UNIVERSITY OF NAIROBI

COLLEGE OF ARCHITECTURE & ENGINEERING

SCHOOL OF ENGINEERING

DEPARTMENT OF GEOSPATIAL & SPACE TECHNOLOGY

IDENTIFICATION OF POTENTIAL ROAD ACCIDENT HOT SPOTS USING GEOSPATIAL TECHNIQUES

A CASE STUDY OF THIKA SUPERHIGHWAY

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A Project submitted in partial fulfilment of the requirements for the Degree of Master of Science in Geographic Information System, in the Department of Geospatial and Space Technology of the University of Nairobi

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DECLARATION

I, Meso Julius, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

STUDENT:

MESO JULIUS: SIGNATURE………………………… DATE………………...

This project has been submitted for examination with my approval as university supervisor.

SUPERVISOR:

DR D. N. SIRIBA: SIGNATURE………………………… DATE……..…………

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Finally, to God, who gives us the desire, strength and impetus to achieve greater and greater, be all glory and honour.

ABSTRACT

Road safety is a matter that does not receive the attention it so requires especially in Kenya. However, according to World Health Organization (WHO), *Global Status Report on Road Safety 2018,* deaths from road traffic crash have been on the rise and are reported to be about 1.35 million every year worldwide.

Traditional approaches to road safety have focussed on road crash history where safety measures are put in place after gathering statistics from accident occurrences. This does little to prevent an increase in deaths and serious injuries since the data is collected after accidents have already occurred. Therefore, there is an urgent requirement to develop a holistic approach that can predict potential road accident hot spots in order to save lives and enhance road safety.

This study therefore focused on identifying high accident risk areas while predicting potential road accident hot spots through use of geospatial models and techniques. The study explored the use of various models including; speed model (designated speed), curve models (horizontal and vertical) and an integrated model using GIS in order to predict road accident hot spots of the study area i.e Thika Superhighway in Nairobi Metropolitan Region. All this was achieved by acquiring and analysing high resolution satellite images, road center-line data, slope analysis and digital elevation models (DEM) of the study area. The geospatial high accident risk prediction model was compared with the existing crash data (NTSA) for the study area for the past two (2) years for validation. This comparison showed consistency of results especially in the area between Kasarani and Githurai roundabouts on Thika Super Highway and Juja area, Kiambu County. It was found out that most road crashes occur at intersections and undesirable curves which are hot spots for loss of control type of accidents.

The study achieved its overall objective of preparing a geospatial high accident risk prediction model that can be used to identify potential road accident hot spots. The geospatial high accident risk prediction model however has limited capability to identify road accident hotspots in areas with straight road profile. Incorporation of road design data coupled with operating speeds data from roads authority can improve the overall performance of this model which can then be replicated by road safety authorities, road engineers and transportation planners for other roads of national importance and ultimately help save lives.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF MAPS

LIST OF EQUATIONS

LIST OF TABLES

LIST OF ACRONYMS

AASHO	American Association of State Highway Officials
ARRB	Australian Road Research Board
CBD	Central Business District
DSi	Death and Serious Injury
GDP	Gross Domestic Product
GIS	Geographic Information System
JKIA	Jomo Kenyatta International Airport
KeNHA	Kenya National Highways Authority
NMR	Nairobi Metropolitan Region
NCC	Nairobi City County Government
NTSA	National Transport and Safety Authority
RAMM	Road Assessment and Maintenance Management
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background Information

There is that phone call or knock on the door that we may all fear, in which we are told that the people we love have been killed or seriously injured in a road traffic accident. We may feel uncomfortable and shiver when emergency vehicles rash past us on the road to attend to a road accident. Our hearts skip a beat when news is given about a road traffic crash. However though, road traffic crashes may not be ‘accidents’, they are preventable.

