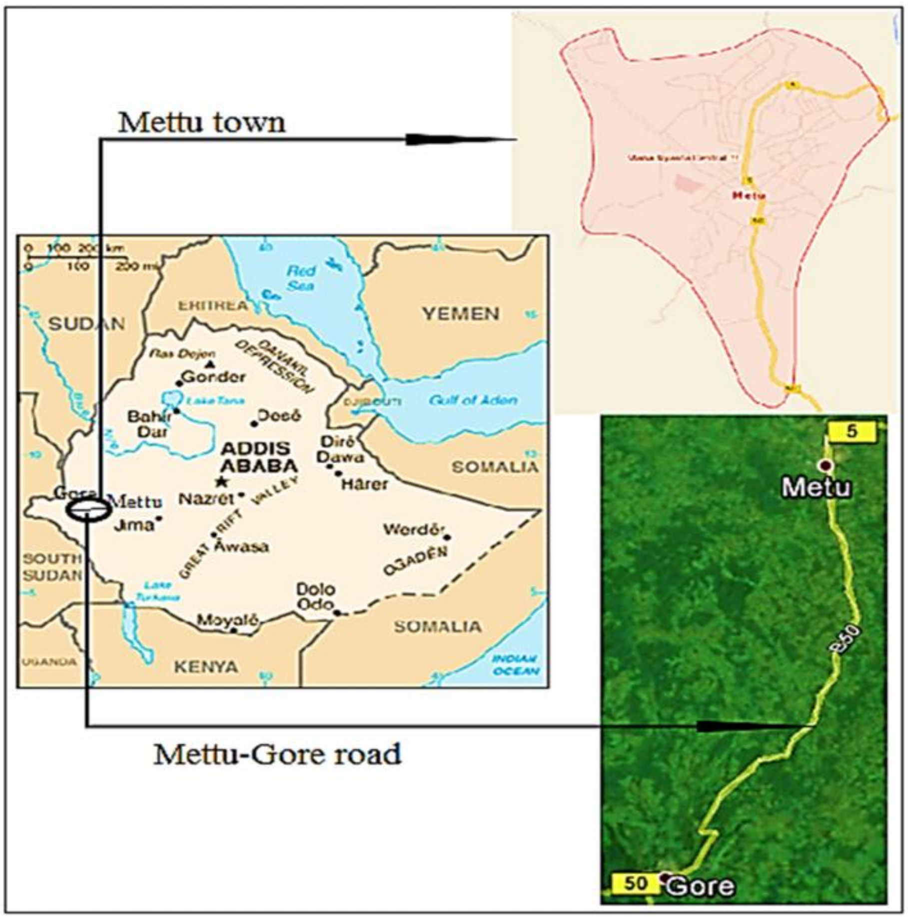
The above literature has suggested horizontal curvature as a significant causal factor in this relationship. However, there are a number of other design elements that should be considered. Early studies suggest that in order to further analyze the relationship between road geometry and road safety, it is necessary to further classify road geometry into various road 'design elements' as some elements alone may be higher causal factors.

CHAPTER THREE

METHODOLOGY OF THE STUDY

3.1. Study area

The research were conducted on Mettu-Gore road as a case study, which is found in Oromia region, Ilu Abba Bora zone.



- ✓ The road is found in **Mettu** (Latitude: ***8^{0} 16’0” N*** and Longitude: ***35^{0} 34’60” E***) to **Gore** (Latitude: ***8^{0} 9’4.83” N*** and Longitude: ***35^{0} 32’8.47”*** *E*)
- ✓ Altitude: 1580m to 2000m

Position from Earth center*: ENE*, in *UTM Zone of 36P*, and *UTC/GMT difference: +03:00.*

Figure 3.1: Map of the study area (Source: Google Map and Google Earth)

3.2. Study design

The aim of the study was to identify accident intensive prone or accident hot spot areas and to identify the causalities of road geometric design mainly focusing on the accident hot spot areas and then suggesting safety procedures applicable for the area. It is possible to use multi-stage design strategies for the completion of the research since in situations where two strategies might be considered attractive. Thus, descriptive research with document analysis was applied.

3.3. Target population

The populations of the study were Mettu-Gore road Geometric features, road users, vehicles, and topography and land use conditions of the area.

3.4. Data sources

The primary data source were the best guiding sources for the study such as field survey was considered to observe the actual safety problems related to characteristics of road geometry which was helpful to suggest alternative safety solutions. Whereas, the secondary data were collected from Mettu and Gore town police commission, ERA Jimma district, and Ethiopian Mapping Agency.

3.5. Data collection

In order to analyze concerned safety problems due to road geometry and setting possible safety solutions, information is needed on accidents and as-built geometric features of Mettu-Gore road, and desired to correlate road traffic accidents with geometric design. The necessary data that were collected are traffic accidents, road geometric design, AADT, Maps and also field observation contributes a lot.

3.5.1. Road accident data

Traditionally road safety measures rely heavily on crash data to tell a story of what has been 'recorded' on roads. Emphasis is placed on the fact that the accident events used in this study are reported data, not observed data. In Ethiopia, police commission records crash data at or after the crash site has been visited. This data can provide useful information on the collision type, the number of people involved, the characteristics of the road and environmental factors such as weather and surface conditions. A disadvantage to this data is that it is estimated based on second hand information obtained by either the people involved in the collision or by the traffic police officer. Post-crash reports may result:

- ✓ In bias opinions from the driver influencing speed and time of collision in order to avoid penalties/prosecution.
- ✓ The location of the accident may also be estimated by the police officer due to cars being projected further from the point of collision.

The road accident data of four (4) years during 2004 to 2007 E.C. were collected from Mettu and Gore police commission booklet. From these, the available and collected data include:

- Rough drawing to show the location type of the area that is nearest for college, factory, religious, recreation, office, hospital, residential, open area, petrol pump, pedestrian crossing, narrow bridge culvert, and others ;
- Classification of the accident (fatal, serious injury, light injury, property damage only);
- Date, month, year;
- Light conditions (day light, dark hour with good, street, dark hour with poor street light, dark hour with no street light);
- Involvement (pedestrian, animal and other objects);
- Name, sex, age, education, address of the driver, type and license number;
- Economical loss estimated by police officers:

Since geographic information systems (GIS) were not used to place the accurate locations of accidents, as much as possible, marking of the collected accident data (which is found in hard copy) have been estimated by the researcher to the actual locations.

3.5.2. Road geometric design

Plotted drawings of the final As-built Mettu-Gore road geometric design was collected from ERA, Jimma district. From these, the collected data include:

- Road way (number of lanes, lane width (m), shoulder width (m), side slope (%));
- Vertical Alignment (grade on tangent (%) , grade on curve (%), sight distance in terms of K value, curve length (m));
- Horizontal alignment (radius of curve (m), rate of super elevation (%), length of runoff (m));

- Median (median width (m)).

All the existing geometric parameters are documented from as-built hard copy paper and attached in appendix A: Table A-2 and Table A-3 of this report.

3.5.3. Traffic data

Cameron, and Fildes (1985) note that if AADT volumes are unavailable, estimates will often suffice since the calculation of exposure is not sensitive to minor estimation errors. Similarly, if count data are not available for every year, interpolation between years is acceptable. Thus, in this study AADT data were collected from average daily traffic report of ERA 2013 G.C. that were summarized by districts in 2012 G.C.

3.5.4. Map data

For the analysis of road accident data to identify hot spot locations with ArcGIS 10.2 and relating with risky geometric design of the existing road were done on the digitized maps of Mettu and Gore town. Thus, the geographical land use maps of Mettu and Gore town were collected from Ethiopian mapping agency and Oromia master plan institute.

3.6. Data processing and analysis

After collecting all the necessary information, data processing and interpretation of analysis result were done using ArcGIS Version 10.2, Excel program and descriptive presentation methods in the form of tables, charts and Maps. To obtain the objectives of the study, a descriptive presentation of maps were used to show accident intensive prone areas and hazardous geometric feature locations along the road. Applicable safety solution were suggested for the statistically significant areas of both accident hot spot and geometrically hazardous locations in order to keep the journey safe.

For accident Hot-spots, there is a wide range of methodologies available ranging from simple models based on actual accident count to advanced statistical models based to estimates. One of the most important benefits of GIS is its ability to graphically represent a large amount of data on a single map. This type of representation is very helpful in understanding multiple data types and values at a glance according to the location.

One of the continuing goals of conducting this study is to convey the feasibility of road safety analysis study, among the safety engineers and others in the system. However, due to the variety of implementations of GIS that exist within various organizations, developing models in highway safety analysis requires an understanding of the requirements of GIS, Data collection & digitization systems, and GIS-based highway safety analysis applications. Using GIS, one can merge accident related data with other factors such as road feature related data and represent the results in a user friendly way. Data processing and analysis of accident hot spot area identification of this study were done by ArcGIS Version 10.2 software running Gi*hot spot tool which uses accident frequency for identification of statistically significant locations of crashes. The results were outputted in both of Table and Map form. Based on the final result of ArcGIS, the accident hot spot areas were prioritized according to their statistical significance.

For the road geometric design assessment, Excel program was developed for safe road geometric design according to the limiting values of ERA design standard. All the geometric design elements were outputted for Mettu-Gore road with the governing values of design standards based on the topography of each segment which indicates the limiting safe values of the corresponding design elements. Thus, the output governing values was compared with the existing geometric element of the road and identification of the hazardous locations were done based on the comparison results.

The identified problematic segments of the road were then digitized and mapped on the digitized map of the road approximately to the exact locations in descriptive form, to illustrate the hazardous locations of the road. Thus, the ranked accident hot spot area map was merged with hazardous locations of as-built road map in order to assess the effects of road geometry on traffic safety. *Black-spot* areas of Mettu-Gore road were identified based on the descriptive result of the two merged maps. Finally to meet the purpose of the study, the safety solutions applicable for the area were suggested based on the problem and significance of the existing geometric design.

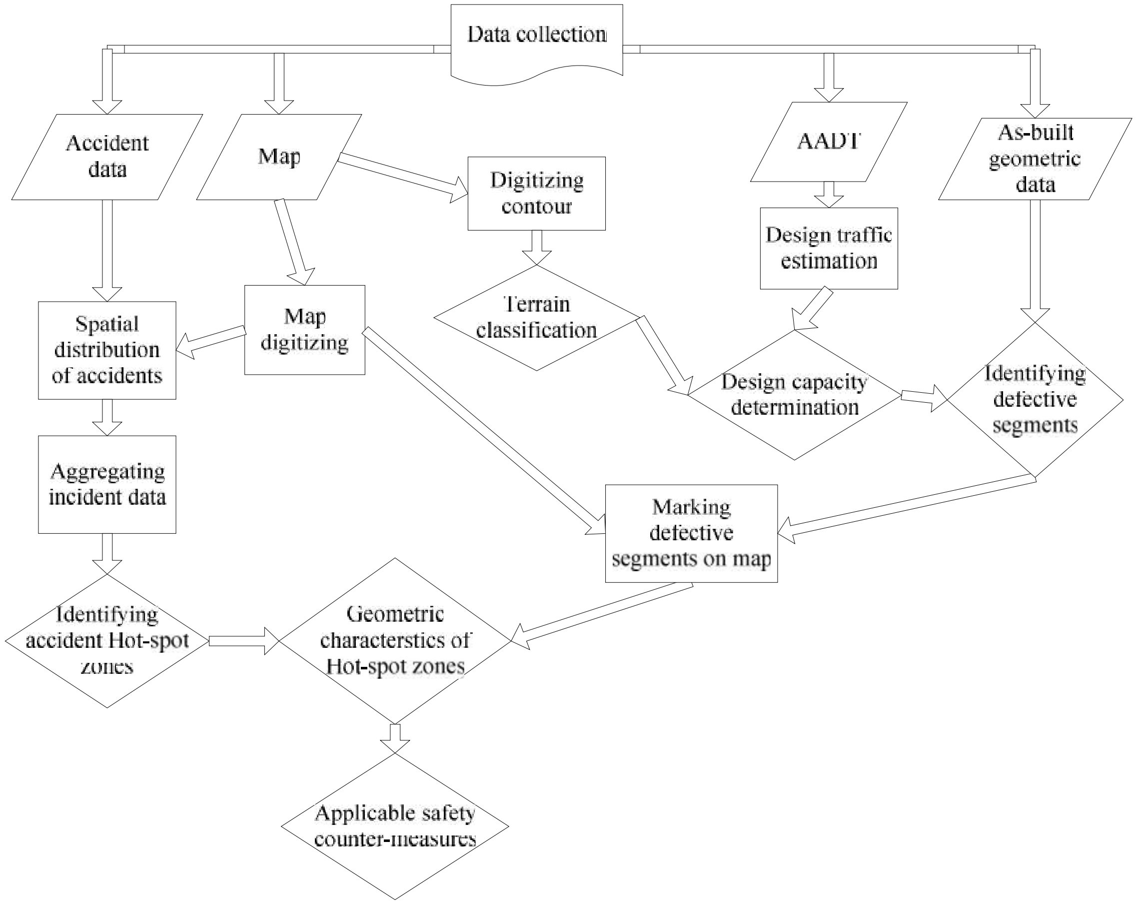


Figure 3.2: Flow chart showing data processing and analysis

3.6.1. Digitized Map of Mettu-Gore Road

The maps of Mettu and Gore towns were linked and digitized in order to distribute the spatial locations of accident points and identify accident hot spot areas. And also, the digitized map of the road was found helpful to map the hazardous locations of the road and finally the results were compiled together graphically to identify the black-spot areas with the corresponding bad geometric characteristics.

The road maps were digitized in ArcMap 10.2 editing toolbox after all the important shape files of the features were created in ArcCatalog 10.2. All the important contributing features of the map were digitized. These were:

- Major road from Mettu to Gore town;
- Road networks connected to or near the major road;

- Manmade and natural features, such as; bridges, rivers, and others;
- Town blocks;
- Contour lines near the major road;
- Horizontal curves as a point features approximately at the center of the curves which were used as a reference to locate other features, such as; accident, and other unsafe geometric features on the road.

All of the digitized map of Mettu-Gore road reported as map presentation in Appendix A of this report.

CHAPTER FOUR

FINDINGS AND DISCUSSIONS

Based on the methodology reported in Chapter Three, the results gained from input data was used for analysis. This chapter presents the findings of the study from analysis result followed by discussions.

4.1. Accident analysis and Hot-Spot identification

A traffic accident has various different characteristics associated with it. For proper traffic accident analysis use of GIS technology has become an inevitable tool (Ghosh, Parida, & Uraon, 2004).

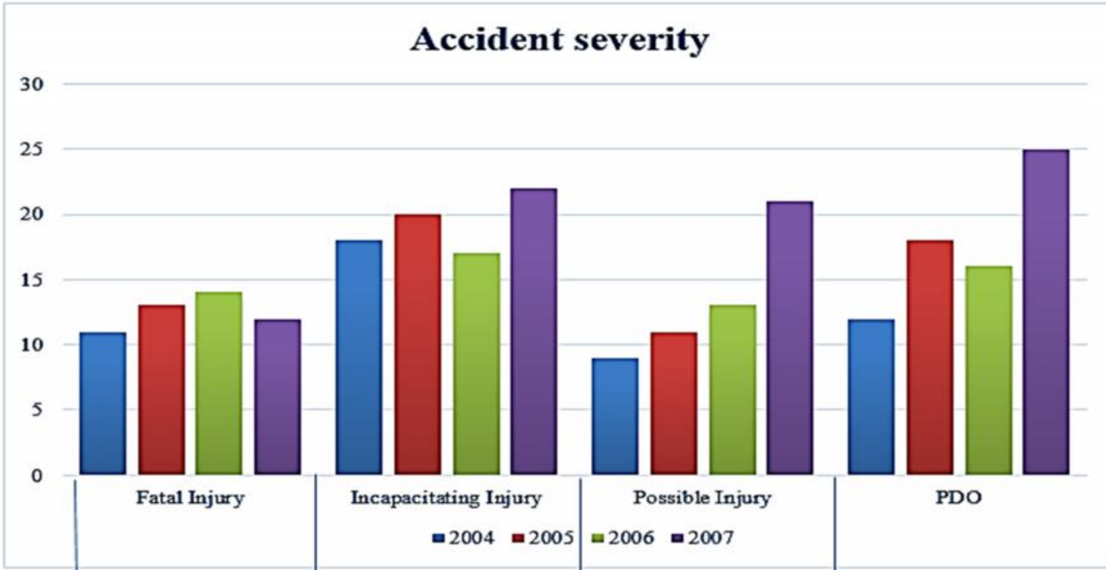
In this part the researcher discusses RTAs by severity extent in terms of accident number and economical loss, accident by road character, identification and prioritization of accident Hot-spot areas and descriptive method of discussion also included.

4.1.1. RTA Severity on Mettu-Gore road

All of the RTA data for a period of four consecutive years that were collected from police commission booklets are presented in Appendix A: Table A-5 of this report. From these collected data accident severity by their category and the property damages estimated due to the occurred accidents are discussed in this section.

4.1.1.1. Accident Severity by Category

Figure 4.1 below shows the number of accident that occurred on Mettu-Gore road in the period of four (4) years from 2004 to 2007 E.C. with increasing trend from year to year. Slight accidents have decreasing tendency though; possible injury accident rates have tremendous growth. Fatal reports, in turn, show fluctuation and start decreasing in 2007.

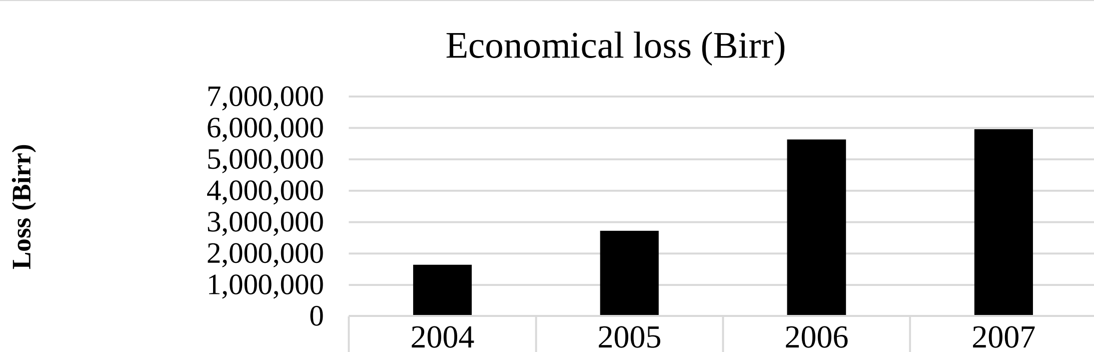


2004	11	18	9	12
2005	13	20	11	18
2006	14	17	13	16
2007	12	22	21	25
AAGR	3.862	8.508	33.981	31.713

Figure 4.1: Accident severity on Mettu-Gore road

4.1.1.2. RTA Severity by Economic Loss

RTA causes great economical loss to the country which directly affects GDP and Figure 4.2 below shows a tremendous increases of economic loss occurred due to an increasing rate RTA on Mettu-Gore road.



	2004	2005	2006	2007
Economical loss (Birr)	1,642,915	2,727,370	5,636,118	5,964,665

Years

Figure 4.2: Economic loss due to accident on Mettu-Gore road

4.1.2. Identification of Hot-Spot areas using ArcGIS Software

4.1.2.1. How Hot-Spot analysis tool works in ArcGIS

It is based on statistical values and most statistical tests are based on null hypothesis. The null hypothesis for the pattern analysis tools (Clustering done in hot spot analysis) is Complete Spatial Randomness (CSR), either of the features themselves or of the values associated with those features. The Z-scores and P-values returned by the pattern analysis tools tell you whether you can reject that null hypothesis or not. For pattern analysis tools it is the probability that the observed pattern was created by some random process. Z-score and P-values are Statistical values. Z-score is standard deviation and P-value is the probability. Main concept in it is that the values in the middle of the normal distribution (Z-scores for example), represent the expected outcome. When the value of the Z-score is large and the probability is small (in the tails of the normal distribution), however, the results are somewhat unusual and generally very interesting.

For the Hot-Spot Analysis tool, for example, "unusual" means either a statistically significant hot spot or a statistically significant cold spot. This tool calculates the resultant Z-score and presents features with either high or low values cluster spatially. The Gi* statistic value given for each feature in the dataset is a Z-score. For statistically significant positive Z-scores, the larger the Z-score is, the more intense is the clustering of high values (Hot-spot). For statistically significant negative Z-scores, the smaller the Z-score is, the more intense the clustering of low values (Cold-Spot).

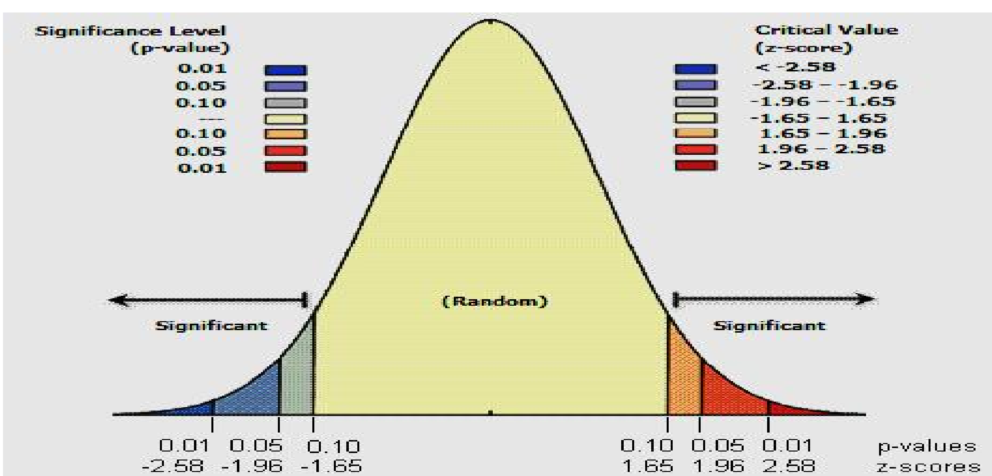


Figure 4.3: Hot-Spot distribution (Source: Esri Website, 2012)

Local method of spatial autocorrelation is more useful in its application for finding statistically significant cluster of accident locations. This tool was used to calculate Geary's ratio (local) for all the data points. Inverse distance method and zone of indifference are used to get the spatial relationships. Such points can be easily displayed as shown in Figure 4.3, where red colored locations (the right side of normal distribution curve) are statistically significant cluster formations and light colored ones represent statistically insignificant cluster locations.

4.1.2.2. Accident Hot-Spot Identification on Mettu-Gore Road

After the map was digitized and a road segments were given and numbered specific ID the followings were the procedures done for Hot-Spot Analysis result:

1. Spatial distribution of accident points to their crash occurrence

In this study, the accident data of four (4) consecutive years (2004-2007 E.C) from Mettu and Gore town traffic police were used and the spatial locations of RTAs are presented in Appendix A: Table A-6 of this report. The Latitude and Longitude of each accident points were marked as a point object according to the locations that were roughly drawn and indicated nearest specific features during crash occurrence that were recorded in police commission booklet. Geographical Information System Software (ArcGIS 10.2) was used for accident mapping on Mettu-Gore road. Figure 4.4 shows marked accident points.

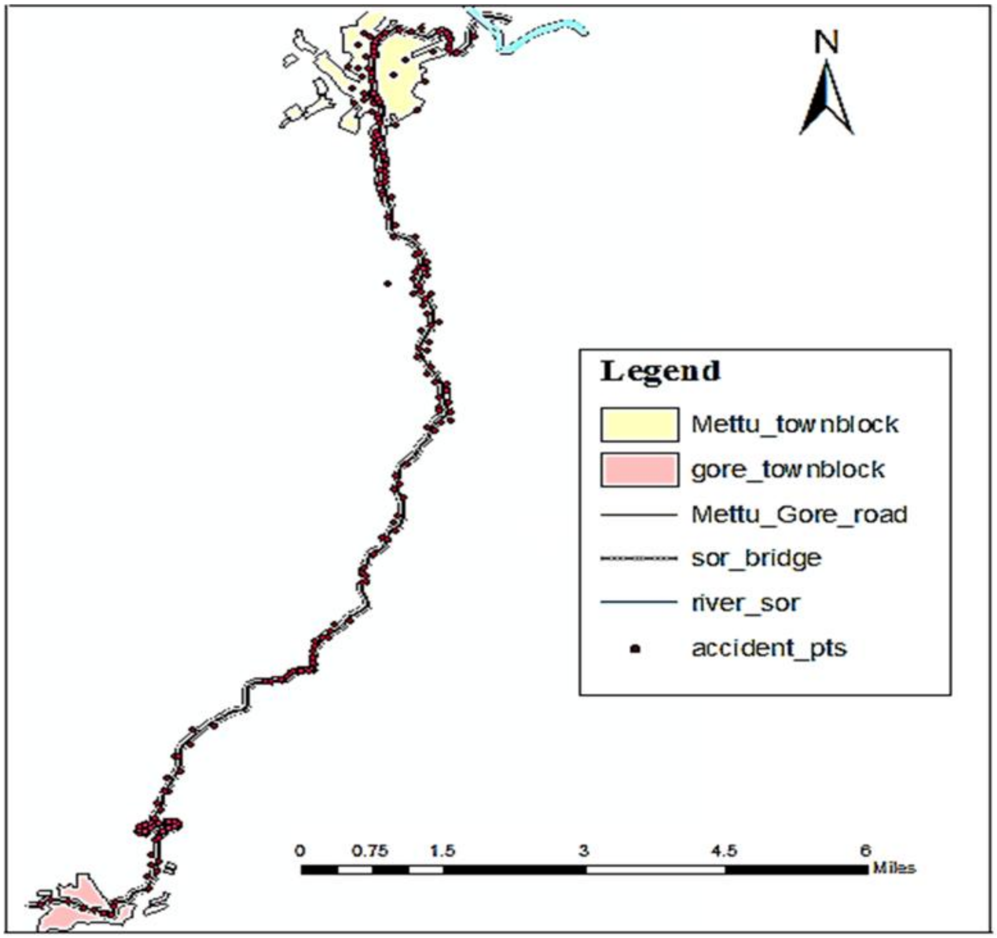


Figure 4.4: Accident spatial distribution Map

2. Projecting the accident points

Whenever distance is a component of Hot-spot analysis, which is almost always the case with spatial statistics, the data is projected using a Projected Coordinate System (rather than a Geographic Coordinate System based on degrees, minutes, and seconds).

In this study the mapped RTA's were projected to WGS 1984-UTM-zone 37N In order to minimize the distortion of the mapped accident point distance calculations.

3. Aggregating the incident data

The Hot-Spot analysis tool assesses whether high or low values (the number of accident and severity) cluster spatially. The field containing those values is named as Analysis Field. For point incident data, however, it may be more interesting in assessing incident intensity than in analyzing the spatial clustering of any particular value associated with the incidents. The incident data aggregated by using Integrate and Collect Event Tool of ArcGIS.

Thus, the projected RTAs were aggregated using Integrate and Collect Event Tool in ArcGIS prior to running Hot-Spot analysis. On running this tool features within some specified default distance of each other snap to the same location thus creating a 'stack of the coincident features' with same X Y coordinates and counted to 'ICount' field of the attribute table. The aggregated RTAs are shown in Figure 4.5.

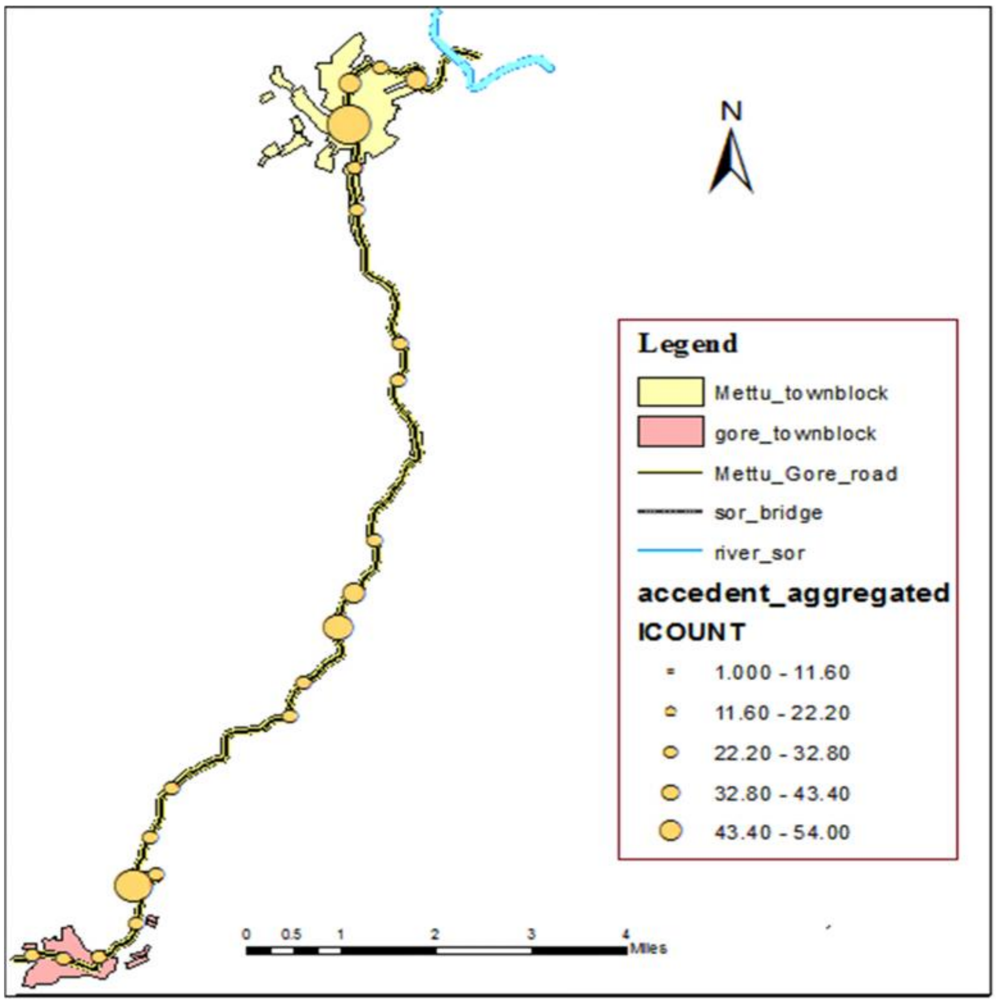


Figure 4.5: Aggregated incident data of accident

4. Finally, after collecting the events Hot-Spot Analysis (Getis-Ord Gi* Spatial Statistics tool) was applied to identify accident the Hot-spot locations with 'ICount' as an input field for statistical determination.

The result of the Hot-Spot Analysis tool were a new feature class where every feature in the dataset is symbolized based on whether it is part of a statistically significant Hot-Spot, a statistically significant cold spot, or is not part of any statistically significant cluster. The Red color represents Hot-Spots areas, or areas where high numbers of accidents were occured. The Blue color represents areas Cold-Spots areas, or areas where low numbers or no accidents were occured. The Beige area are not part of statistically significant clusters. Statistical significance were done based on the results of P-values and Z-scores that were calculated in Hot-Spot Analysis.

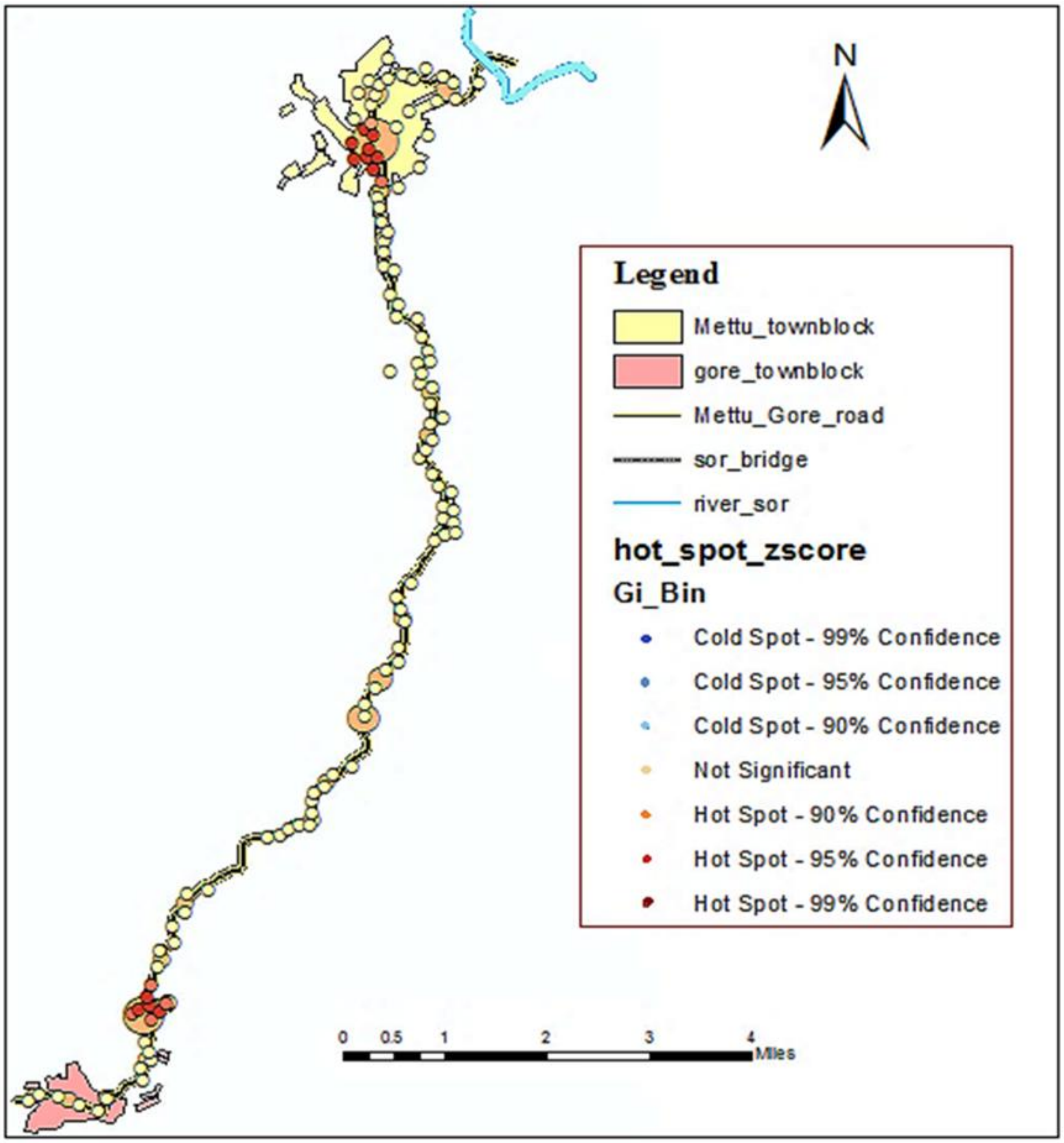


Figure 4.6: Accident Hot-Spot Map

The results from ArcGIS for Z-score and P-values were conducted and as shown in Appendix A: Table 4.3. In this section the results are shown graphically in Chart form in Figure 4.7 and Figure 4.8 below respectively for Z-score and P-value.

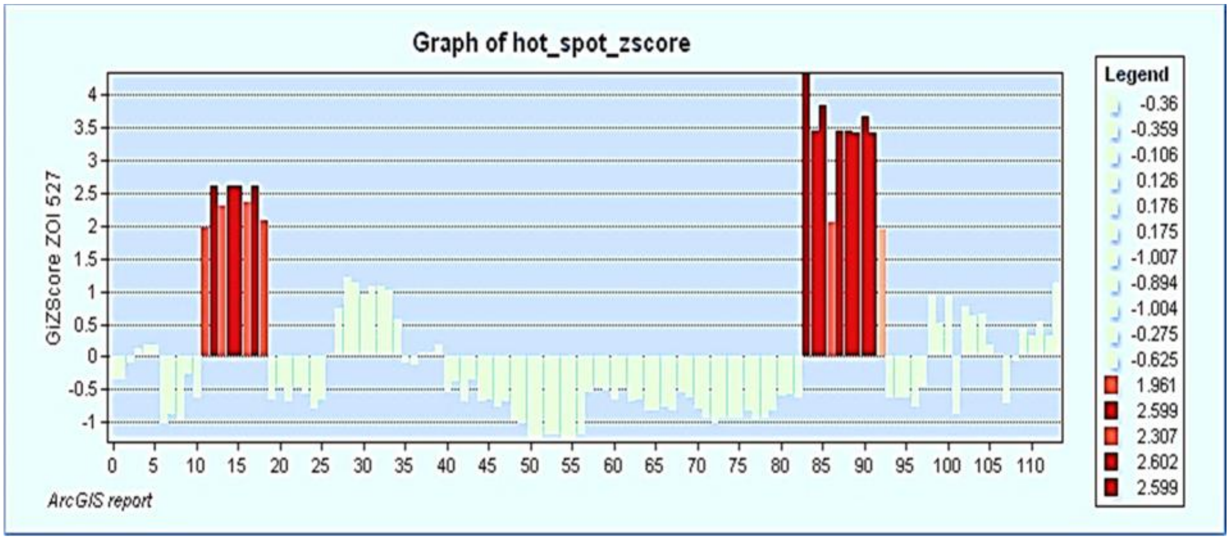


Figure 4.7: Z-score chart

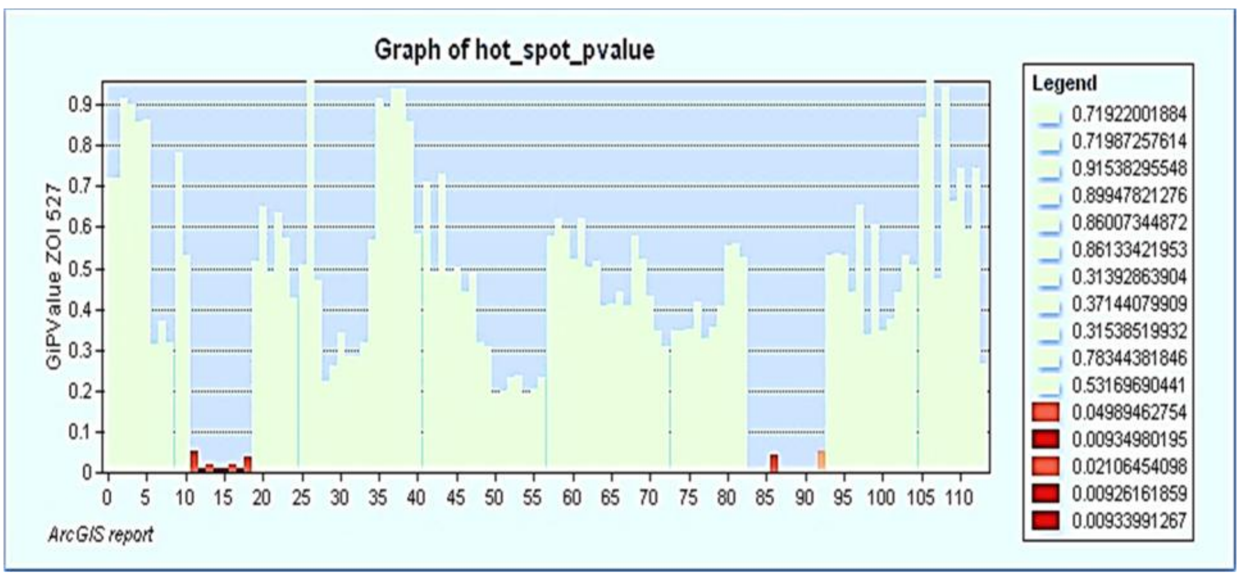


Figure 4.8: P value chart

As shown in above Figures the Red colored area represents accident Hot-Spot locations.

5. Creating a visualization surface

There are many ways to create an interpolated surface that will effectively visualize the results of a hot spot analysis. In this study, Inverse Distance Weighted, IDW tool (Spatial Analyst), were used which interpolates a raster surface from points using an inverse distance weighted technique. The Figure 4.9 below shows a visualization surface that were created by IDW tool of ArcGIS software.

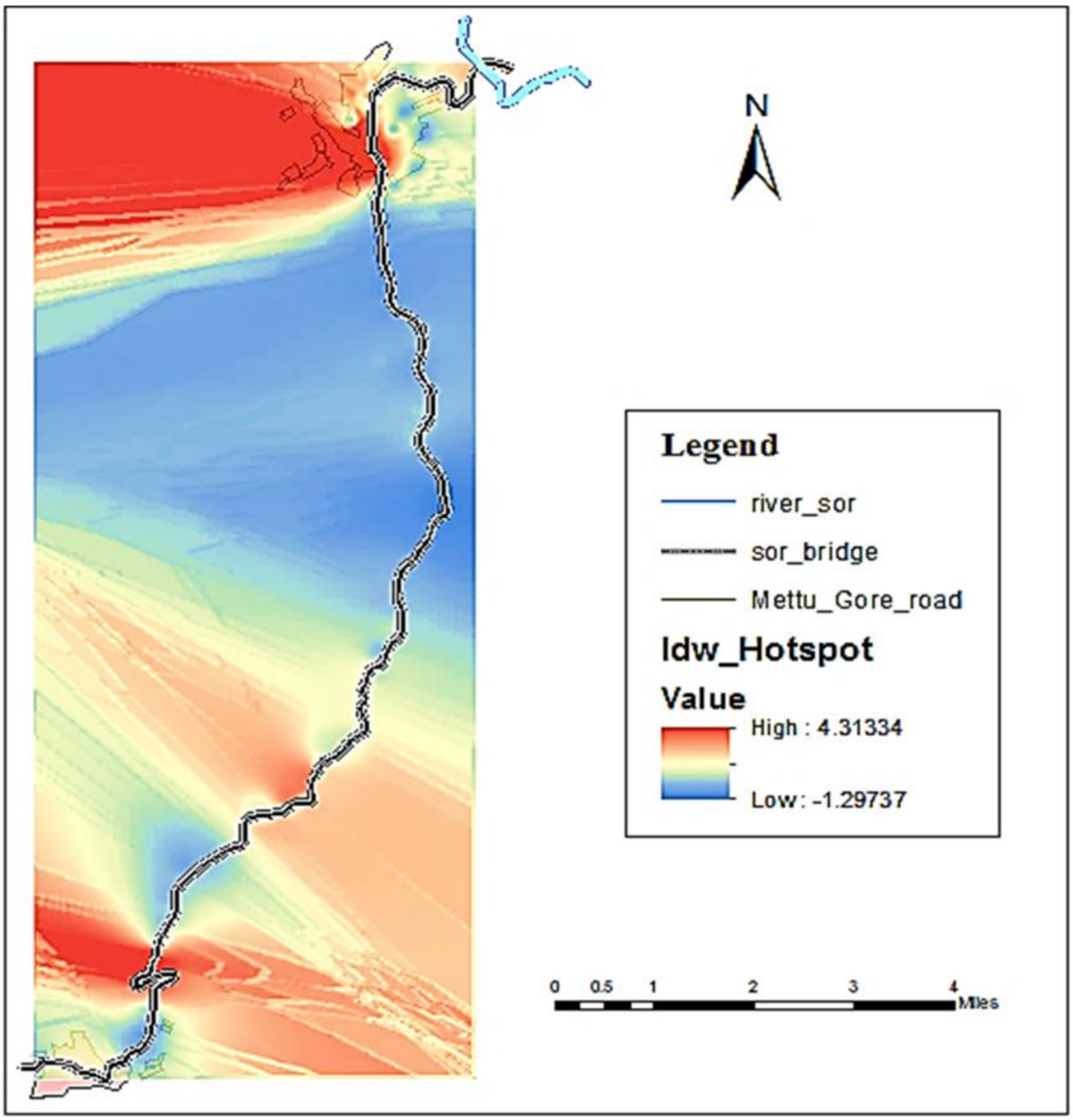
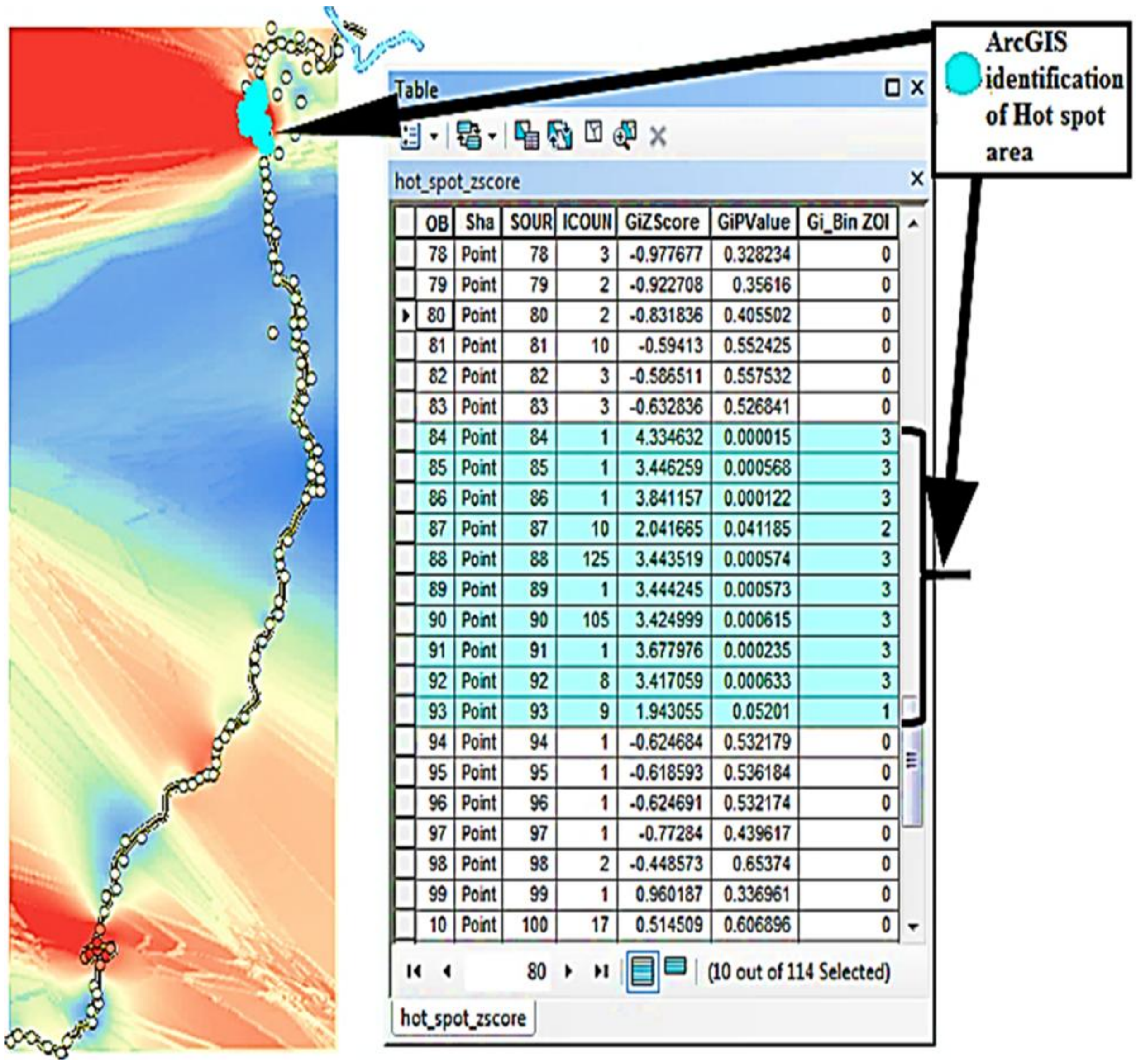


Figure 4.9 Created visualization surface for accident Hot-Spot analysis

4.1.3. Prioritizing Accident Hot-Spot locations on Mettu-Gore Road

Prioritization of the hot spot location were done according to the results obtained from ArcGIS Hot-spot analysis and visually discussed in this part of the report.

1. The place locally named "Arat-kilo" square in Mettu town were being prioritized as the first accident Hot-spot area. Which was found in the object ID of 84 to 93 in accident Hot-Spot results of attribute table in ArcGIS and this is shown in Figure 4.10 below.