According to World Health Organization (WHO), *Global Status Report on Road Safety 2018*, deaths from road traffic crash have been on the rise and are reported to be about 1.35 million every year worldwide. Approximately 3,700 people die on the world’s roads everyday while tens of millions get injured or disabled while others suffer life threatening injuries with long lasting effects. More specifically, road traffic accidents are, according to WHO 2016 report, the eighth leading cause of death globally, which surpasses HIV/AIDS, tuberculosis and diarrhoeal diseases. It is the leading cause of death for children and young adults between 5 – 29 years. These losses have therefore take a huge toll on families and communities. The cost of emergency response, health care and human grief has been too grave to bear (WHO, 2018).

However, deaths and serious injuries through road accidents should not be on the increase. Some of the causes of deaths through road carnage are preventable. Addressing the preventable causes of road safety requires deliberate and conceited effort by all stakeholders.

This study seeks to achieve enhanced road safety through a safe road system which is increasingly free of death and serious injury. This requires safer speeds, safer vehicles, safer road use and safe roads and roadsides. It has been evident that a smooth and good conditioned road, in terms of surface, terrain and design, promise better driving and road safety as compared to poor conditioned roads which increase the probability of road traffic accidents. Therefore, the study aimed to identify high accident risk areas on the roads in order to inform road users in advance of the accident hot spots through use of geospatial techniques and other methods in order to save lives.

1.2 Problem Statement

Road safety has been an issue that does not receive the attention it so deserves in many countries, especially in Kenya. Despite the increasing number of deaths and serious injuries through road carnage reported in global and national statistics, little has been done to move from the reactionary approaches to road safety.

Traditionally, the approach of addressing road safety issues in many developing countries has focussed on historical crash data. This data on crashes per location is mapped into zones of multiple occurrence areas known as blackspots. This traditional approach based on past fatal and serious injury crashes in particular is however not adequate since lives are lost while others sustain long term injuries.

There is an urgent requirement therefore for a better approach to road safety that has a strong indicator on high probability zones of future fatal and serious crashes. The departure from a completely reactive approach to road safety allows for high risk roads, road sections and road sides to be identified before accidents occur. Government institutions, road safety authorities, transport planners, road users and interested partners therefore require to identify parts of a road system that can be used to predict and prevent loss of lives on the roads.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of the study therefore is to identify potential road accident hot spots through use of geospatial models and techniques.

1.3.2 Specific Objectives

Therefore, the study aims to meet the following specific objectives:

i. To design and develop spatial speed model for designated speeds on Thika Superhighway.
ii. To design a suitable integrated geospatial model using speed and curve to predict road accident hot spots.
iii. To compare and validate results of the geospatial high risk prediction model against crash findings from National Transport and Safety Authority (hot spots vs black spots).

1.4 Research Questions

The objectives of the study translate to the following research questions:

a) What are the major high risk road segments likely to cause accidents in the study area?
b) What are the major factors besides road geometry and profile that potentially cause road crashes in the study area?
c) How can we best use road profile/alignment and other factors to predict and identify potential road accident hot spots?
d) How can GIS models be integrated with other related concepts to offer a tool to promote road safety with regards to road profile?

1.5 Justification of the Study

According to the World Health Organization 2018, Kenya experiences between 3,000 to 13,000 road traffic crashes in a year. It has been reported by National Transport and Safety Authority (NTSA) that road accidents cost Kenya 5.6% of its economic value (GDP), an equivalent of Ksh 341 billion. According to NTSA reports in 2016, Nairobi City County accounted for about 22% of the country-wide fatalities resulting out of road accidents. NTSA reported that the high number of deaths experienced in the capital city of Nairobi and its environs may be as a result of the high number of motor vehicles and pedestrians.