OB	Sha	SOUR	ICOUN	GiZScore	GiPValue	Gi_Bin ZOI
78	Point	78	3	-0.977677	0.328234	0
79	Point	79	2	-0.922708	0.35616	0
80	Point	80	2	-0.831836	0.405502	0
81	Point	81	10	-0.59413	0.552425	0
82	Point	82	3	-0.586511	0.557532	0
83	Point	83	3	-0.632836	0.526841	0
84	Point	84	1	4.334632	0.000015	3
85	Point	85	1	3.446259	0.000568	3
86	Point	86	1	3.841157	0.000122	3
87	Point	87	10	2.041665	0.041185	2
88	Point	88	125	3.443519	0.000574	3
89	Point	89	1	3.444245	0.000573	3
90	Point	90	105	3.424999	0.000615	3
91	Point	91	1	3.677976	0.000235	3
92	Point	92	8	3.417059	0.000633	3
93	Point	93	9	1.943055	0.05201	1
94	Point	94	1	-0.624684	0.532179	0
95	Point	95	1	-0.618593	0.536184	0
96	Point	96	1	-0.624691	0.532174	0
97	Point	97	1	-0.77284	0.439617	0
98	Point	98	2	-0.448573	0.65374	0
99	Point	99	1	0.960187	0.336961	0
10	Point	100	17	0.514509	0.606896	0

Figure 4.10: The First Ranked Hot-Spot Map of "Arat-kilo" square

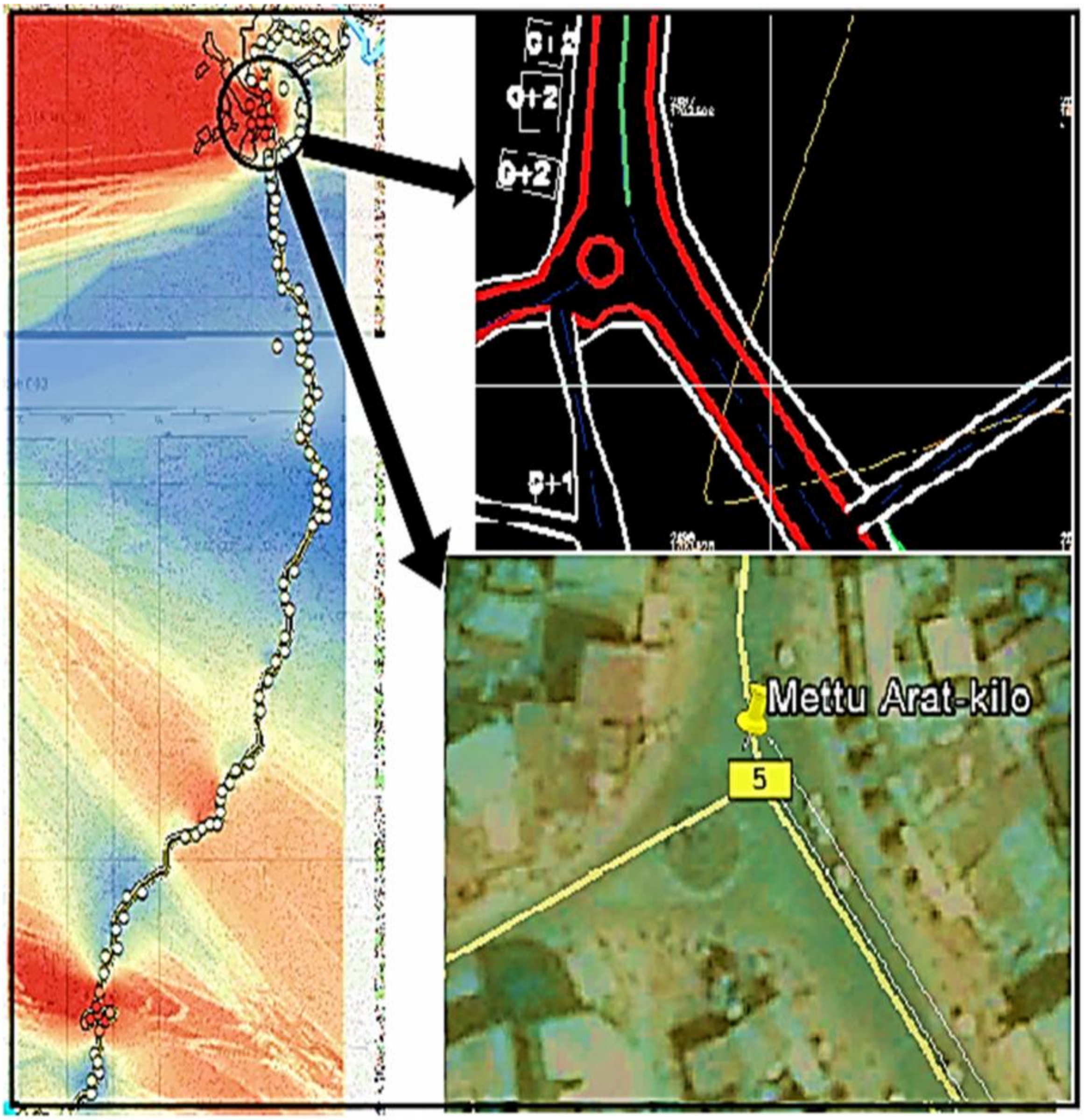
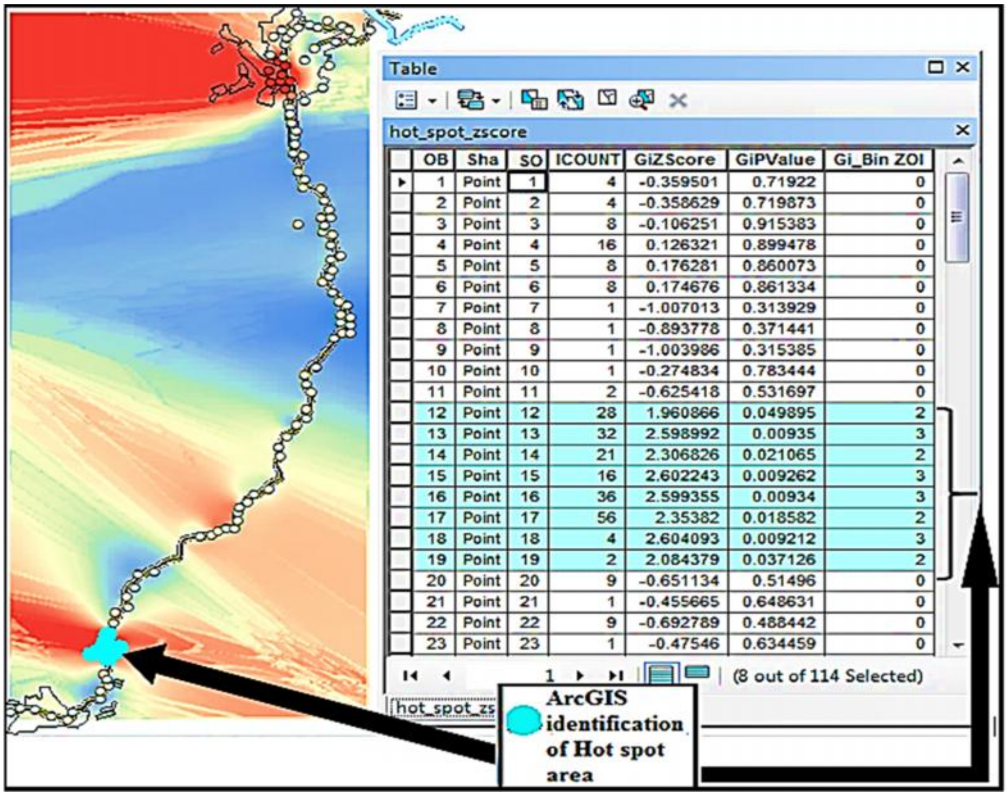


Figure 4.11: Map of "Arat-kilo" square

2. The place that have 'S-curve' Geometry near to the entrance to Gore town was being identified as the second Hot-spot area of RTAs. That was found in the Object ID of 12 to 19 in accident Hot-spot analysis result of attribute table in ArcGIS and shown in Figure 4.12 below.



	OB	Sha	SO	ICOUNT	GiZScore	GiPValue	Gi_Bin ZOI
▸	1	Point	1	4	-0.359501	0.71922	0
	2	Point	2	4	-0.358629	0.719873	0
	3	Point	3	8	-0.106251	0.915383	0
	4	Point	4	16	0.126321	0.899478	0
	5	Point	5	8	0.176281	0.860073	0
	6	Point	6	8	0.174676	0.861334	0
	7	Point	7	1	-1.007013	0.313929	0
	8	Point	8	1	-0.893778	0.371441	0
	9	Point	9	1	-1.003986	0.315385	0
	10	Point	10	1	-0.274834	0.783444	0
	11	Point	11	2	-0.625418	0.531697	0
	12	Point	12	28	1.960866	0.049895	2
	13	Point	13	32	2.598992	0.00935	3
	14	Point	14	21	2.306826	0.021065	2
	15	Point	15	16	2.602243	0.009262	3
	16	Point	16	36	2.599355	0.00934	3
	17	Point	17	56	2.35382	0.018582	2
	18	Point	18	4	2.604093	0.009212	3
	19	Point	19	2	2.084379	0.037126	2
	20	Point	20	9	-0.651134	0.51496	0
	21	Point	21	1	-0.455665	0.648631	0
	22	Point	22	9	-0.692789	0.488442	0
	23	Point	23	1	-0.47546	0.634459	0

Figure 4.12: The Second Ranked Hot-Spot Map, near the entrance to Gore town

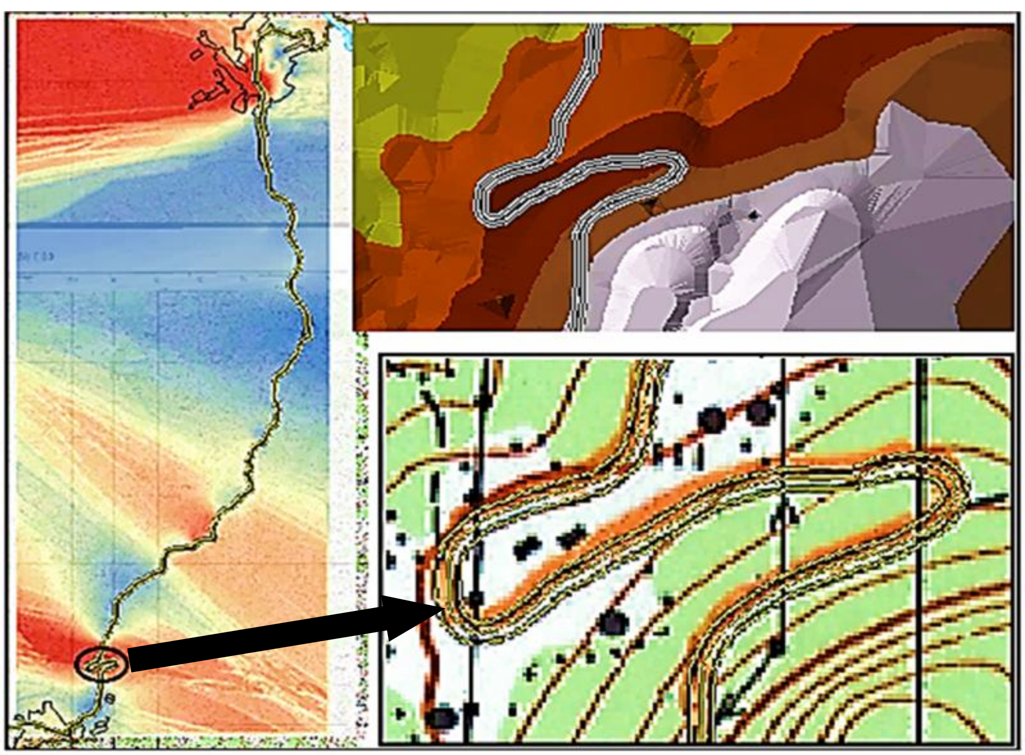


Figure 4.13: Map of 'S-curve' along the entrance to Gore town

3. Others which needs attention even if their Z-score is in a category of below Hot-spot but above "Significant" region were also prioritized as follows according to Z-score results obtained. These areas have positive Z-scores that varies from positive 0.9 to 1.22.

- Around "Bechano and Gagi" area

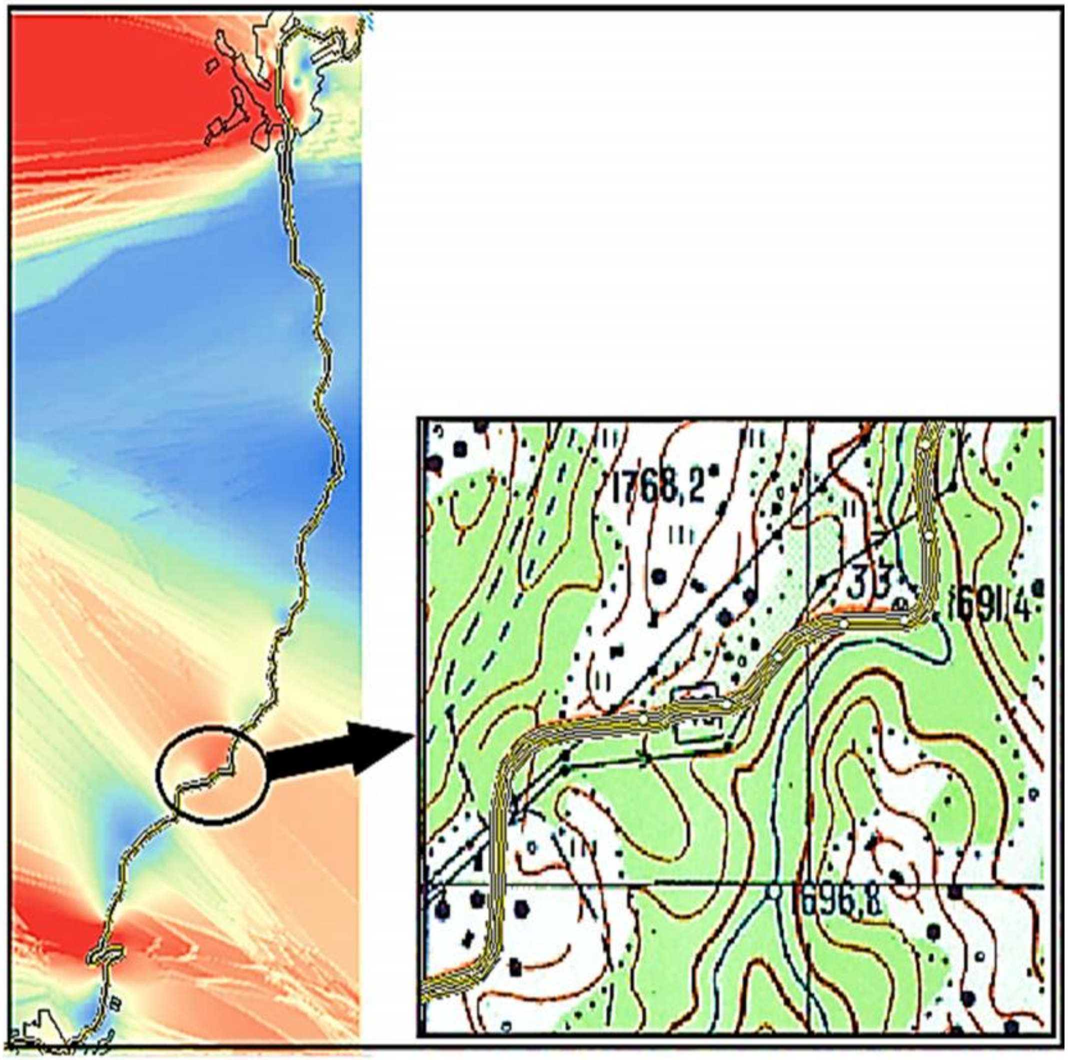


Figure 4.14: The Third Ranked Hot-Spot Map of "Bechano and Gagi" area

- Near "Sor-bridge" along the entrance to Mettu town from Bedelle. This place have a sharp continuous curves and locally named as "Sidist-Mato" Mountain.

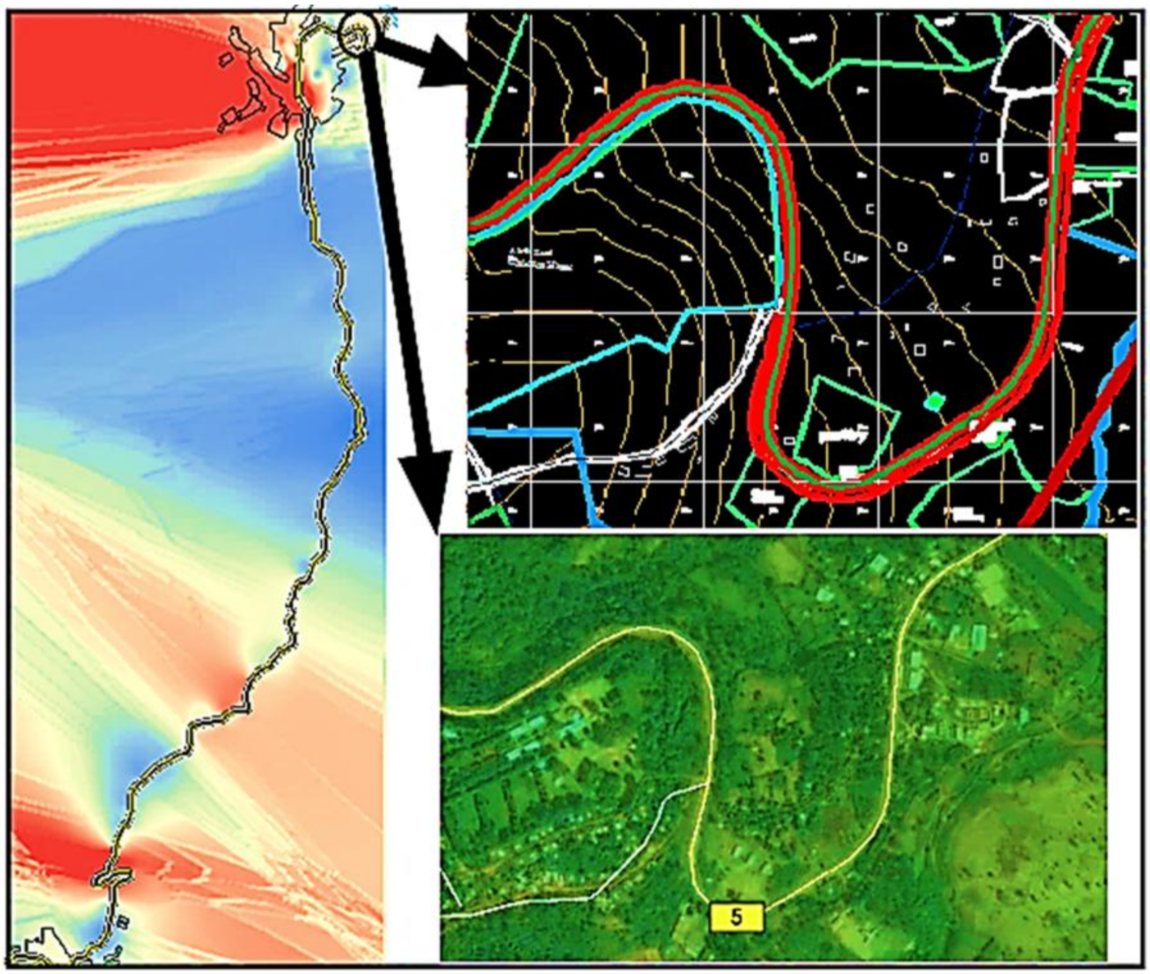


Figure 4.15: The Fourth Ranked Hot-Spot Map of “Sor-River” area

- And lastly the Hot-Spot analysis result prioritizes, the area in front of Post Office in Mettu town as the last ranked accident intensive-prone location. Thus the other segments of the roads were decided as accident Cold-Spot areas since their Z-score value of Hot-spot analysis showed below significant value.

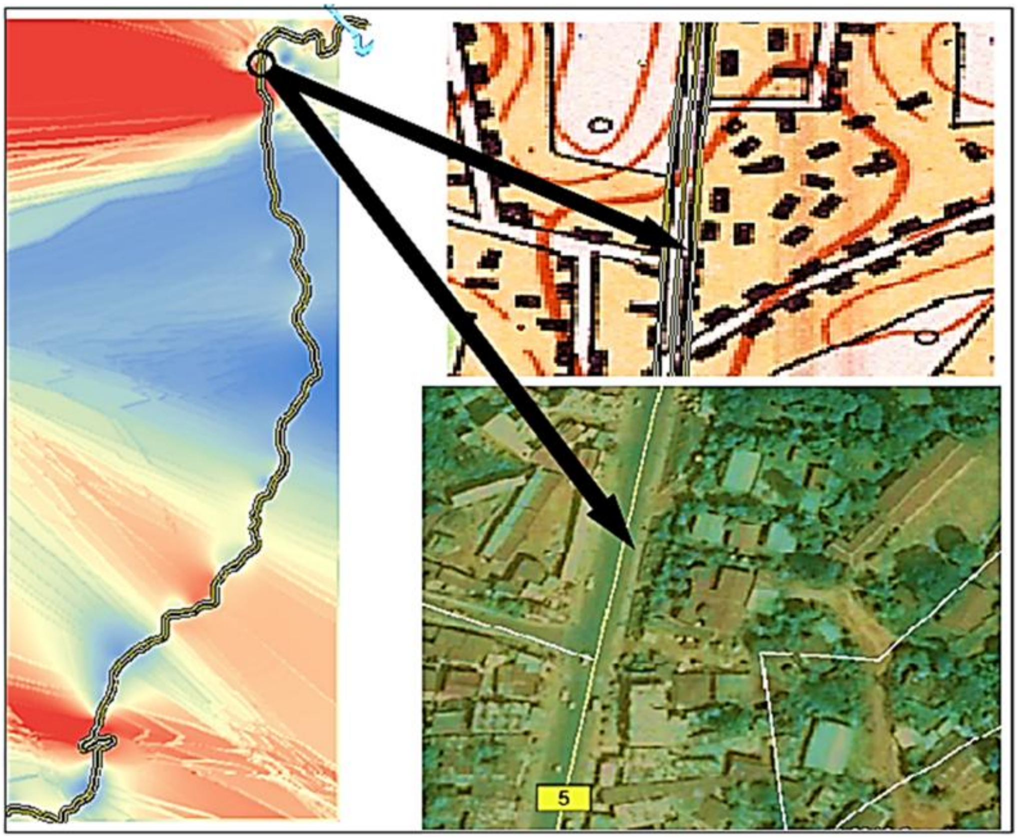


Figure 4.16: The Fifth Ranked Hot-Spot Map of Mettu Post Office area

According to the above results and discussions there were found five (5) location or segments of a roadway under the category of Accident Hot-Spot or accident intensive-prone location.

4.2. As-built Road geometric design assessment

The safe and efficient operation of vehicles on the road depends very much on the visibility of the road ahead of the driver. Thus the geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead.

4.2.1. Design speed

Design speed is a selected speed used to determine the various geometric design features of the roadway. Design speeds are selected to achieve a desired level of operation and safety on a highway. It is important to design roadways with elements in balance, consistent with an appropriate deign speed.

Design elements such as lane and shoulder widths, horizontal curve radius, super elevation, sight distance and gradient are directly related to, and vary, with design speed. Thus all of the geometric design parameters of a road are directly related to the selected design speed.

It is important to note that the design of a road in accordance with a chosen design speed should ensure a safe design.

In this study, road geometric elements; radius of horizontal curve (R), super elevation (e), gradient (G), and sight distance (which is checked by a constant value K or a horizontal distance required to achieve 1% change in grade) are influenced by the selected design speed.

The control factors to select the design speed for this study were:

1. The functional classification of highway
2. Topography (Terrain class)

4.2.1.1. The functional classification of the road from Mettu to Gore

The roads can be classified in many ways. The classification based on speed and accessibility is the most generic one. Note that as the accessibility of road increases, the speed reduces.

In Ethiopia roads are classified based on the location and function of the road. The functional classification in Ethiopia includes five classes i.e. – *Trunk roads, Link roads, Main access roads, Collector road* and *Feeder roads.*

The road from Mettu to Gore was fall under the category of *Link Road* (15 years design period), since it connects principal town (Mettu) and urban center (Gore). Thus categorized in design capacity between DC7 to DC 3 depending on AADT according to ERA Geometric design manual, 2013.

The AADT of the road from Mettu to Gore summarized by district was 781 with a traffic growth rate of 3.5% in the report year of 2012 (ERA, Annex 1-Average Daily Traffic summarized by district, 2013) and attached in Appendix A: Table A-1 of this report. Thus, estimating the AADT at the traffic opening (2010) and design traffic flow at mid-life, the

Design Standard of Mettu-Gore road fall in a category of DC5 by using ERA Geometric Design Manual, 2013.

Table 4.1: The design speeds given in ERA manual, 2013 for DC5

Terrain type	Flat	Rolling	Mountainous	Escarpment	Urban/Peri-Urban
Design speed (Km/hr)	85	70	60	50	50

4.2.1.2. Topography

The final design speed for each segments of the road have been selected depending on the terrain type of the area in correlation with design capacity of DC5. ERA classifies the terrain types in to four (4) classes depending on the transverse terrain slope through which the road passes.

In order to classify the terrain types of Mettu-Gore road, the digitized contour Map of Mettu and Gore towns were used. The terrain evaluation of the road is done using slope analysis tool of ArcGIS 10.2. Figure 4.17 shows the terrain class of Mettu-Gore road, the figure classifies the terrain type with color according to their percent rise of transverse slope. The green color indicates a flat terrain which have a transverse slope from 0% to 5%, the red color represents an escarpment terrain categorized in transverse slope of greater than 50% and rolling, and mountainous terrains are followed in an orderly manner as shown in the slope analysis map.

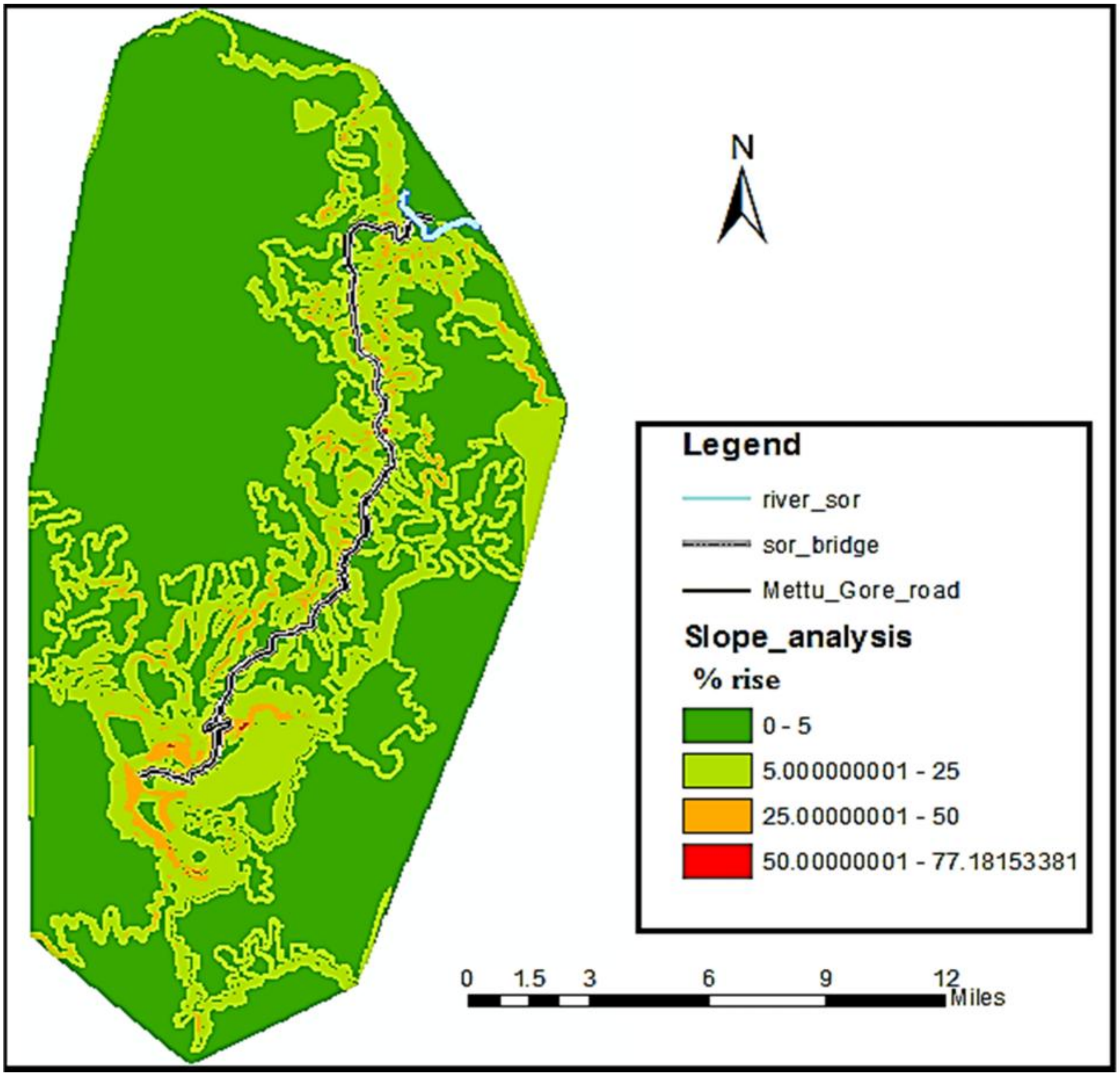


Figure 4.17: Terrain classification Map

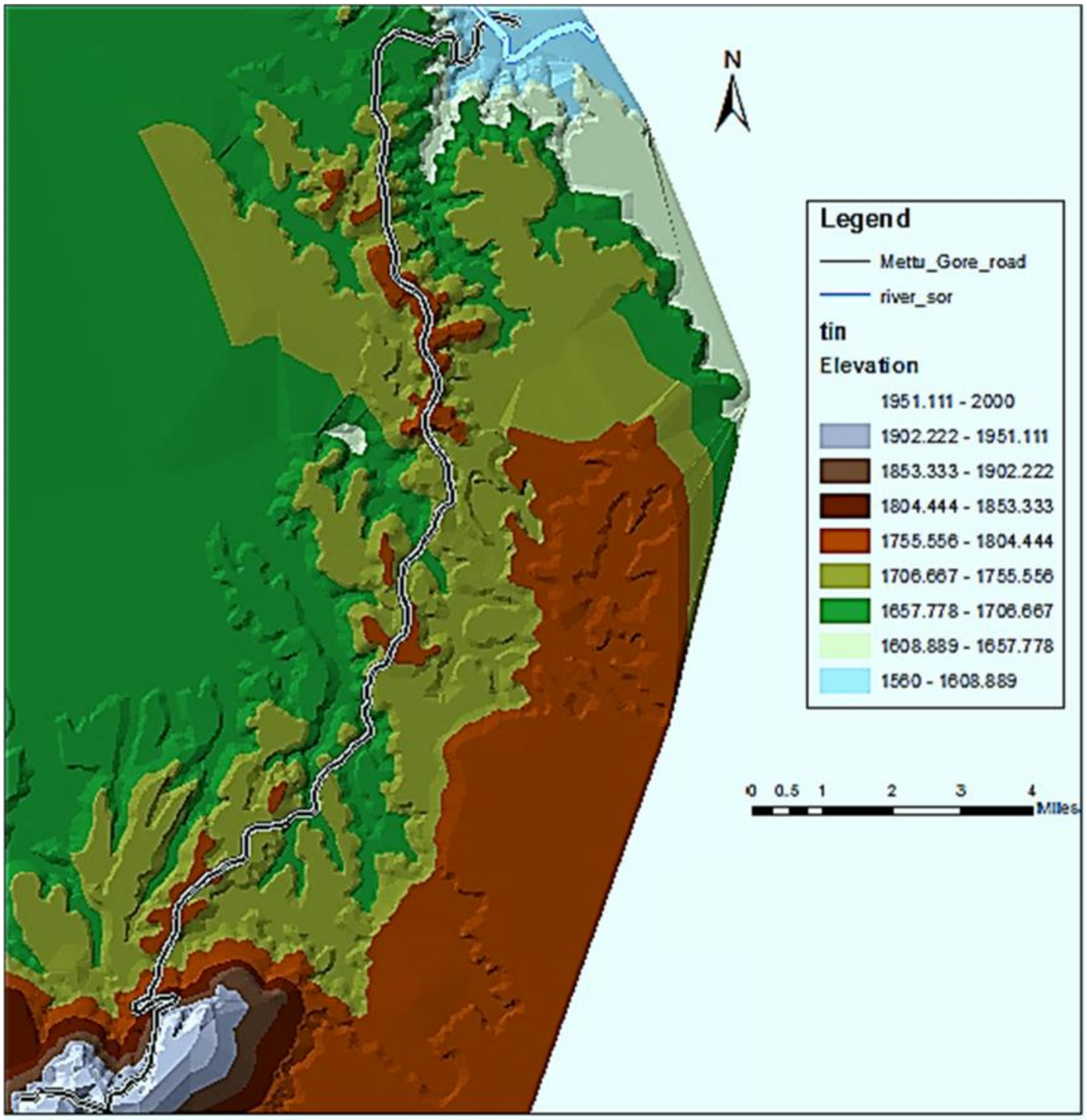


Figure 4.18: TIN created to evaluate the terrain in 3D visual

Since there is no speed limit posts along Mettu-Gore road, the design speed for each vertical and horizontal curves obtained from the above results have been used to assess the geometric parameters of the road.

4.2.2. Assessment of Horizontal Alignment

Horizontal alignment is one of the most important features influencing the efficiency and safety of a highway. A poor design will result in lower speeds and resultant reduction in highway performance in terms of safety and comfort. Horizontal alignment design involves the understanding on the design aspects such as design speed and the effect of horizontal curve on the vehicles.

The presence of horizontal curve imparts centrifugal force which is a reactive force acting outward on a vehicle negotiating it. Centrifugal force depends on speed and radius of the horizontal curve and is counteracted to a certain extent by superelevation and transverse friction between the tyre and pavement surface.

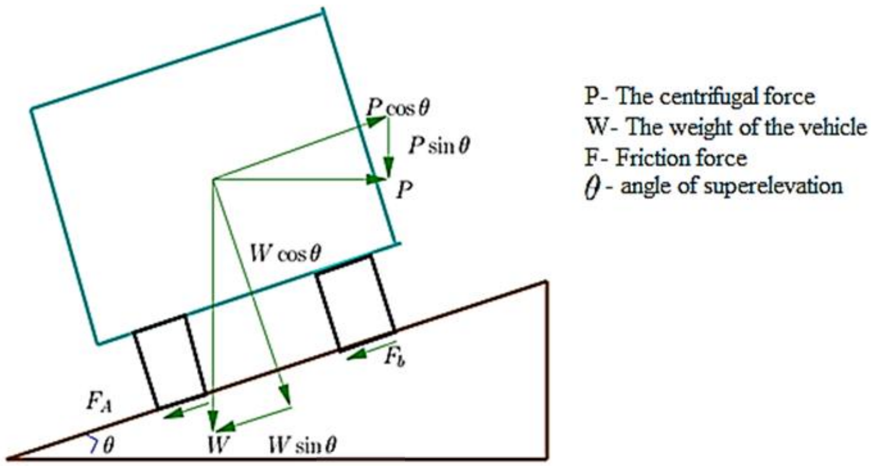


Figure 4.19: Forces acting on horizontal curve of radius R (m) at a speed of V (Km/hr)

$$R = \frac{V^2}{127(e+f)}$$

Where, R is a minimum radius of a curve (m)

V is speed of the vehicle

e is super elevation

f is transverse friction

AASHTO specifies the safe values of radius of a curve and superelevation rates for different design speeds and ERA agreed on the values which is included in ERA manual of geometric design portion, 2002. The calculation is done in order to provide safe highway for the drivers. The researcher, used those values to assess the final As-built horizontal curve whether the curve is designed in-standard value or not, for the selected design speed.

Table 4.2: Safe values of radius and superelevation rate for emax=8% (Source ERA, 2002)

	V_d=30km/h		V_d=40 km/h		V_d=50 km/h		V_d=60 km/h		V_d=70 km/h		V_d=85 km/h		V_d=100 km/h		V_d=120 km/h	
R (m)	e (%)	L(m)	e (%)	L (m)	e (%)	L (m)	e (%)	L(m)	e (%)	L(m)	e (%)	L(m)	e (%)	L(m)	e (%)	L(m)
7000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0
5000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0
3000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	RC	56	2.4	101
2500	NC	0	NC	0	NC	0	NC	0	NC	0	RC	47	2.1	56	2.9	101
2000	NC	0	NC	0	NC	0	NC	0	NC	0	2.2	47	2.6	56	3.5	101
1500	NC	0	NC	0	NC	0	NC	0	RC	39	2.5	47	3.4	56	4.6	101
1400	NC	0	NC	0	NC	0	RC	33	2.1	39	2.6	47	3.6	56	4.9	101
1300	NC	0	NC	0	NC	0	RC	33	2.2	39	2.8	47	3.8	56	5.2	101
1200	NC	0	NC	0	NC	0	RC	33	2.4	39	3.0	47	4.1	56	5.6	101
1000	NC	0	NC	0	RC	28	2.2	33	2.8	39	3.5	47	4.8	56	6.5	101
900	NC	0	NC	0	RC	28	2.4	33	3.1	39	4.2	47	5.2	56	7.1	101
800	NC	0	NC	0	RC	28	2.7	33	3.4	39	4.6	47	5.7	56	7.6	103
700	NC	0	RC	22	2.2	28	3.0	33	3.8	39	5.1	47	6.3	56	8.0	108
600	NC	0	RC	22	2.6	28	3.4	33	4.3	39	6.5	47	6.9	56	R_{min} = 665	
500	NC	0	2.2	22	3.0	28	3.9	33	4.9	39	7.2	47	7.8	56		
400	RC	17	2.7	22	3.6	28	4.7	33	5.7	39	7.8	51	8.0	64		
300	2.1	17	3.4	22	4.5	28	5.6	34	6.7	44	8.0	55	R_{min} = 395			
250	2.5	17	4.0	22	5.1	28	6.2	37	7.3	48	R_{min} = 270					
200	3.0	17	4.6	24	5.8	31	7.0	42	7.9	52						
175	3.4	17	5.0	26	6.2	33	7.4	44	8.0	52						
150	3.8	18	5.4	28	6.7	36	7.8	47	R_{min} = 175							
140	4.0	19	5.6	29	6.9	37	7.9	47								
130	4.2	20	5.8	30	7.1	38	8.0	48								
120	4.4	21	6.0	31	7.3	39	R_{min} = 125									
110	4.7	23	6.3	32	7.6	41										
100	4.9	23	6.5	33	7.8	42										
90	5.2	25	6.9	36	7.9	43										
80	5.5	26	7.2	37	8.0	43										
70	5.9	28	7.5	39	R_{min} = 80											
60	6.4	31	7.8	40												
50	6.9	33	8.0	41												
40	7.5	36	R_{min} = 50													
30	8.0	38														
	R_{min}=30															

e_{max} = 8.0%
R = radius of curve
V = assumed design speed
e = rate of superelevation
L = minimum length of runoff(does not include tangent runout)
NC = normal crown section
RC = remove adverse crown, superelevation at normal crown slope

Note : Lengths rounded in multiples of 10m to permit simpler calculations

Table 4.3: Safe values of radius and superelevation rate for emax=4% (Source ERA, 2002)

	V_d=30km/h		V_d=40 km/h		V_d=50 km/h		V_d=60 km/h		V_d=70 km/h		V_d=85 km/h		V_d=100 km/h	
R (m)	e (%)	L(m)	e (%)	L (m)	e (%)	L (m)	e (%)	L(m)	e (%)	L(m)	e (%)	L(m)	e (%)	L(m)
7000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0
5000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0
3000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	RC	56
2500	NC	0	NC	0	NC	0	NC	0	NC	0	RC	47	2.2	56
2000	NC	0	NC	0	NC	0	NC	0	NC	0	2.1	47	2.6	56
1500	NC	0	NC	0	NC	0	NC	0	RC	39	2.2	47	2.7	56
1400	NC	0	NC	0	NC	0	NC	0	RC	39	2.3	47	2.8	56
1300	NC	0	NC	0	NC	0	RC	33	RC	39	2.5	47	2.9	56
1200	NC	0	NC	0	NC	0	RC	33	RC	39	2.7	47	3.2	56
1000	NC	0	NC	0	NC	0	RC	33	2.2	39	2.9	47	3.4	56
900	NC	0	NC	0	RC	28	2.1	33	2.4	39	3.2	47	3.5	56
800	NC	0	NC	0	RC	28	2.3	33	2.5	39	3.4	47	3.7	56
700	NC	0	NC	0	RC	28	2.5	33	2.7	39	3.5	47	3.9	56
600	NC	0	RC	22	2.1	28	2.7	33	2.9	39	3.7	47	4.0	56
500	NC	0	RC	22	2.3	28	2.9	33	3.1	39	3.9	47	R_{min} = 490	
400	NC	0	2.1	22	2.5	28	3.3	33	3.4	39	4.0	47		
300	RC	17	2.3	22	2.8	28	3.6	33	3.8	39	R_{min} = 285			
250	RC	17	2.6	22	3.0	28	3.8	33	3.9	39				
200	2.3	17	2.8	22	3.3	28	3.9	33	R_{min} = 215					
175	2.4	17	2.9	22	3.5	28	4.0	33						
150	2.5	17	3.1	22	3.7	28	R_{min} = 150							
140	2.6	17	3.2	22	3.8	28								
130	2.6	17	3.3	22	3.8	28								
120	2.7	17	3.4	22	3.9	28								
110	2.8	17	3.5	22	4.0	28								
100	2.9	17	3.6	22	4.0	28								
90	3.0	17	3.7	22	R_{min} = 100									
80	3.2	17	3.8	22										
70	3.3	17	3.9	22										
60	3.5	17	4.0	22										
50	3.7	18	R_{min} = 60											
40	3.9	19												
	R_{min}=35													

e_{max} = 4.0%
R = radius of curve
V = assumed design speed
e = rate of superelevation
L = minimum length of runoff(does not include tangent runout)
NC = normal crown section
RC = remove adverse crown, superelevation at normal crown slope

Note : Lengths rounded in multiples of 10meters to permit simpler calculations
Use of e_{max} = 4.0% should be limited to urban conditions

Source: AASHTO

All of the final As-built horizontal curve parameters are attached in Appendix A: Table A-2 of this report and in this section the existing curve radius ranges are presented in Figure 4.20 and Figure 4.21 to show the dominated curve radius value.

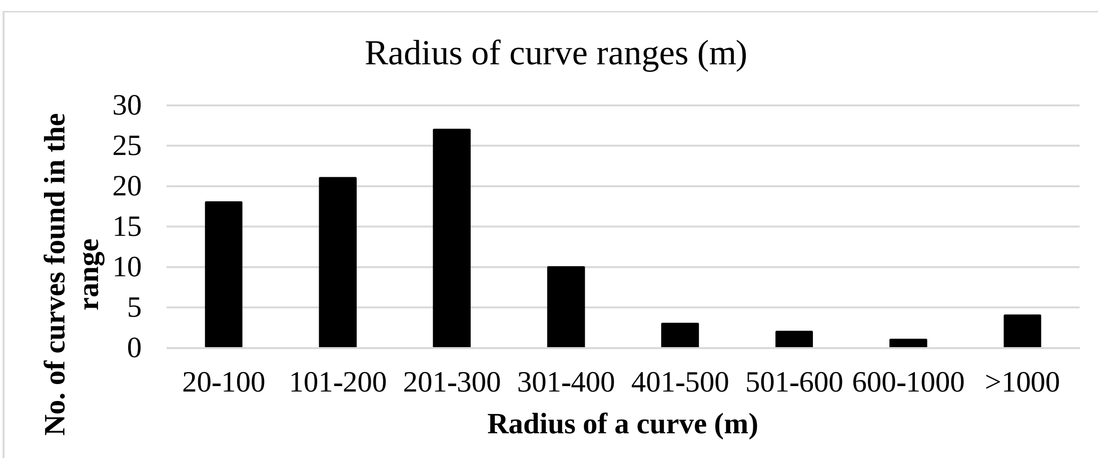


Figure 4.20: Radius value ranges of Mettu-Gore road

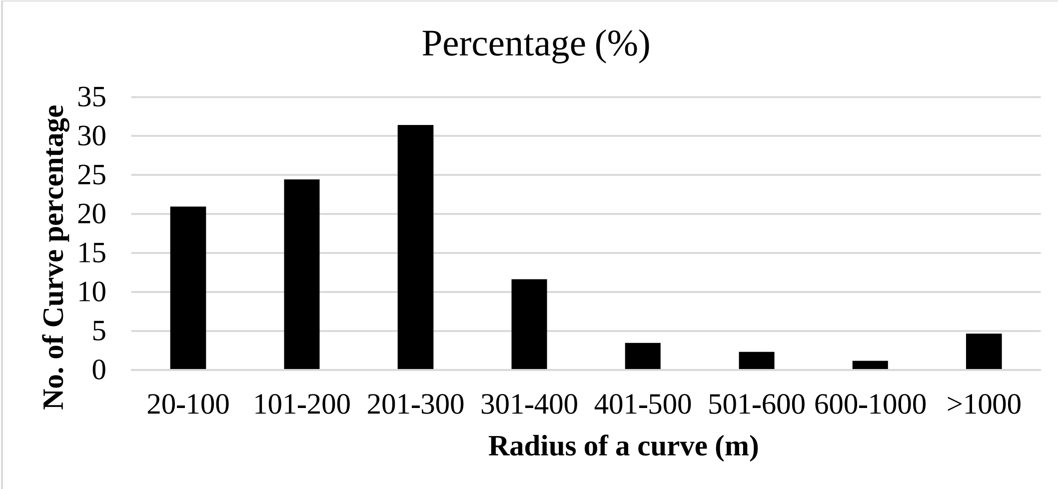


Figure 4.21: Percentage of existing curve range

An Excel program was developed to identify those curves designed satisfying the minimum values specified in standards from those not keeping according to ERA Geometric Design Manual. For all of the eighty six horizontal curves found on Mettu-Gore road, the horizontal curve elements (for this study, radius of a curve R and super elevation e) are checked whether they are "in-standard" or "out-of-standard". This spread sheet was done in two different parts of programs.

The first one checks whether the minimum radius of a curve specified in standard was being kept or not. The absolute minimum radius specified as the safest value in standard for each curve along Mettu-Gore road was determined based on the selected design speed. And the program records, these values as the minimum standard values for all the curve numbers. Finally, the program was checked all of the existing curve radiuses on Mettu-Gore road with each recorded standard values and shows the output as "in-S" for curves designed in-standards or "Out-of-S" for curves designed out-of-standard which have a radius of less than the specified minimum value. The output was also includes the values of variation from standards which is important to visualize the significance of the problem. The result of the first spread sheet program was showed that, on Mettu-Gore road (with a total of 86 curves) there were found nineteen (19) curves designed less than the minimum specified values of curve radius.

Table 4.4: Horizontal curves built with radius below the specified minimum safe value

Curve No.	**R min (m)**	**Result**	**Variation from Standard (m)**
3	175	out-of-S	-93
13	145	out-of-S	-60
20	215	out-of-S	-40
27	120	out-of-S	-20
32	175	out-of-S	-85
37	175	out-of-S	-50
39	120	out-of-S	-35
40	120	out-of-S	-35
41	120	out-of-S	-35
42	175	out-of-S	-110
43	175	out-of-S	-100
45	175	out-of-S	-50
50	175	out-of-S	-103
51	175	out-of-S	-30
65	120	out-of-S	-65
66	120	out-of-S	-65
68	120	out-of-S	-58.5
69	120	out-of-S	-58.5
77	80	out-of-S	-17

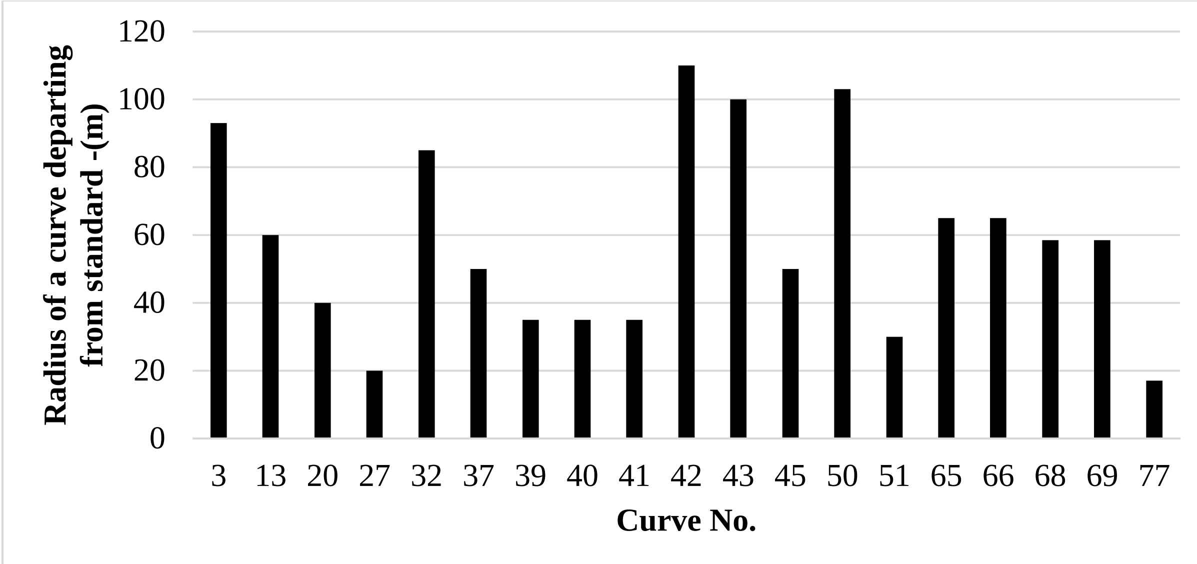


Figure 4.22: Sharp Horizontal curves and their variation from Standard

The second, excel spreadsheet was designed to check the existing superelevation rate in combination with radius of a curve. In this case, the spreadsheet checks the required radius of a curve for the provided superelevation was being kept or not as calculated and specified in standard. First, the program was designed to determine the minimum or safe values of curve radius for the existing superelevation rates by interpolating from ERA standard values of radius and superelevation table (shown in Table 4.2 and Table 4.3 of this report) and represented as the minimum or safest curve radius value. Thus, the existing curve radius can be checked with the minimum curve radius specified in standard for the existing superelevation rate. The output for all of the existing curves were the results needed to show the problematic curves and bend extents from standard value.

The result showed that, there were forty one (41) curves found below the specified minimum standard radius of a curve for the provided super elevation.

Table 4.5: Horizontal curves that are not kept to standard limit values of Radius for the provided Superelevation

Curve No.	R required for e provided (m)	Result	Variation from Standard (m)
2	200	out-of-S	-10

3	175	out-of-S	-93
4	400	out-of-S	-100
6	400	out-of-S	-300
7	400	out-of-S	-200
8	400	out-of-S	-275
9	400	out-of-S	-100
10	140	out-of-S	-5
13	145	out-of-S	-60
14	140	out-of-S	-10
20	300	out-of-S	-125
21	800	out-of-S	-430
22	900	out-of-S	-650
27	130	out-of-S	-30
29	400	out-of-S	-100
32	300	out-of-S	-210
37	175	out-of-S	-50
39	130	out-of-S	-45
40	130	out-of-S	-45
41	130	out-of-S	-45
42	175	out-of-S	-110
43	175	out-of-S	-100
45	175	out-of-S	-50
50	175	out-of-S	-103
51	175	out-of-S	-30
63	130	out-of-S	-5
64	130	out-of-S	-5
65	130	out-of-S	-75
66	130	out-of-S	-75
68	130	out-of-S	-68.5
69	130	out-of-S	-68.5

70	400	out-of-S	-210
73	400	out-of-S	-235
74	400	out-of-S	-290
75	400	out-of-S	-305
76	400	out-of-S	-275
77	400	out-of-S	-337
78	400	out-of-S	-80
79	400	out-of-S	-300
81	400	out-of-S	-100
86	400	out-of-S	-270

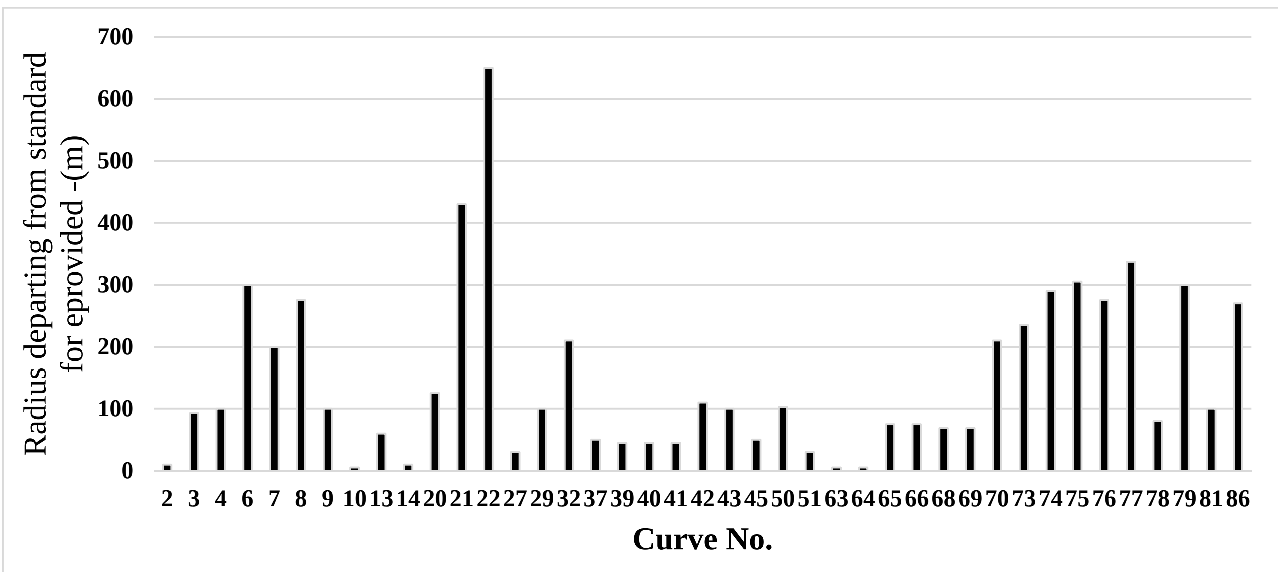


Figure 4.23: Horizontal curves with inadequate Radius and superelevation with their bend values

Taking the significant problematic curves and extracting off curves that satisfy the minimum curve radius specified in standard and taking that were not, identifies the hazardous or major problematic existing horizontal curves. The study investigated the horizontal curves that were not keep the minimum standard values were not treated in superelevation provision. Thus, those curves were identified as defective sharp curves.

Table 4.6: Defective Horizontal curves

Curve No.	**R** required for **e** provided (m)	Result	Variation from Standard (m)
3	175	out-of-S	-93
13	145	out-of-S	-60
20	300	out-of-S	-125
27	130	out-of-S	-30
32	300	out-of-S	-210
37	175	out-of-S	-50
39	130	out-of-S	-45
40	130	out-of-S	-45
41	130	out-of-S	-45
42	175	out-of-S	-110
43	175	out-of-S	-100
45	175	out-of-S	-50
50	175	out-of-S	-103
51	175	out-of-S	-30
65	130	out-of-S	-75
66	130	out-of-S	-75
68	130	out-of-S	-68.5
69	130	out-of-S	-68.5
77	400	out-of-S	-337

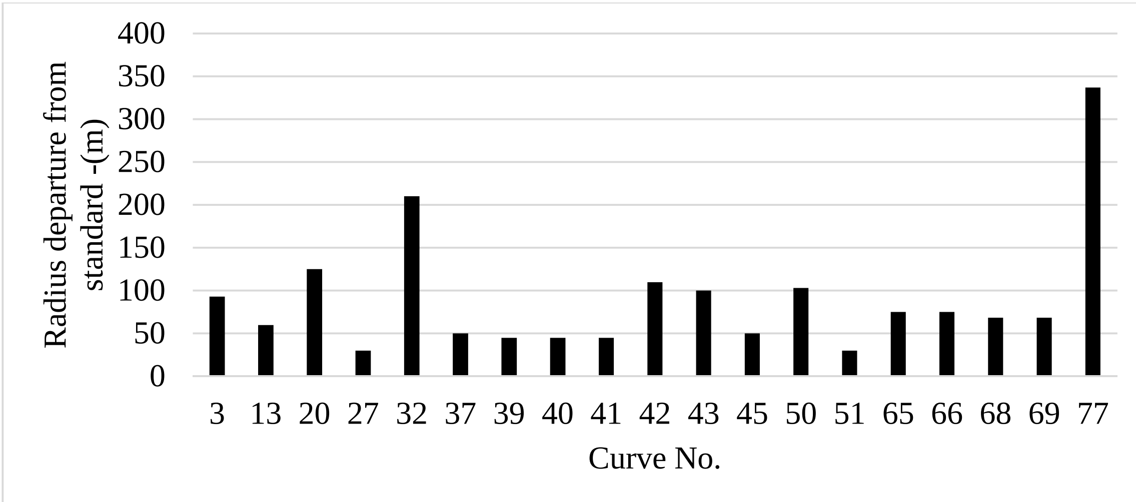


Figure 4.24: Sharp Horizontal curves and their bends from standard

Marking hazardeous Horizontal curves on Map

According to the above results, all of the curves identified as problamatic curves on the first program were also found on the second program. Which shows that the curves not kept to the minimum radius of a curve (that specified in standard) also doesn't treated on the provision of superelevation. So, this study concluded that the nineteen (19) horizontal curves were identified as the risky or 'black spot' locations of the road in the assessment of horizontal alignment and marked to their as-built locations. All the problamatic curves were marked to their original longitude and latitude locations of the digitized map of Mettu-Gore road by using ArcGIS 10.2 software.

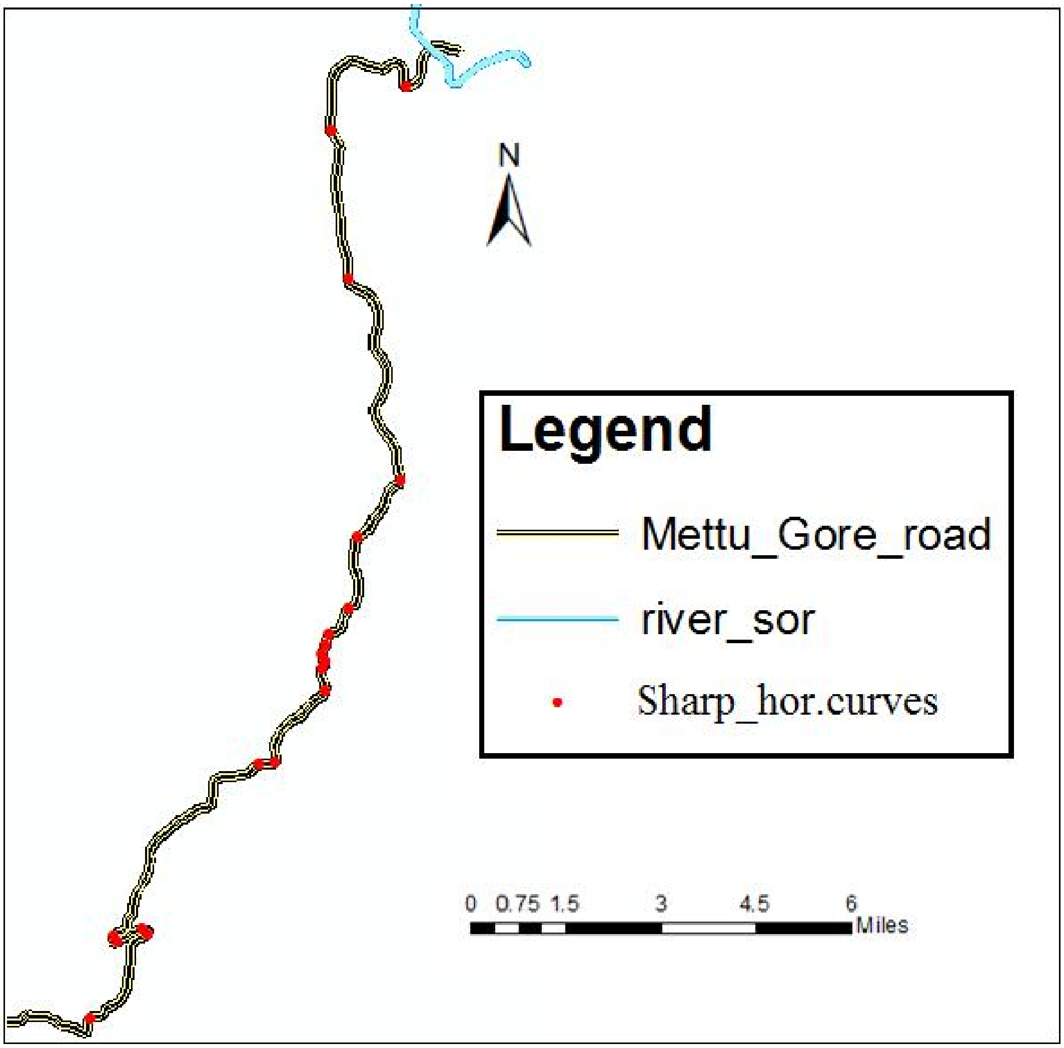


Figure 4.25: Marked defective horizontal curves

4.2.3. Assessment of Vertical Alignment

The two major aspects of vertical alignment are vertical curvature, which is governed by sight distance criteria, and gradient, which is related to vehicle performance and level of service. Vertical curves are required to provide smooth transitions between consecutive gradients. These curves transition between two sloped roadways and are important in allowing the driver to negotiate the roads elevation rate (grade).

The minimum lengths of crest and sag curves have been designed to provide sufficient stopping sight distance. These minimum length of vertical curves have been recommended based on design speeds and stopping sight distance requirements. They provide for ride comfort, appearance, and most importantly, safety. The design is based on minimum allowable "K" values.

$$L = KA$$

Where, L Length of vertical curve (m)

K Limiting value, horizontal distance required to achieve a 1% change in grade

A Algebraic difference in approach and exit grades (%)

Sight distance is the distance visible to the driver of a passenger car. For highway safety, the designer must provide sight distances of sufficient length that drivers can control the operation of their vehicles. They must be able to avoid striking an unexpected object on the traveled way.

The required minimum sight distance for vertical curves are given in ERA manual, 2013 in terms K values for the specific design speed. In this study, these values were used as the governing values for safe design of vertical curve.

Table 4.7: Minimum sight distance for crest vertical curve, ERA 2013

Design speed (Km/hr)	20	30	40	50	60	70	85	100	120
K for stopping sight distance	2	3	5	10	18	31	60	105	210

Table 4.8: Minimum sight distance for sag vertical curve, ERA 2013

Design speed (Km/hr)	20	30	40	50	60	70	85	100	120
K for stopping sight distance	2	4	8	12	18	25	36	51	74

Vehicle operations on gradients are complex and depend on a number of factors: severity and length of gradient; level and composition of traffic; and the number of overtaking opportunities on the gradient and in its vicinity. Important criterion for maximum gradient:

- ✓ Greatly affects the serviceability and cost of the road
- ✓ Standards for desirable maximum gradients are set to assure user comfort in safety terms and to avoid severe reductions in the design speed**.**

The vehicle fleet in Ethiopia is composed of a high percentage of vehicles that are underpowered and poorly maintained. Certain existing roads in fact are avoided and underutilized by traffic due to an inability to ascend the existing grades. The ERA finds it is in a position where it has no choice but to limit gradients based on the design vehicle of existing fleet, although this translates into an added cost to develop the road infrastructure.

Accordingly, the Design Standards of ERA Manual, 2013 specifies the basic limiting criteria for gradients including both desirable and absolute maximum values.

Table 4.9: Maximum gradients for DC5, ERA manual 2013

Terrain type	Flat	Rolling	Mountainous	Escarpment	Urban
Desirable (%)	4	6	8	8	7
Absolute (%)	6	8	10	10	7

An Excel program was developed on the basis of standard limiting values to extract the problematic segments of the existing vertical alignment design from those kept to design standard values. In this study, sight distance (S) and gradient (G) of the curves were the selected factors to assess the vertical alignment. Since the sight distance is directly related to the limiting value K (horizontal distance required to achieve 1% change in gradient), K was used to check the adequacy of the existing sight distance. The excel programs were designed for both sight distance and gradient. All As-built vertical alignment parameters are presented in Appendix A: Table-3 of this report.

The first result of the spread sheet shows that, there were found sixteen (16) vertical curves that doesn't provide adequate sight distance for the drivers and the result is shown in Table 4.10 and Figure 4.26.

Table 4.10: Existing Vertical curves with inadequate sight distance

Curve No.	standard value (K)	variation from standard (K)	Result
15	10	-1.622	out-of-S
22	31	-3.821	out-of-S
24	25	-7.735	out-of-S
25	31	-20.98	out-of-S
33	31	-2.359	out-of-S
34	25	-0.784	out-of-S
41	18	-5.678	out-of-S
52	31	-1.75	out-of-S
53	25	-6.275	out-of-S
55	25	-12.306	out-of-S
63	25	-1.031	out-of-S
70	18	-4.589	out-of-S
71	18	-5.579	out-of-S
84	18	-5.982	out-of-S
85	18	-5.858	out-of-S
87	18	-6.937	out-of-S

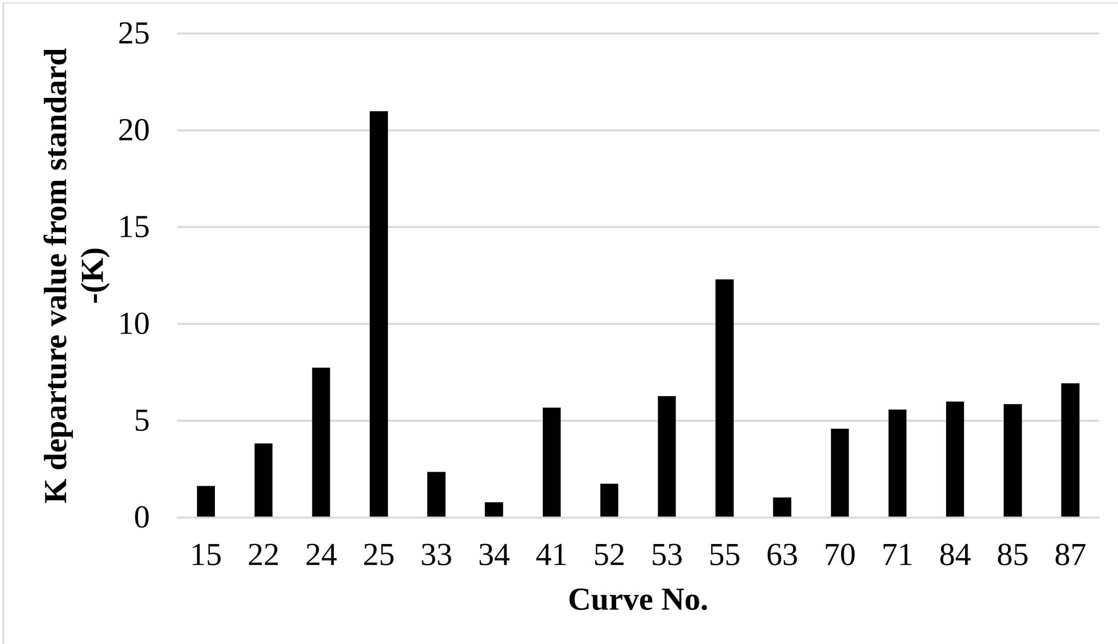


Figure 4.26: Defective Vertical curves and their bend values

When the result of the output says, K provided is “out-of-S” means that the existing sight distance on that vertical curve is less than the governing limit value of the design standard.

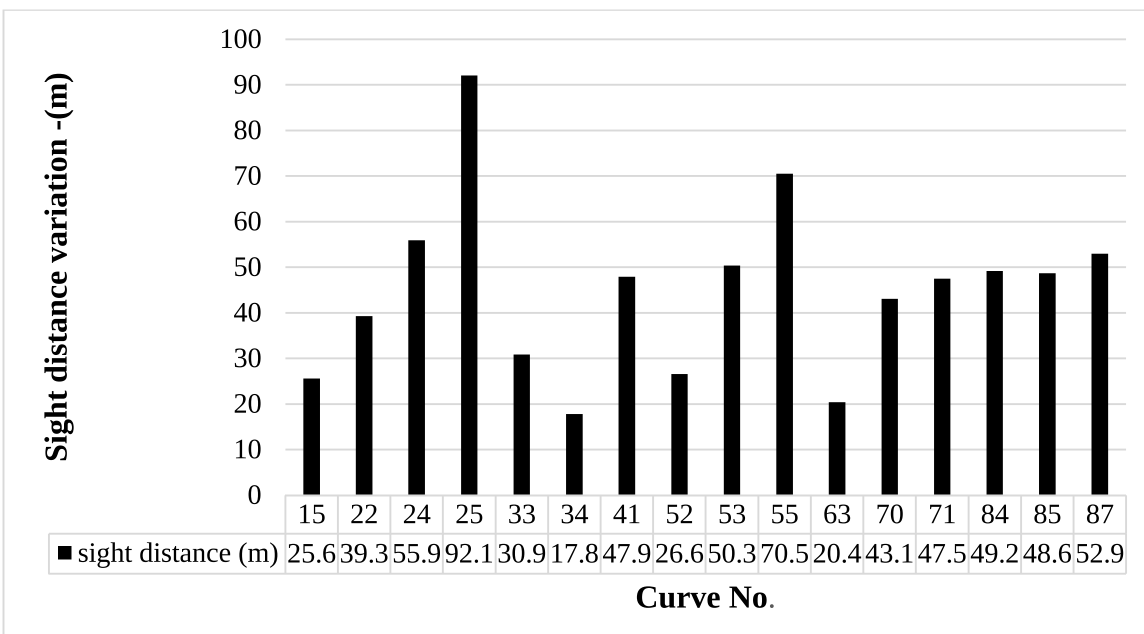


Figure 4.27: Defective vertical curves with their sight distance departure values

Maximum grade on a highway should be carefully selected based on the design speed and design vehicle for safe operation of the highway. The second program output verifies that on Mettu-Gore road, thirteen (13) grades of vertical alignment tangents were exceeded the desirable maximum grades of the design standard. Table 4.11 shows the provided high gradients on Mettu-Gore road.

Table 4.11: High Gradient Vertical tangents

Curve No.	Maximum standard value (%)	Variation (%)	Result
2	6	1.4	out-of-S
4	7	1.23	out-of-S
6	7	1.84	out-of-S
8	7	0.69	out-of-S
15	7	2.94	out-of-S
20	7	0.43	out-of-S
21	6	3.18	out-of-S
26	6	1.75	out-of-S
32	8	0.09	out-of-S
34	6	3.6	out-of-S
42	6	2.48	out-of-S
44	6	1.39	out-of-S
49	6	2.51	out-of-S
59	6	0.78	out-of-S
69	8	0.24	out-of-S
72	8	1.41	out-of-S
74	8	0.71	out-of-S
77	8	0.28	out-of-S
79	8	0.88	out-of-S
84	8	1.94	out-of-S
86	8	1	out-of-S
89	7	2.26	out-of-S
G2 of 89	7	3	out-of-S

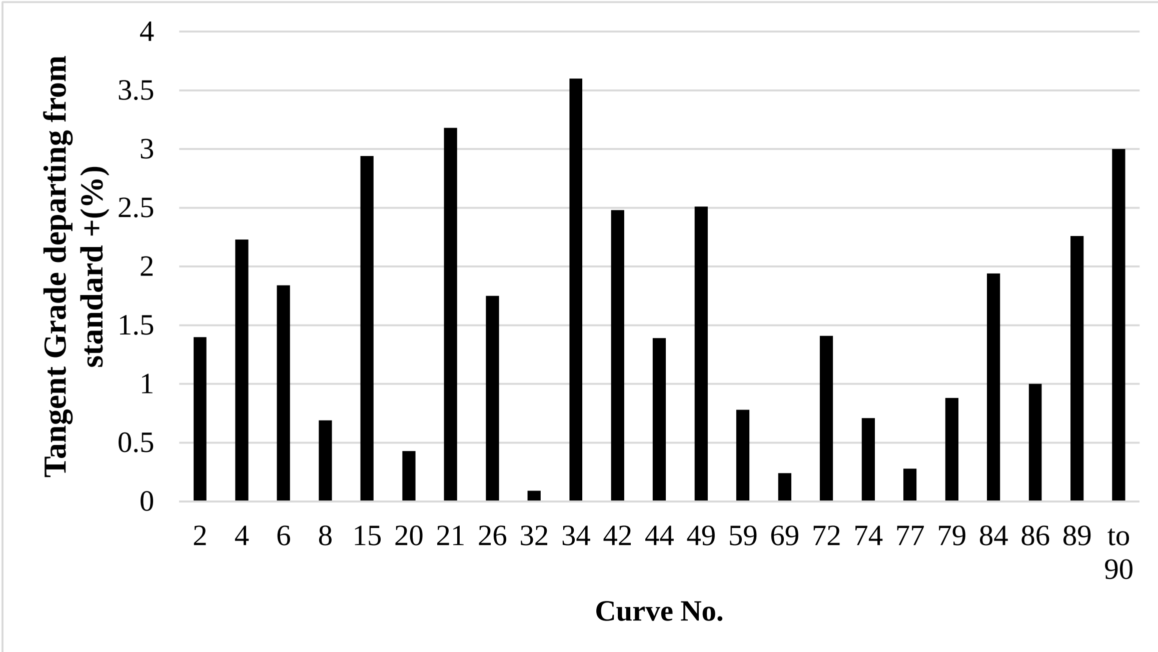


Figure 4.28: High gradient vertical tangents and departure values

Marking hazardous locations of the vertical alignment on map

The problematic or segments of the vertical alignment that were out-of-standard, were marked to their latitude and longitudinal locations on the digitized map. The problematic vertical curves were digitized as a point shape on the center of the vertical curve and the vertical tangent that were Out-of-Standards, were digitized as a polyline shape by drawing along their lengths.

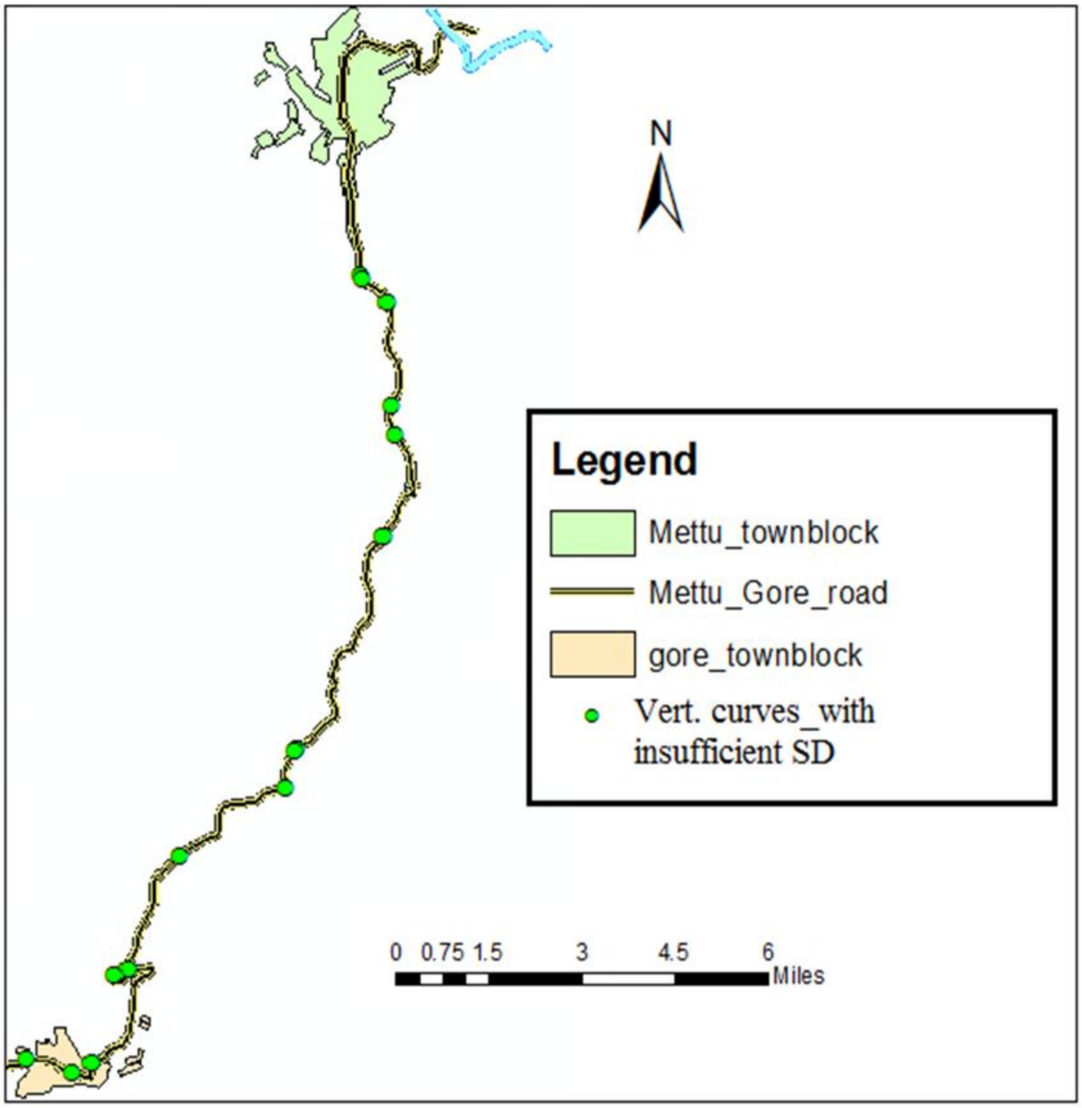


Figure 4.29: Marked Vertical curves that are Out-of-Standard

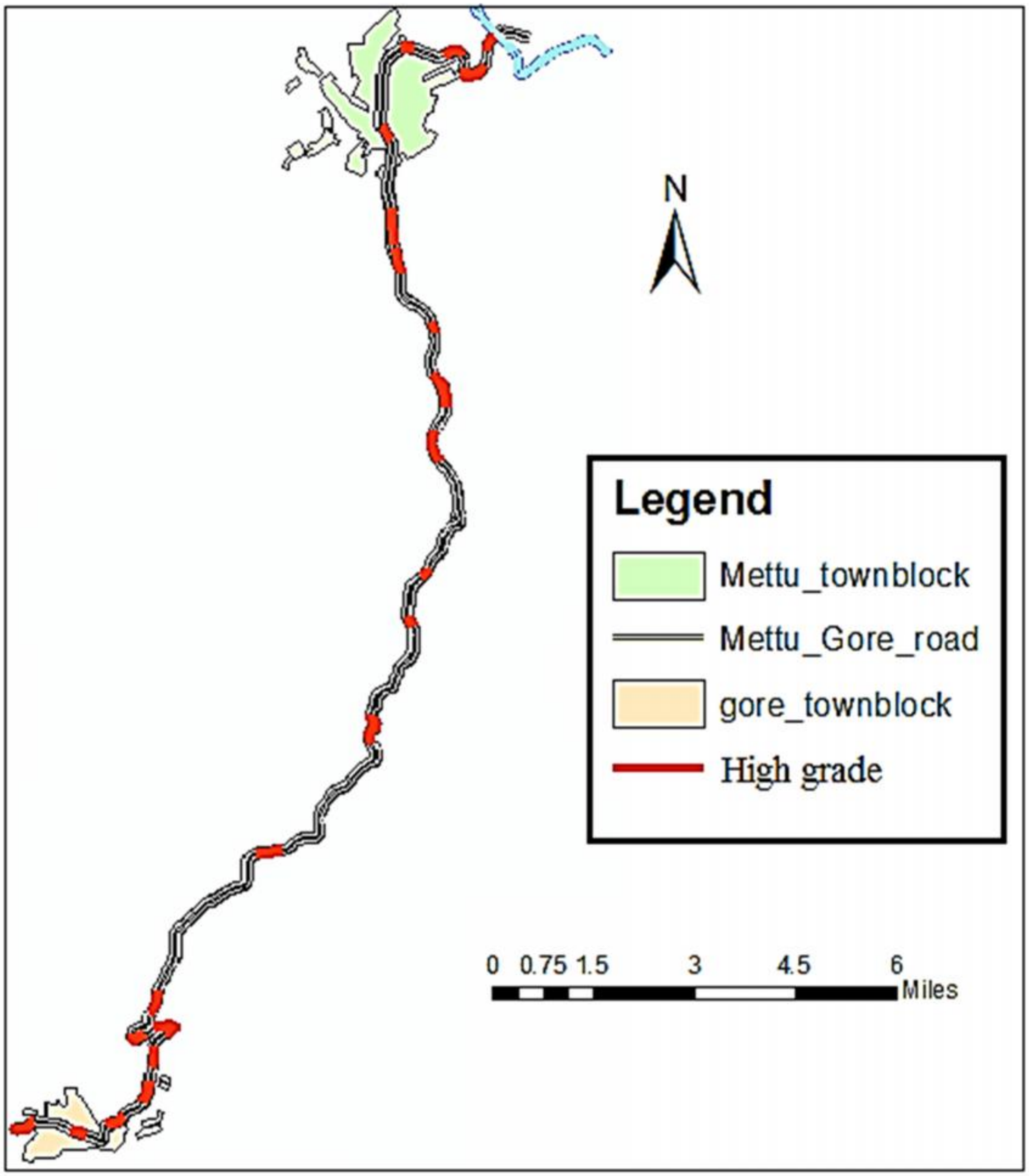


Figure 4.30: Drawn Vertical tangents that are Out-of-Standard

The significant problematic segments of the road was taken in order to identify the more risky locations and compiling both the problematic segments of the road due to insufficient sight distance and higher gradients. For gradient, segments of the road having variations greater than 1.5% from standards were identified as more risky locations. Thus, the compiled assessment result was digitized and mapped to show the hazardous geometric location.

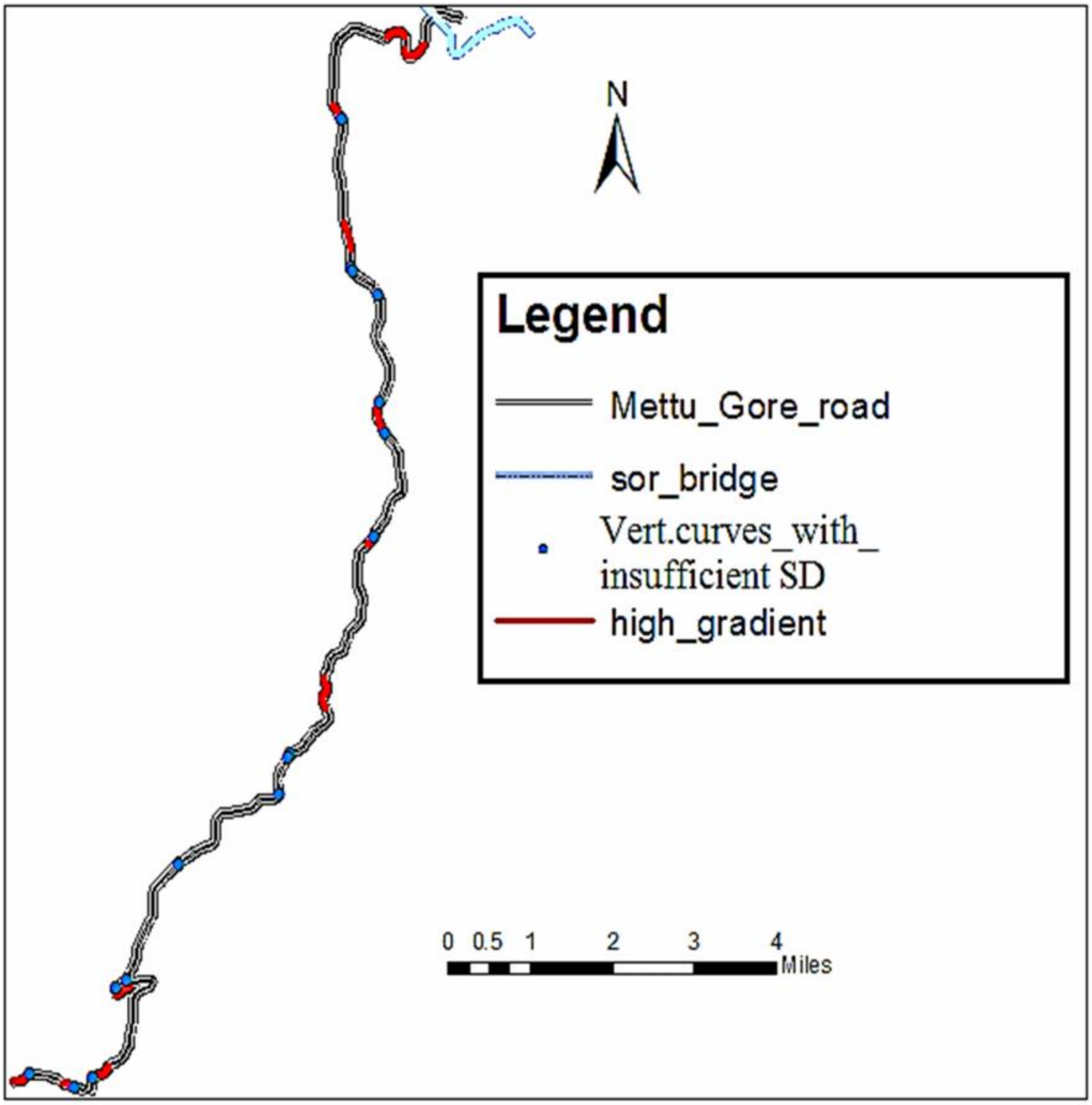


Figure 4.31: Defective locations of Vertical Alignment Map

4.3. Linking Geometric characteristics with accident Hot-Spot locations and recommended safety solutions

In the Previous sections of this chapter, accident analysis and road geometric assessments were discussed independently. In this section the researcher discussed, the five hot spot locations identified previously in accident analysis portion in correlation with the geometric assessment results of the specific areas and finally, recommends the applicable safety and engineering solutions to the 'black spot' locations according to their geometric design defects.

4.3.1. "Arat-kilo" square

This place was prioritized as the first accident Hot-Spot location of the road in accident analysis section of this Chapter. And the study found, four (4) basic defects of Geometric Design and the details are discussed as follows.

- Sharp Horizontal curves: horizontal curve number thirteen (13) is found at the first turn of "Arat-kilo" square
- High Gradient: the first grade (G1) of a vertical curve number fifteen (15) which meets "Arat-kilo" square directly have high gradient slope. Which is too risky to have such a grade at the center of a town.
- Insufficient sight distance of Vertical curve: a Vertical curve number fifteen (15) was designed with insufficient sight distance provision to the drivers, which is found on upper side of the square.

All of the defective segments with their bend values from standard limits and a descriptive map showing this location are presented in Table 4.12, Table 4.13 and Figure 4.32 below respectively.

Table 4.12: Horizontal curves depart from Standard on the first Hot-Spot

Curve No.	Description	Existing value	Departing from standard
13	Sharp curve	R=85m	-60m

Table 4.13: Vertical curves depart from Standard on the first Hot-Spot

Curve No.	Description	Existing value	Departing from standard
15	G1 with high gradient	G=9.94%	+2.94%
15	Insufficient sight distance	SD=58.15m	-25.60m

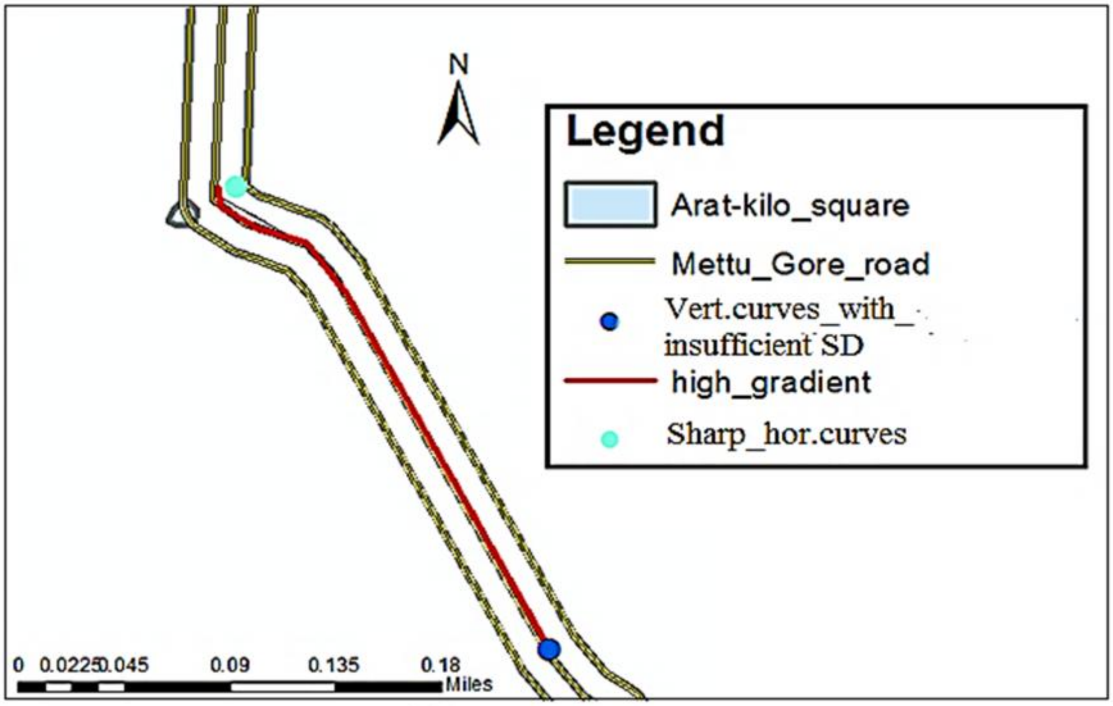


Figure 4.32: Map of “Arat-kilo” square with defective Geometric parameters

- The fourth problem identified were, In “Arat-kilo” square a small Roundabout is found but a roundabout with no rotary while roundabout was must have to be rotated counter clock wise, which doesn’t fulfill one of the basic roundabout design principle. The weaving width and lengths of this roundabout is very small so as to turn track-trailers. And unfamiliar or new drivers in this area getting in trouble of rotating the roundabout since there is no any sign of showing that the roundabout is not for a rotary. The satellite image of the square is shown in Figure 4.33 below.

Figure 4.33: Image of "Arat-kilo" square showing a Roundabout with no Rotary (Source: Google Earth)

Recommended Engineering solution

The recommended engineering solutions for this area was made for future upgrading of the road.

Selecting alternative routes

Mettu Structural Plan Map shows that there are an existing flatter minor roads which starts at "Arat-kilo" square and joins a roundabout named "Mettu square" which is found on Mettu-Gore road. Thus, this alternatives road were been decided to be the first and prime most alternative solutions for future upgrading. It were found that there are two possible alternative routes which are possibly ensure road safety on this area. Figure 4.34 below shows the structural plan map of Mettu town with the drawn alternative routes.

Figure 4.34: Safe Alternative routes at “Arat-kilo” square (Source: Structural plan map of Mettu town)

The contour data found on Structural Plan Map of Mettu town was digitized and exported to Anadelta Tessera software for terrain modeling and then, design of upgrading the alternative routes were done in this software.

The Horizontal and Vertical alignments of the alternative routes were designed with in safe design standard values by using Anadelta Tessera software. Horizontal alignment and profile of the alternative roads are shown in Figure 4.35 and figure 4.36 with existing other road networks.

Horizontal alignment drawing

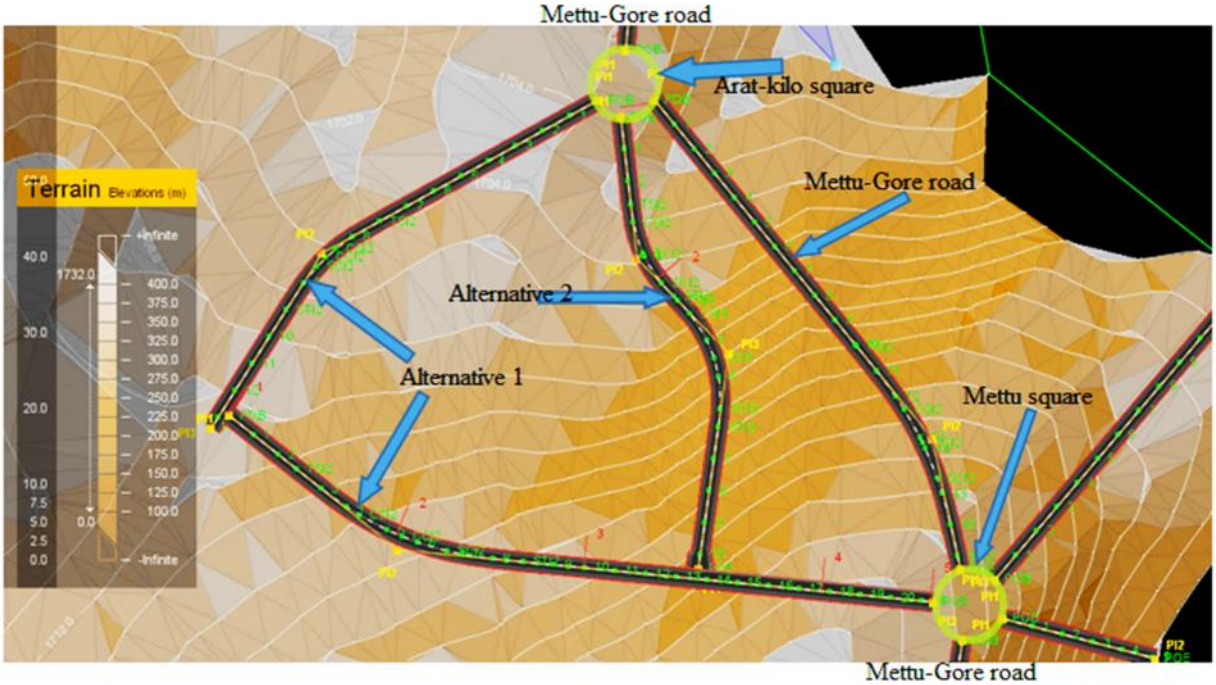


Figure 4.35: Horizontal alignment drawings for the selected alternative roads at "Arat-kilo"

Profile drawing

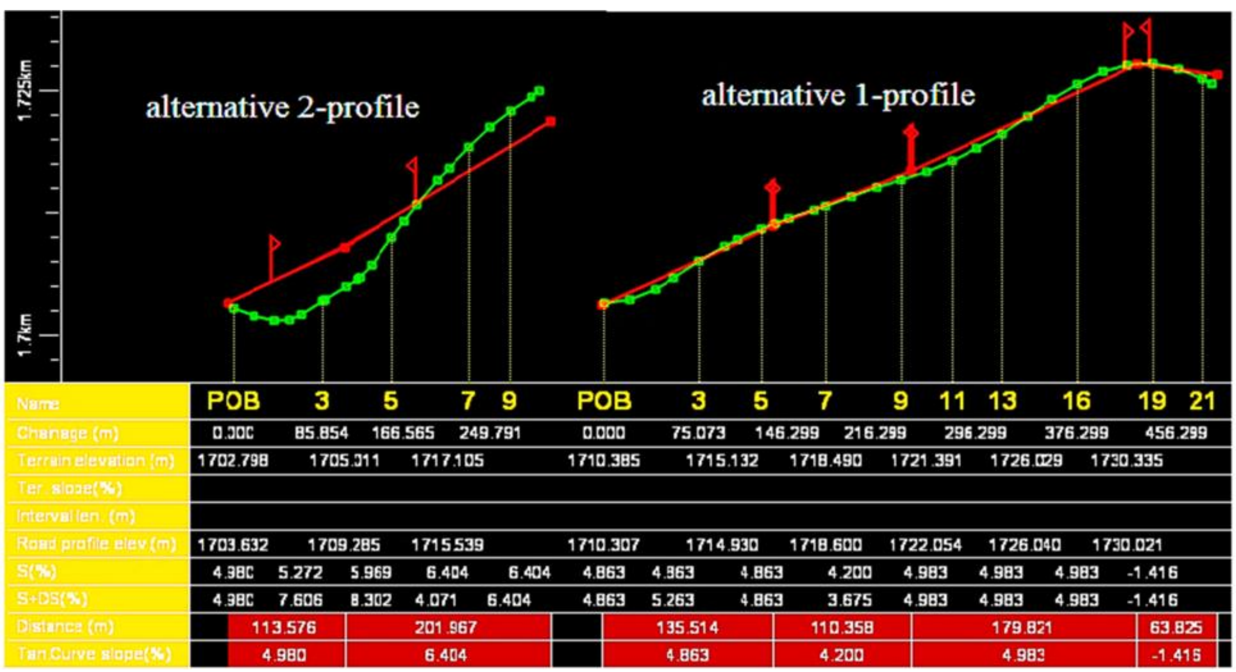


Figure 4.36: Profile drawings of safe alternative roads at "Arat-kilo" square

The upgrading design values of the two alternative road shows the advantage and disadvantages of the proposed routes and this are listed as follows. The choice for implementation of the alternative routes will be decided on the desired user costs and highway costs.

Alternative 1

- Very gentle grade than alternative 2
- Longest path
- Asphalt road
- More access to towns such as hospital and town blocks

Alternative 2

- Grade slope of 6.404% is found
- Shortest path
- More earthwork

Recommended safety countermeasures

- Identification of geometric type: The geometric type of "Arat-kilo" square has been identified as a four legged 'uncontrolled intersection'.

Commonly known contributing factors affecting safety at intersection are:

- Number of legs
- Angle of intersection
- Sight distance
- Alignment
- Turning radii
- Lane and shoulder width
- Approach speed
- Driveways
- Auxiliary lanes
- Friction and so on

- Factors affecting safety at "Arat-kilo" square:
    1. Alignment: the designed roundabout is not rotated and aligned off the center thus, increasing car-to-car collision opportunity;
    2. Turning radii- sharp curve found at the bend of the intersection
    3. Inadequate sight distance
    4. Approaching speed- vehicles moving down on the high gradient are over speeding due to the uncontrolled down gradient force.
- The selected safety countermeasures: Finally, it has been decided to control the safety problems of this area by speed management techniques of 'enforcement speed control' and the applicable safety procedures are listed alternatively as follows.

Alternative 1

Adequate Roundabout design for the design vehicle with central alignment and ensure that vehicles in all road segments have access of rotary in counter-clock wise direction. Roundabout is one of the speed management technique by letting drivers to negotiate themselves for rotary thus, vehicles at this roundabout are forced to slow down and negotiate in order to rotate (Counter-Clock wise) and pass the roundabout safely.

Alternative 2

Construction of transverse ramp strips on the longest and high gradient straight segments of the road is a safety solution that were made in the study. Thus, vehicles on that segment will forced to slow and alerted to be careful. Figure 4.37 shows the recommended transverse ramp provision at "Arat-kilo" square.

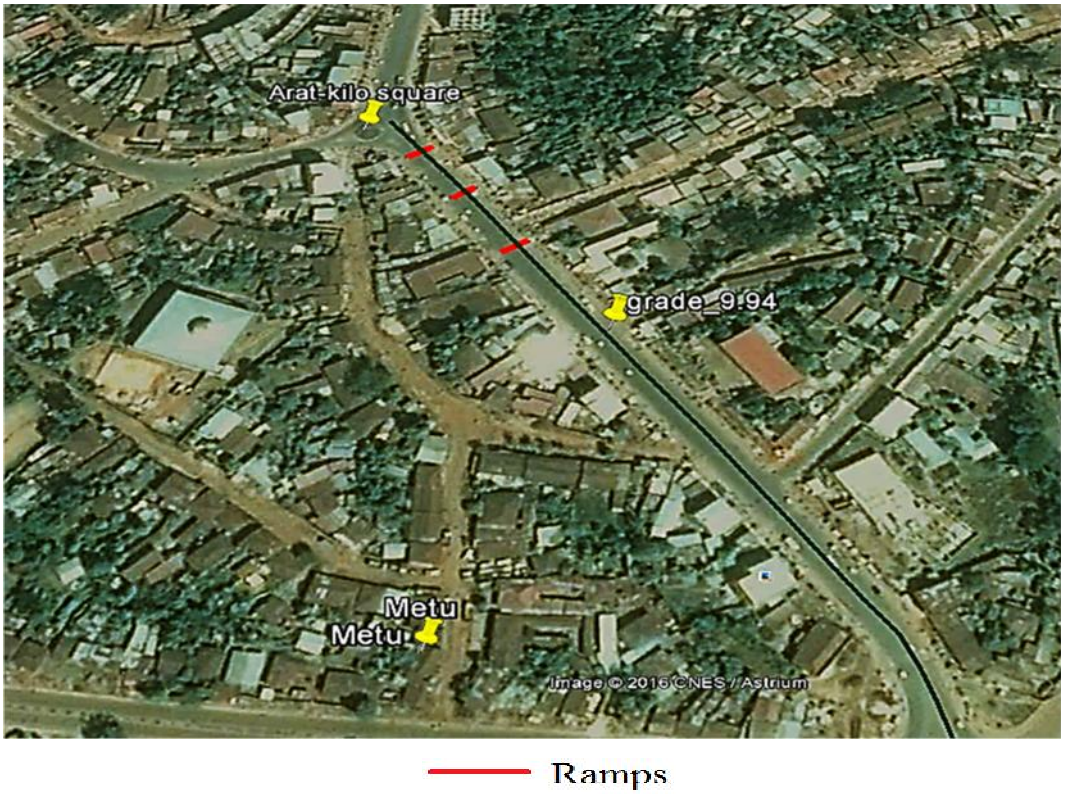


Figure 4.37: Ramp Provision proposal at "Arat-kilo" square

Alternative 3

Traffic signal provision at "Arat-kilo" square was found as the third alternative safety countermeasures recommended. Which is a well-known traffic management method to control car-to-car collision by ensuring no collisions result for each phase signal.

4.3.2. "S-curve" near to the entrance to Gore town

This was the second prioritized accident hot spot location in the accident analysis of Mettu-Gore road. And in this section, the study were investigated there are found three (3) geometric design defects and discussed as follows in table and map description.

- Sharp horizontal curves: in this location four sharp horizontal curves were found.
- High gradient: the first gradient (G1) in a vertical curve number 72 is high gradient slope.
- Insufficient sight distance: Curve number 70 and 71 were designed with inadequate sight distance.

Table 4.14: Horizontal curves depart from Standard on the second Hot-Spot

Curve No.	Description	Existing value	Departing from standard
65	Sharp curve	R=55m	-65m
66	Sharp curve	R=55m	-65m
68	Sharp curve	R=61.5m	-58.5m
69	Sharp curve	R=61.5m	-58.5m

Table 4.15: Vertical curves depart from standard on the second Hot-Spot

Curve No.	Description	Existing value	Departing from standard
70	Insufficient sight distance	SD=72.47m	-43.057m
71	Insufficient sight distance	SD=69.63m	-47.475m
72	G1 is high gradient	G=9.41%	+1.41%

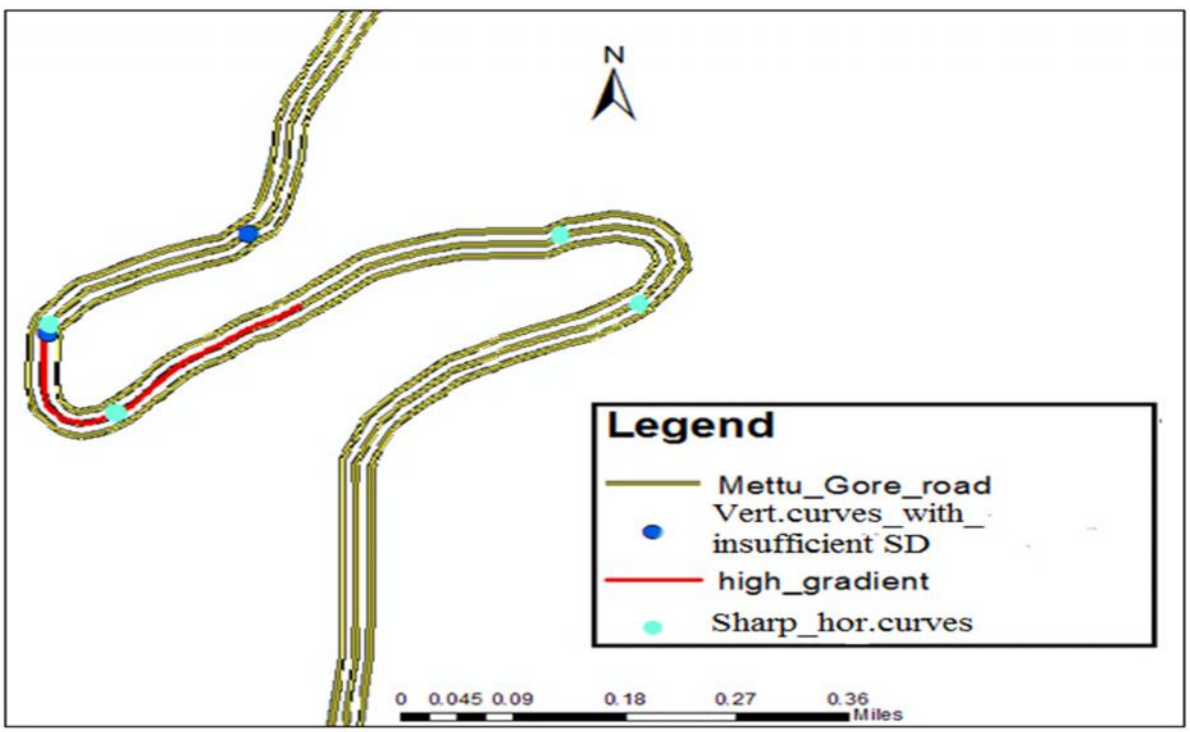


Figure 4.38: Map of "S-curve" on the entrance to "Gore" town with Geometric Design defects

Recommended safety countermeasures

- Providing guardrail for the first turn which was designed on the high gradient slope. The first turn needs high care since the horizontal sharp curves was designed on a gradient slope
- Posting traffic signs on both entrance sides of the S-curve
  - ✓ Warning sign post showing that there is a dangerous S-curve ahead and
  - ✓ Speed limit post that the drivers must have to keep

  Should have to be provided 50 meters before approaching the curve

- Clearing zones for adequate sight line: The drivers have a problem of observing the vehicles coming from opposite direction since mountains and trees are densely found inside the clear sight distance. Thus, sight obstructions must have to be cleared to a distance that will provide sufficient visibility for the drivers by ensuring the sight distance is at-least equal to safe stopping distance.

4.3.3. Around "Bechano and Gagi" area

This area were observed with dense continuous sharp horizontal curves, high gradient slope and insufficient sight distance for vertical curves and detail of the investigated geometric design bends were summarized in the following tables.

Table 4.16: Horizontal curves depart from Standard on the third Hot-Spot

Curve No.	Description	Existing value	Departing from standard
39	Sharp curve	R=85m	-35m
40	Sharp curve	R=85m	-35m
41	Sharp curve	R=85m	-35m
42	Sharp curve	R=65m	-110m
43	Sharp curve	R=75m	-100m
45	Sharp curve	R=125m	-50m
50	Sharp curve	R=72m	-103m
51	Sharp curve	R=145m	-30m

Table 4.17: Vertical curves depart from Standard on the third Hot-Spot

Curve No.	Description	Existing value	Departing from standard
49	G1 is high gradient	G1=8.51%	+2.51%
52	Insufficient sight distance	SD=108.24m	-26.59m
53	Insufficient sight distance	SD=86.97m	-50.35m
55	Insufficient sight distance	SD=71.61	-70.51m

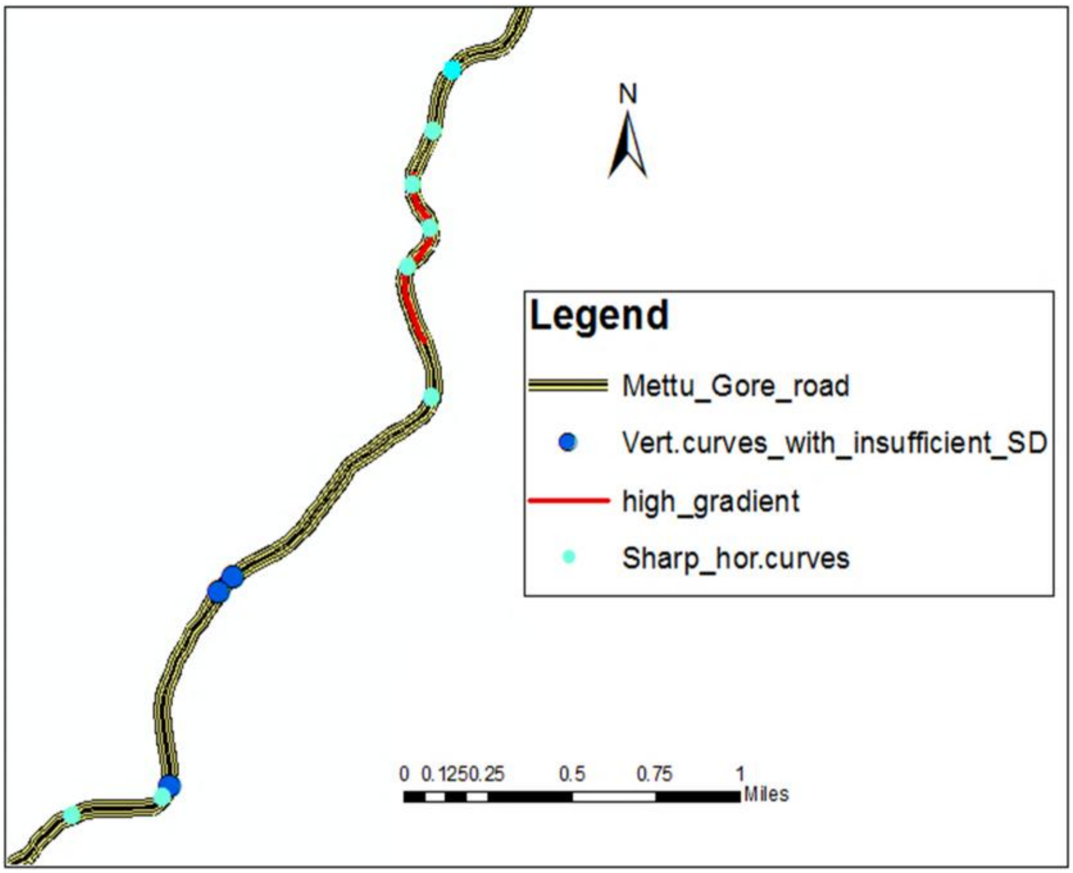


Figure 4.39: Map of the road around "Bechano and Gagi" with Geometric defects

Recommended safety countermeasures

- ❖ Warning sign posts: to warn the drivers there are zigzagged continuous curves ahead. This warning sign will help the drivers to have information of the dangerous road ahead and make them alert and pass carefully.

- Increasing the widening width of the road: the widening widths of the existing road in this black spot area are very small so as to treat the psychological comfort of the drivers while they are traversing this continuous sharp curves.

4.3.4. "Sor-Bridge" in Mettu town

The identified dangerous geometric characteristics were summarized in the following tables.

Table 4.18: Horizontal curves depart from Standard on the fourth Hot-Spot

Curve No.	Description	Existing value	Departing from standard
3	Sharp curve	R=82m	-93m

Table 4.19: Vertical curves depart from Standard on the fourth Hot-Spot

Curve No.	Description	Existing value	Departing from standard
4	G1 is high gradient	G=8.23%	+1.23%
6	G1 is high gradient	G=8.84%	+1.84%

The identified black spot location of the road around "Sor-bride" is presented with the marked and digitized dangerous As-built Geometric characteristics of the road in a visual descriptive map form in Figure 4.40 below.

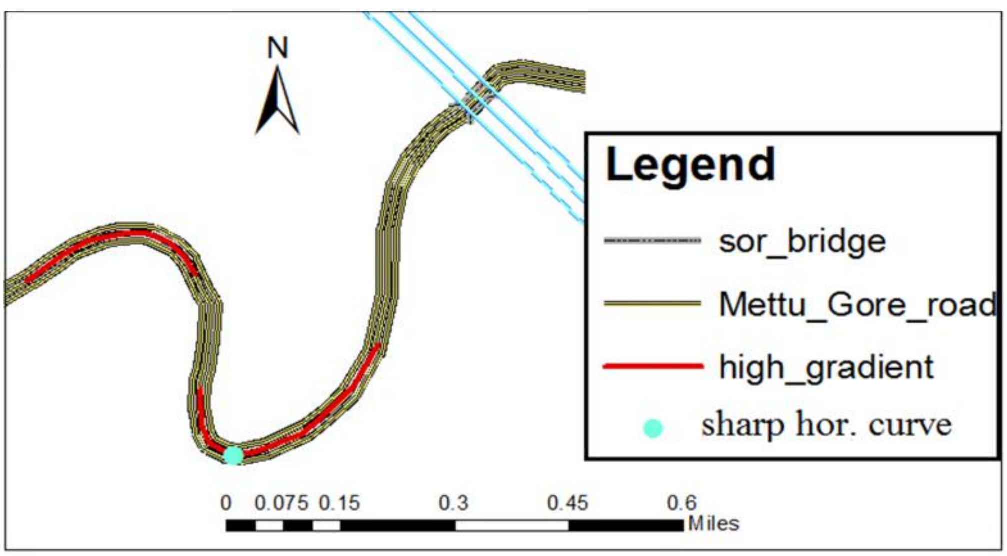


Figure 4.40: Map of the road around "Sor-bridge" with defective Geometry

Recommended safety countermeasures

- ❖ As shown in Figure 4.41 below there are villages and coffee processing houses found at the outer sides of the sharp curve which increases the severity of accidents in that area. The town blocks are found on the deep down elevation relative to the road elevation which needs high fill thus, the study were decided that the provision of *lighting columns and protective guardrails* on the sharper curve is one of the safety procedures need to be implemented in this area.

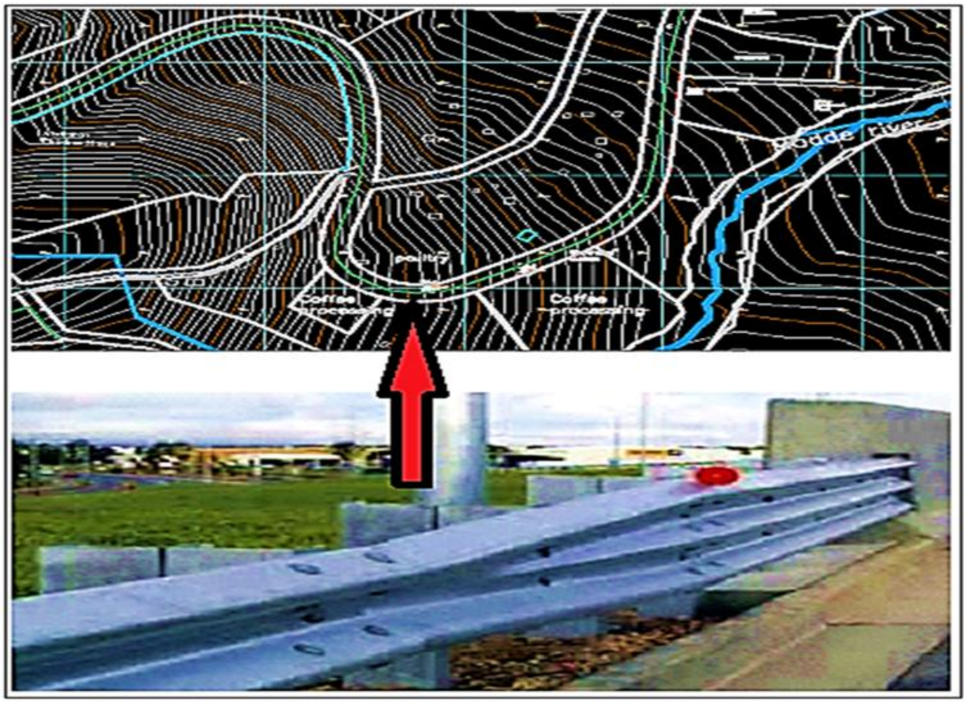


Figure 4.41: Recommended lighting column and protective guardrail, "Sor-bridge"

- ❖ Speed limit post and warning sign: the drivers must need to slow on this area since a sharp curve was designed on high gradient so, the drivers need to be informed which vehicle speed is safer and there is a dangerous road ahead.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusions

Generally, this study has investigated the effects of road geometry and route selection on accident rates on Mettu-Gore road. Results from road traffic accident analysis and geometric analysis have shown that road segments that combine the provision of inadequate sight distance, high gradient and sharp curve bends would have produce significant safety problems.

According to the findings and results revealed in this study, the following specific conclusions are drawn.

- The study sought to examine different geometric features on Mettu-Gore road particularly those containing dangerous geometric characteristics. The study were found using ArcGIS software is an inevitable tool to link accident hot spot areas with segments of the road containing dangerous geometric characteristics.
- .Moreover, the study confirmed the presence of accident differences in different physical geometric features of the road. For instance, close consecutive curves and high gradient segments of the road have very frequent accidents than dispersed curves and gentle segments of the road.
- The findings also agreed that elements of road geometry plays a vital role on road safety. For example, factors such as 'horizontal curvature' has been shown to be related to accident rates particularly at sharp curve bends. In addition, 'sight distance provision' such as inadequate sight distance have also been reported as contributing to lack of visibility of objects and therefore increases accident rates.

5.2. Recommendations

On the basis of the findings of the study and conclusions, the following recommendations were drawn

- Since the investigated study was about safety problems on Mettu-Gore road which was highly influenced by route selection and geometric characteristics, the specified safety counter measures of the study must have to be implemented.
- The research findings confirm that the implementation of safety countermeasures after the construction of roads are being very costy and difficult. And also, concluded the construction in Ethiopia had not been revised by safety audit teams during design phase prior to construction which is a headache of road safety. Thus, in the design of our roads ERA must have to include safety audit teams during design phase for those not constructed yet and also have to intervene the practical investigation of road safety audit report for the existing roads.
- The application of ArcGIS and GPS must have to be adoptable in police commission in order to have the exact global coordinate of accident locations and accident database records thus, decreasing data errors and tedious data acquisition and making road safety audit better and real.
- Based on deep understanding on the effects of road geometry and route selection on road safety, the safety solutions should be considered to minimize the current high frequency of accidents at the Black spots for the most ranked areas particularly for black spots, the proposed details in the findings and discussion parts were given. To summarize, the following recommendations should be implemented.
    - ✓ Upgrading of the alternative routes
    - ✓ Clearing trees or other obstructions from the inner sight lines of the roads
    - ✓ Provide new guard fencing and lighting columns at sharp curves
    - ✓ Curve widening
    - ✓ Posting traffic signs such as speed limit, warning sign, informative sign at curve bends
    - ✓ Appropriate or safe roundabout upgrading

- ✓ Traffic signal provision
- ✓ Transverse ramp construction

- Road traffic accidents cost the country a lot of resources in terms of deaths, injuries and destruction of property. I recommend further research on the detailed information about total costs of accidents in Ethiopia.
- The road transport regulation in Ethiopia was absence of activities to regularly update. I recommend further research on the effects of transport regulation and policy on the safety performance of the road transport industry in Ethiopia.

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APPENDICES

Appendix A: Actual data and analysis results on Mettu-Gore Road

Table A-1: Average daily traffic summarized by districts, ERA Annex, 1 2013

ANNEX I

AVERAGE DAILY TRAFFIC SUMMARISED BY DISTRICT 16/09/2013

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Station	Location	Direction	Car	Land Rover	Small Bus	Large Bus	Small Truck	Medium Truck	Heavy Truck	Truck Trailer	Total
0801	ASENDABO	WELKITI	9	81	147	59	107	137	86	83	709
0802	OMONADA JUNCTION	A ASENDABO	15	224	286	64	18	283	248	128	1,266
		B JIMMA	12	223	265	59	18	398	361	141	1,477
0803	JIMMA (ERA COMP.)	ASENDABO	33	160	483	101	141	279	219	110	1,526
0804	SUNTEMA JUNCTION	A JIMMA	3	66	137	62	13	144	125	33	583
		B SHEBE	3	67	136	62	15	144	122	33	582
0805	SHEKI JUNCTION	A JIMMA	0	12	13	64	22	73	44	0	228
		B CHIDA	0	10	8	33	19	64	40	0	174
		C SHEKI	0	4	7	36	6	19	8	0	80
0806	BONGA JUNCTION	A SHEBE	0	112	104	31	35	117	116	66	581
		B SHISHINDA	0	130	185	27	42	139	127	62	712
		C BONGA	0	154	196	19	54	118	81	34	656
0807	TEPI JUNCTION	A BONGA	0	44	59	32	39	58	46	32	310
		B MIZAN	0	45	68	27	40	60	45	32	317
		C TEPI	0	18	34	17	16	38	28	20	171
0808	MIZAN (EAST)	SHISHINDA	0	53	49	24	73	134	51	3	387
0810	SUNTU JUNCTION	A JIMMA	9	68	474	42	111	202	50	25	981
		B AGARO	7	58	384	29	90	172	42	24	806
		C SUNTU	1	9	68	18	23	36	9	1	165
0811	GERA JUNCTION	A AGARO	5	69	285	26	119	130	107	27	768
		B BEDELLE	5	57	241	13	93	123	96	26	654
		C GERA	0	34	82	2	51	74	38	9	290
0812	BEDELLE (EAST)	AGARO	2	59	98	20	56	49	27	23	334
0813	ARJO JUNCTION	ARJO	2	105	97	14	59	125	116	12	530

ANNEX 1

AVERAGE DAILY TRAFFIC SUMMARISED BY DISTRICT

16 / 09 / 2013

8 JIMMA Cycle 3 Report Year 2012

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Station	Location	Direction	Car	Land Rover	Small Bus	Large Bus	Small Truck	Medium Truck	Heavy Truck	Truck Trailer	Total
0814	DEGA JUNCTION	A BEDELLE	1	53	67	22	32	61	68	45	349
		B METTU	1	52	68	23	32	61	68	43	348
0815	ALGE JUNCTION	A CHORA	1	69	87	15	16	67	51	20	326
		B METTU	1	60	74	13	13	50	40	18	269
		C ALGE	0	23	39	3	10	43	26	0	144
0816	GORE (EAST)	METTU	0	83	96	24	50	68	26	12	359
0817	GORE (WEST)	GAMBELLA	0	85	110	13	68	79	65	38	458
0818	MASHA	A GORE	0	32	25	1	45	27	20	1	151
		B TEPI	0	31	26	1	41	25	20	2	146
0819	WACHA JUNCTION	A CHIDA	0	11	0	22	11	20	7	0	71
		B SODO	0	10	0	20	9	20	7	0	66
0820	GAMBELLA	A JIKAWA	0	88	33	8	29	38	38	5	239
		B SHEBELE	0	23	9	0	14	20	16	2	84
0821	GAMBELLA	A ABOBO	0	91	25	11	100	27	55	15	324
		B EALIA DURA	0	40	7	2	43	27	21	11	151
0822	SAJA	FOFA	0	16	35	0	31	11	1	0	94
0823	AMAN JUNCTION	A MIZAN	3	90	272	35	88	146	39	25	698
		B TEPI	2	25	47	7	32	66	17	13	209
		C AMAN	3	77	246	30	71	107	25	17	576

Table A-2: As-built Horizontal curve parameters of Mettu-Gore Road

CURVE No.	R	e	CURVE No.	R	e	CURVE No.	R	e
1	255	7.3	**30**	350	6.7	**59**	270	8
2	190	7.9	**31**	325	6.7	**60**	250	7.3
3	82	8	**32**	90	6.7	**61**	300	6.7
4	300	5.6	**33**	1800	NA	**62**	160	8
5	350	5.6	**34**	210	7.9	**63**	125	8
6	100	8	**35**	330	6.7	**64**	125	8
7	200	7	**36**	260	7.3	**65**	55	8
8	125	8	**37**	125	8	**66**	55	8
9	300	2.5	**38**	250	7.3	**67**	250	6.7
10	135	3.8	**39**	85	8	**68**	61.5	8
11	220	3.3	**40**	85	8	**69**	61.5	8

12	5000	NA	**41**	85	8	**70**	190	7
13	85	4	**42**	65	8	**71**	500	3.9
14	130	3.8	**43**	75	8	**72**	600	3.9
15	1500	NA	**44**	175	8	**73**	165	7.4
16	450	2.5	**45**	125	8	**74**	110	8
17	400	2.5	**46**	300	6.7	**75**	95	8
18	630	2.5	**47**	260	7.3	**76**	125	7.2
19	500	5	**48**	260	7.3	**77**	63	8
20	175	3.5	**49**	360	5.7	**78**	320	5.6
21	370	2.5	**50**	72	8	**79**	100	7
22	250	NA	**51**	145	8	**80**	300	2.8
23	270	7.3	**52**	225	7.9	**81**	300	5.5
24	400	5.7	**53**	175	8	**82**	175	4
25	290	8	**54**	270	8	**83**	175	4
26	300	8	**55**	600	6.5	**84**	300	4
27	100	8	**56**	350	8	**85**	250	4
28	230	7.3	**57**	270	8	**86**	130	8
29	300	5.7	**58**	1750	2.5			

Table A-3: As-built Vertical curve parameters of Mettu-Gore Road

Curve No.	**Curve type**	**K**	**L**	**G1**	**G2**	**Curve No.**	**Curve type**	**K**	**L**	**G1**	**G2**
1	SAG	31.372	80	4.85	7.4	46	SAG	25.304	160	-3.54	2.78
2	CREST	43.039	160	7.4	3.68	47	CREST	31.352	290	2.78	-6.47
3	SAG	39.593	180	3.68	8.23	48	CREST	48.923	100	-6.47	-8.51
4	CREST	34.764	150	8.23	3.91	49	SAG	26.718	360	-8.51	4.96
5	SAG	30.431	150	3.91	8.84	50	CREST	33.939	110	4.96	1.72
6	CREST	30.961	320	8.84	-1.5	51	SAG	32.833	80	1.72	4.16
7	SAG	14.154	130	-1.5	7.69	52	CREST	29.25	280	4.16	-5.42
8	CREST	36.108	120	7.69	4.37	53	SAG	18.725	110	-5.42	0.46

9	CREST	18.919	140	4.37	-3.03	54	CREST	25.041	130	0.46	-4.82
10	SAG	36.684	130	-3.03	0.51	55	SAG	12.694	160	-4.82	7.99
11	SAG	28.678	180	0.51	6.79	56	CREST	50.509	80	7.99	6.4
12	CREST	21.883	160	6.79	-0.53	57	CREST	20.201	100	6.4	1.46
13	SAG	41.191	110	-0.53	2.14	58	SAG	25.344	135	1.46	6.78
14	SAG	17.964	140	2.14	9.94	59	CREST	31.412	160	6.78	1.69
15	CREST	8.378	120	9.94	-4.39	60	CREST	60.177	220	1.69	-1.97
16	SAG	48.244	240	-4.39	0.59	61	SAG	43.899	200	-1.97	2.59
17	SAG	41.725	250	0.59	6.58	62	CREST	32.297	220	2.59	-4.22
18	CREST	41.007	160	6.58	2.95	63	SAG	23.969	80	-4.22	-0.88
19	CREST	14.454	150	2.95	-7.43	64	SAG	37.59	160	-0.88	3.37
20	SAG	34.305	570	-7.43	9.18	65	CREST	32.245	210	3.37	-3.14
21	CREST	34.185	120	9.18	5.67	66	SAG	38.004	100	-3.14	-0.51
22	CREST	27.179	110	5.67	1.63	67	CREST	33.783	90	-0.51	-3.17
23	CREST	36.803	160	1.63	-2.72	68	SAG	30.669	350	-3.17	8.24
24	SAG	17.265	120	-2.72	4.23	69	CREST	118.26	150	8.24	6.97
25	CREST	10.02	120	4.23	-7.75	70	CREST	13.411	140	6.97	-3.47
26	SAG	25.844	270	-7.75	3.14	71	SAG	12.421	160	-3.47	9.41
27	SAG	25.844	270	-7.75	3.14	72	CREST	35.171	300	9.41	0.88
28	CREST	31.329	130	3.14	-1.01	73	SAG	31.946	250	0.88	8.71
29	SAG	26.14	140	-1.01	4.35	74	CREST	42.961	80	8.71	6.85
30	CREST	32.978	160	4.35	-0.5	75	CREST	42.196	80	6.85	4.95
31	CREST	21.083	160	-0.5	-7.09	76	SAG	24.022	80	4.95	8.28
32	SAG	39.538	520	-8.09	5.06	77	CREST	124.75	100	8.28	7.48
33	CREST	28.641	420	5.06	-9.6	78	SAG	71.653	100	7.48	8.88
34	SAG	24.216	260	-9.6	1.13	79	CREST	31.973	280	8.88	0.12
35	CREST	62.331	250	1.13	-2.88	80	SAG	18.609	145	0.12	7.91
36	SAG	63.682	250	-2.88	1.05	81	CREST	39.785	140	7.91	4.39
37	CREST	32.252	230	1.05	-6.08	82	SAG	47.268	120	4.39	6.93
38	SAG	56.707	80	-6.08	-4.67	83	SAG	66.342	200	6.93	9.94

39	CREST	126.34	80	-4.67	-5.31	84	CREST	12.018	140	9.94	-1.7
40	SAG	99.834	80	-5.31	-4.5	85	SAG	12.142	130	-1.7	9
41	SAG	12.322	160	-4.5	8.48	86	CREST	41.585	80	9	7.08
42	CREST	47.386	180	8.48	4.68	87	CREST	11.063	150	7.08	-6.48
43	SAG	36.946	100	4.68	7.39	88	CREST	28.828	80	-6.48	-9.26
44	CREST	53.772	260	7.39	2.55	89	SAG	134	100	-9.26	-10
45	CREST	31.171	190	2.55	-3.54						

Table A-4: RTA data on Mettu-Gore Road

Accident data from Mettu and Gore town police commission									
Year	**Phase**	**Fatal Injury**		**Incapacitating Injury**		**Possible Injury**		**Property Damage Only**	
		Mettu	Gore	Mettu	Gore	Mettu	Gore	Mettu	Gore
2004	1st	0	3	1	0	0	2	1	2
	2nd	2	0	2	1	3	1	0	1
	3rd	2	0	2	4	2	0	0	0
	4th	1	3	7	1	1	0	3	5
	SUM	**11**		**18**		**9**		**12**	
				Mettu		Gore		**SUM**	
	Estimated property damages (Birr)			780,425		862,490		**1,642,915**	
2005	1st	1	2	0	2	0	0	2	3
	2nd	2	0	3	3	3	0	1	3
	3rd	1	0	2	3	1	2	2	0
	4th	5	2	6	1	4	1	3	4
	SUM	**13**		**20**		**11**		**18**	
				Mettu		Gore		**SUM**	
	Estimated property damages (Birr)			1,847,000		880,370		**2,727,370**	
2006	1st	1	2	1	1	3	0	2	0
	2nd	0	2	2	1	1	1	0	1
	3rd	4	0	1	3	5	1	6	4
	4th	3	2	3	5	0	2	1	2
	SUM	**14**		**17**		**13**		**16**	
				Mettu		Gore		**SUM**	
	Estimated property damages (Birr)			2,150,888		3,485,230		**5,636,118**	
	1st	2	2	0	3	3	0	1	4
	2nd	1	1	3	2	4	0	1	7

2007	3rd	1	0	4	2	6	1	5	1
	4th	3	2	7	1	3	4	5	1
	SUM	**12**		**22**		**21**		**25**	
				Mettu		Gore		**SUM**	
	Estimated property damages (Birr)			3,984,245		1,980,420		**5,964,665**	

Table A-5: Spatial locations of RTAs

Accident Locations Recorded on Mettu and Gore Police Commission Booklets																
Locations	**2004**				**2005**				**2006**				**2007**			
	FI	II	PI	PDO	FI	II	PI	PDO	FI	II	PI	PDO	FI	II	PI	PDO
1.Sidist-Mato mountain, Sor-River	2	1	0	1	3	4	0	2	2	3	1	2	1	5	2	1
2. Ilu Car Learners	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	3
3. Total, Mettu town	0	0	1	1	1	0	1	0	0	1	0	0	0	0	0	0
4. Post Office, Mettu	1	1	0	0	2	2	1	2	1	1	2	0	1	2	0	1
5. Sena Hotel	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	3
6. Arat-Kilo	4	3	4	0	4	8	1	1	6	3	2	4	4	7	3	5
7. Mettu Square	0	0	0	0	0	0	1	1	0	0	1	0	1	2	0	0
8. China Road Construction Camp	2	1	0	0	0	0	0	0	0	1	1	0	1	0	3	0
9. Ihud Gebya	0	0	0	2	0	0	1	0	0	0	1	0	0	1	2	1
10. Bechano and Gagi Area	0	5	1	1	1	4	2	2	1	3	2	2	1	5	3	1
11. S-curve, Gore town	2	7	0	0	2	1	4	5	3	2	2	3	3	0	5	7
12. Gore town square	0	0	0	3	0	0	0	2	0	0	0	1	0	0		2
13. Others	0	0	3	0	0	1	0	2	1	2	1	3	0	0	2	1
Total	11	18	9	9	13	20	11	18	14	17	13	16	12	22	21	25

Table A-6: Accident Hot-Spot analysis result of ArcGIS

OBJECTID	SOURCE_ID	ICOUNT	GiZScore	GiPValue	Gi_Bin
1	1	4	-0.359501	0.71922002	0
2	2	4	-0.358629	0.71987258	0
3	3	8	-0.106251	0.91538296	0
4	4	16	0.1263205	0.89947821	0
5	5	8	0.1762807	0.86007345	0
6	6	8	0.174676	0.86133422	0
7	7	1	-1.007013	0.31392864	0
8	8	1	-0.893778	0.3714408	0
9	9	1	-1.003986	0.3153852	0
10	10	1	-0.274834	0.78344382	0
11	11	2	-0.625418	0.5316969	0
12	12	28	1.9608662	0.04989463	2
13	13	32	2.5989918	0.0093498	3
14	14	21	2.3068257	0.02106454	2
15	15	16	2.6022431	0.00926162	3
16	16	36	2.599355	0.00933991	3
17	17	56	2.3538205	0.01858158	2
18	18	4	2.6040928	0.00921178	3
19	19	2	2.0843789	0.03712572	2
20	20	9	-0.651134	0.51496032	0
21	21	1	-0.455665	0.64863076	0
22	22	9	-0.692789	0.48844222	0
23	23	1	-0.47546	0.6344594	0
24	24	1	-0.566085	0.57133626	0
25	25	1	-0.797058	0.42541738	0
26	26	1	-0.66476	0.50620426	0
27	27	8	0.0537476	0.95713628	0
28	28	8	0.7251958	0.46833192	0

29	29	12	1.2155371	0.22416134	0
30	30	16	1.1193616	0.26298592	0
31	31	28	0.9553391	0.33940627	0
32	32	32	1.066873	0.28602922	0
33	33	4	1.075479	0.28216032	0
34	34	5	1.0028367	0.31593969	0
35	35	13	0.5706204	0.56825701	0
36	36	13	-0.105403	0.9160563	0
37	37	1	-0.136553	0.89138421	0
38	38	24	0.0749761	0.94023375	0
39	39	4	0.0751045	0.94013155	0
40	40	1	0.1798759	0.85725	0
41	41	13	-0.54672	0.58457141	0
42	42	1	-0.367768	0.71304657	0
43	43	1	-0.694743	0.48721627	0
44	44	2	-0.344988	0.73010371	0
45	45	2	-0.695612	0.48667162	0
46	46	8	-0.667258	0.50460735	0
47	47	1	-0.769208	0.44176964	0
48	48	2	-0.689941	0.49023123	0
49	49	2	-0.995268	0.31960607	0
50	50	1	-1.014801	0.31020054	0
51	51	1	-1.298522	0.194108	0
52	52	2	-1.289436	0.19724646	0
53	53	1	-1.200094	0.230103	0
54	54	2	-1.179081	0.23836579	0
55	55	1	-1.295396	0.19518379	0
56	56	1	-1.27361	0.20280184	0
57	57	1	-1.200027	0.23012898	0
58	58	1	-0.556108	0.57813698	0

59	59	13	-0.496631	0.61944959	0
60	60	1	-0.526728	0.59838271	0
61	61	2	-0.644331	0.51936091	0
62	62	9	-0.496264	0.61970835	0
63	63	1	-0.67326	0.50078218	0
64	64	1	-0.650981	0.51505902	0
65	65	5	-0.831213	0.4058536	0
66	66	5	-0.820479	0.41194334	0
67	67	2	-0.768503	0.44218839	0
68	68	5	-0.831463	0.40571202	0
69	69	11	-0.552795	0.58040375	0
70	70	1	-0.641293	0.52133262	0
71	71	5	-0.788247	0.43055209	0
72	72	2	-0.939789	0.34732604	0
73	73	1	-1.018257	0.30855599	0
74	74	1	-0.940924	0.34674377	0
75	75	1	-0.938223	0.34812978	0
76	76	1	-0.934064	0.35027083	0
77	77	1	-0.814699	0.41524461	0
78	78	3	-0.977677	0.32823415	0
79	79	2	-0.922708	0.3561596	0
80	80	2	-0.831836	0.40550161	0
81	81	10	-0.59413	0.55242531	0
82	82	3	-0.586511	0.55753225	0
83	83	3	-0.632836	0.52684107	0
84	84	1	4.3346319	1.46E-05	3
85	85	1	3.4462593	0.0005684	3
86	86	1	3.841157	0.00012246	3
87	87	10	2.0416653	0.04118475	2
88	88	125	3.443519	0.0005742	3

89	89	1	3.4442453	0.00057266	3
90	90	105	3.4249992	0.0006148	3
91	91	1	3.6779759	0.00023509	3
92	92	8	3.4170588	0.00063302	3
93	93	9	1.9430549	0.05200952	1
94	94	1	-0.624684	0.53217853	0
95	95	1	-0.618593	0.53618439	0
96	96	1	-0.624691	0.53217371	0
97	97	1	-0.77284	0.43961705	0
98	98	2	-0.448573	0.65374007	0
99	99	1	0.9601868	0.33696124	0
100	100	17	0.5145095	0.60689582	0
101	101	32	0.9421783	0.34610139	0
102	102	1	-0.886638	0.37527364	0
103	103	2	0.7737681	0.43906795	0
104	104	40	0.6238122	0.53275095	0
105	105	4	0.6629645	0.50735332	0
106	106	1	0.1682398	0.86639466	0
107	107	4	0.0531798	0.95758865	0
108	108	4	-0.712213	0.47633309	0
109	109	2	-0.070052	0.94415221	0
110	110	1	0.4342321	0.66411992	0
111	111	4	0.3250617	0.7451344	0
112	112	28	0.5367813	0.59141871	0
113	113	28	0.3263053	0.74419336	0
114	114	4	1.1149011	0.26489284	0

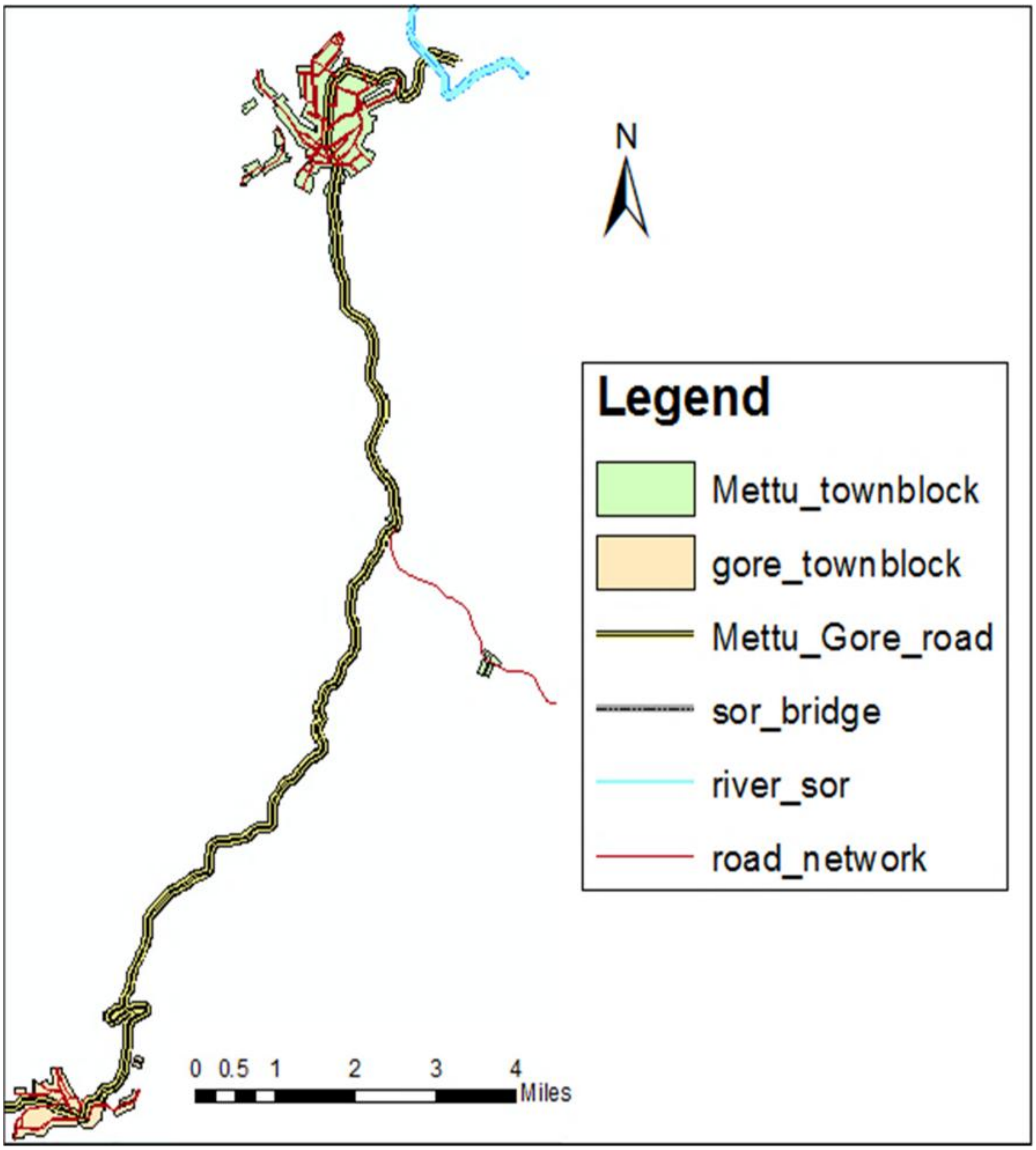

Figure A-1: Digitized map of Mettu-Gore road

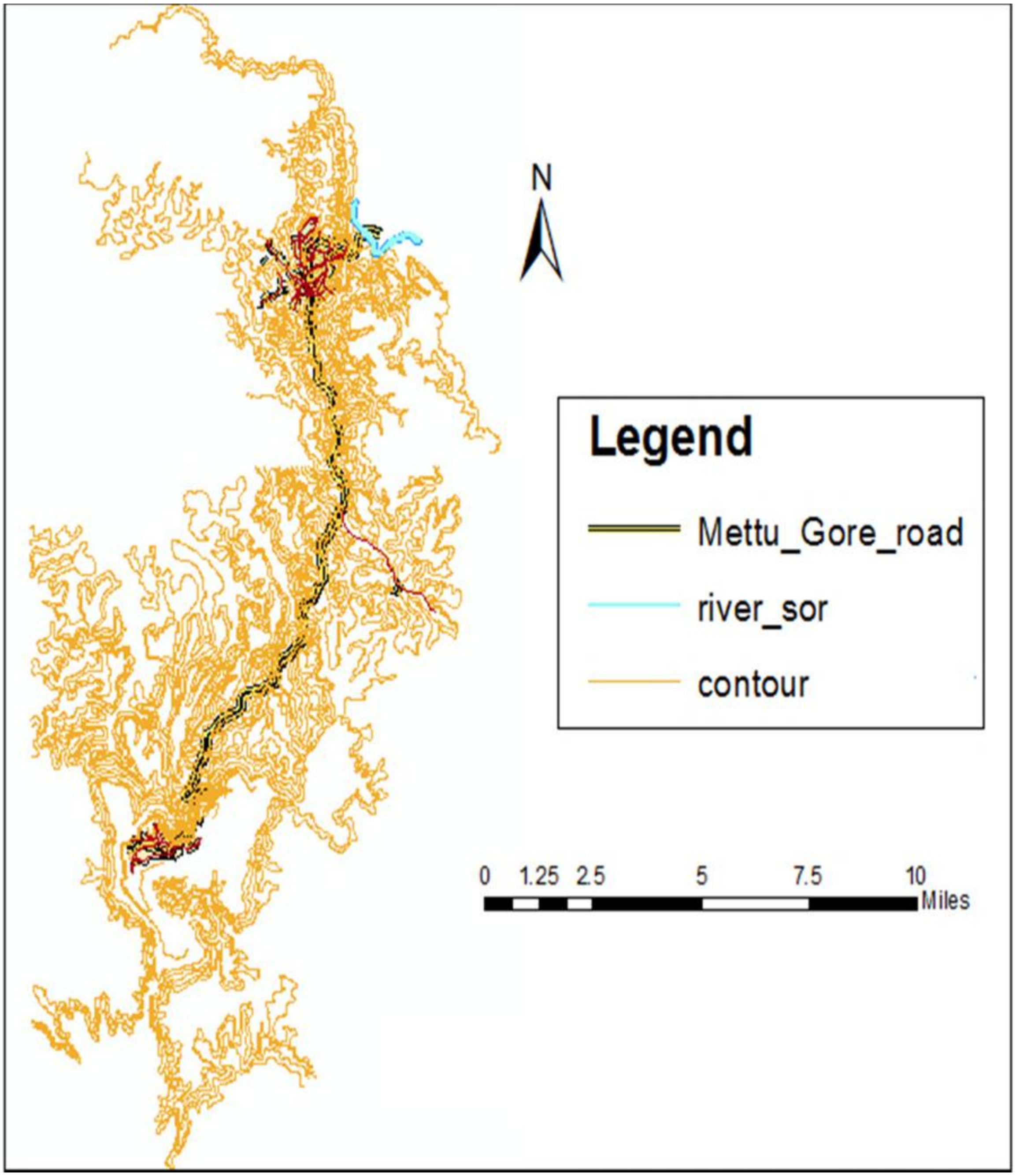

Figure A-2: Digitized contour map of Mettu-Gore road

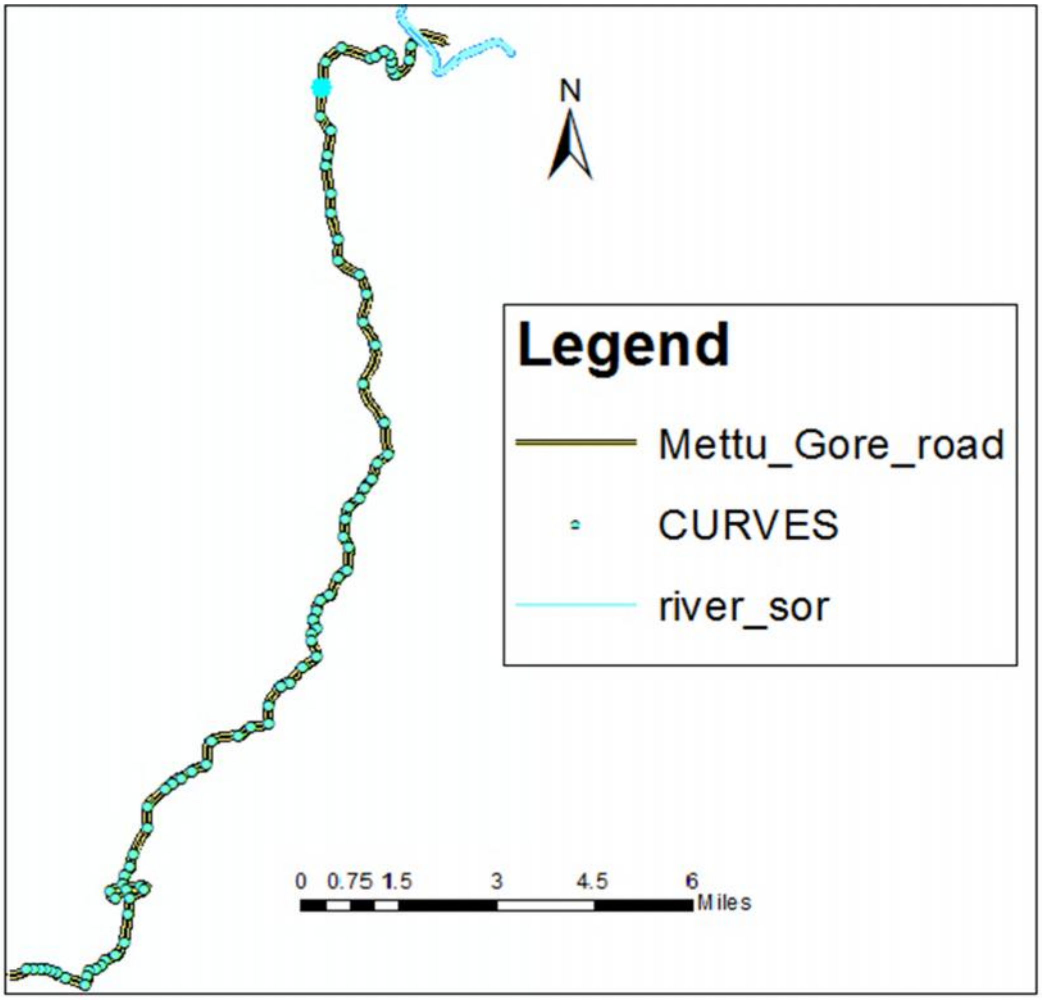

Figure A-3: Numbered and pointed map of Horizontal curves on Mettu-Gore road

Appendix B: Analysis procedures

Appendix B-1: Procedure for digitizing map features

1. Georeferencing maps and then add to ArcMap using add tool  in Arcmap.
2. Create shapefiles in ArcCatalog for each features to be digitized according to their shapes on the map. For example for:
    - Road-polyline shape
    - Town block- polygon shape
    - Trees- point shape
    - Curve center points- point shape
3. Add the created shapefiles to ArcMap in order to digitize the selected features.

4. Start editing in editing toolbox of ArcMap by selecting a shapefile to be digitized.

And draw by tracing on the features on the map

5. For digitizing contour lines, elevation field is added to the attribute table and each contour values are recorded by writing the elevation values on the map in the elevation field of the attribute table after finishing each contour line sketches.

Appendix B-2: Procedures for slope analysis of the terrain

1. Create x, y and z coordinated of the terrain near to the road.

Change contour vertices to point that have x, y, and z values: in catalog tree> 'Data management tool'> 'Features'>' Feature vertices to points' using digitized contour as an input field.

2. Interpolate surface

'Spatial analyst tool'> 'Interpolation'> 'Natural neighbor' using created points as an input data and choosing elevation field as z-value.

3. Run slope analysis tool for the interpolated terrain surface in spatial analyst tool

Appendix B-3: Spread sheet program to assess Geometric characteristics

- Procedure 1: Horizontal curve Assessment

✓ For emax=8%

Minimum standard value of curve radius for V=70 km/hr.: =IF(C5<=2.1,"1400",IF(C5<=2.8,"1000",IF(C5<=3.4,"800",IF(C5<=4.3,"600",IF(C5<=4.9,"500",IF(C5<=5.7,"400",IF(C5<=6.7,"300",IF(C5<=7.3,"250",IF(C5<=7.9,"200",IF(C5<=8,"175"))))))

Minimum standard value of curve radius for V=60 km/hr.:

=IF(C5<=2.2,"1000",IF(C5<=2.4,"900",IF(C5<=2.7,"800",IF(C5<=3,"700",IF(C5<=3.4,"600",IF(C5<=3.9,"500",IF(C5<=4.7,"400",IF(C5<=5.6,"300",IF(C5<=6.2,"250",IF(C5<=7,"200",IF(C5<=7.4,"175",IF(C5<=7.8,"150",IF(C5<=7.9,"140",IF(C5<=8,"130"))))))))))))

Minimum standard value of curve radius for V=50 km/hr.:

=IF(C5<=2.2,"700",IF(C5<=2.6,"600",IF(C5<=3,"500",IF(C5<=33.6,"400",IF(C5<=4.5,"300",IF(C5<=5.1,"250",IF(C5<=5.8,"200",IF(C5<=6.2,"175",IF(C5<=6.7,"150",IF(C5<=6.9,"140",IF(C5<=7.1,"130",IF(C5<=7.3,"120",IF(C5<=7.6,"110",IF(C5<=7.8,"100",IF(C5<=7.9,"90",IF(C5<=8,"80"))))))))))))))))

Where, C5= provided superelevation rate

V= design speed

✓ For emax=4%

Minimum standard value of curve radius for V=70 km/hr.:

=IF(C7<=2.2,"1000",IF(C7<=2.4,"900",IF(C7<=2.5,"800",IF(C7<=2.7,"700",IF(C7<=2.9,"600",IF(C7<=3.1,"500",IF(C7<=3.4,"400",IF(C7<=3.8,"300",IF(C7<=4,"215")))))))))

Minimum standard value of curve radius for V=60 km/hr.:

=IF(C7<=2.1,"900",IF(C7<=2.3,"800",IF(C7<=2.5,"700",IF(C7<=2.7,"600",IF(C7<=2.9,"500",IF(C7<=3.3,"400",IF(C7<=3.6,"300",IF(C7<=3.8,"250",IF(C7<=3.9,"200",IF(C7<=4,"145"))))))))

Minimum standard value of curve radius for V=50 km/hr.:

=IF(C7<=2.1,"600",IF(C7<=2.3,"500",IF(C7<=2.5,"400",IF(C7<=2.8,"300",IF(C7<=3,"250",IF(C7<=3.3,"200",IF(C7<=3.5,"175",IF(C7<=3.7,"150",IF(C7<=3.8,"140",IF(C7<=3.9,"120",IF(C7<=4,"100")))))))))))

Where, C7= provided superelevation rate

V= design speed

All the relative values for emax=8% and emax=4% were taken from ERA design standard manual table.

For all of the existing horizontal curves the standard minimum values were estimated in this way and finally this values were compared with the existing curve radius to identify if curves are safe or not.

- ➢ Procedure 2: Vertical curve Assessment

✓ Minimum Standard ‘k’ values for the design speed

For sag vertical curves

=IF(H4<=20,"2",IF(H4<=30,"4",IF(H4<=40,"8",IF(H4<=50,"12",IF(H4<=60,"18",IF(H4<=70,"25",IF(H4<=85,"36",IF(H4<=100,"51",IF(H4>=120,"74")))))))))

For crest vertical curves

=IF(H4<=20,"2",IF(H4<=30,"3",IF(H4<=40,"5",IF(H4<=50,"10",IF(H4<=60,"18",IF(H4<=70,"31",IF(H4<=85,"60",IF(H4<=100,"105",IF(H4>=120,"210")))))))))

✓ The final minimum standard values for each vertical curve:

=IF (B4="SAG", J4, IF (B4="CREST", K4))

Where, H4= design speed

B4= existing vertical curve type (SAG or CREST)

J4= the minimum standard ‘k’ value for SAG vertical curve

K4= the minimum standard ‘k’ value for CREST vertical curve

And all the respective values were taken from ERA design manual.

For all the vertical curves the minimum standard ‘k’ values were estimated in this way and finally compared with as-built ‘k’ values for all respective curves.

✓ Maximum gradient slopes according to standard specification:

=IF (I4="F","4", IF (I4="R","6", IF (I4="M","8", IF (I4="U","7"))))

Where, I4= terrain types of the area (Flat ‘F’, Rolling ‘R’, Mountainous ‘M’, Escarpment ‘E’ and Urban/peri-urban ‘U’)

And all the respective values were taken from ERA design manual.

For all the existing tangent grades the maximum allowable gradient slope were compared to identify the high gradient tangents.