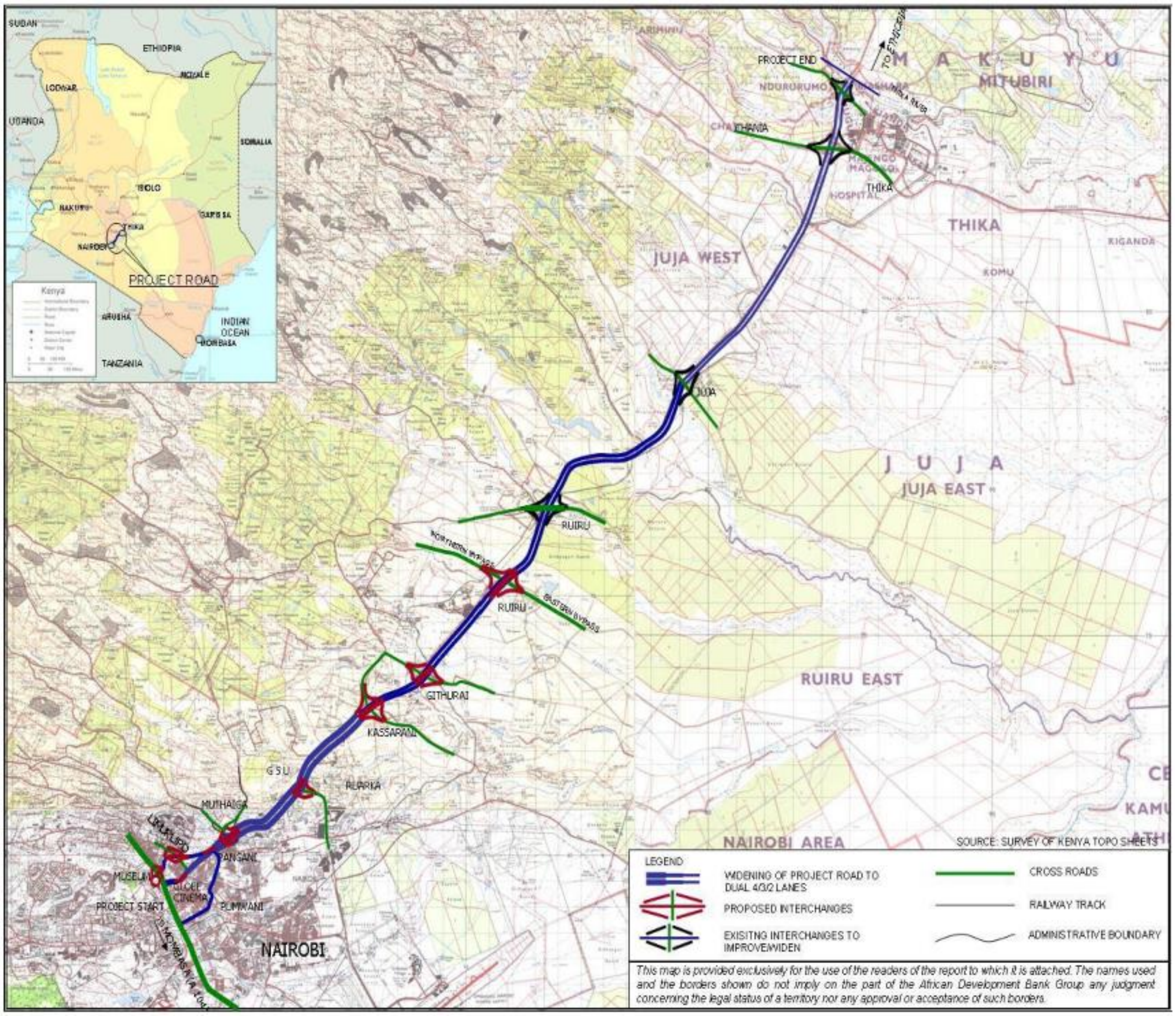
Some of the high risk roads in the Nairobi and its environs according to NTSA include Thika Superhighway, Airport North Road, Eastern Bypass, Jogoo Road and Mombasa Road which account for the highest number of accidents in the city. Worth noting, the Northern Corridor, which stretches from Mombasa to Malaba and passes through major towns of Mombasa, Nairobi, Nakuru, Eldoret and Busia, accounted for about 18% of the total fatalities in 2015, an equivalent of 541 deaths.

Therefore, road accidents not only cause loss of lives and serious injuries but also cause loss of revenue in a country. For this reason, it is necessary for new holistic approaches that promote road safety to be adopted in Kenya to replace the traditional approaches which are largely reactive. The adoption of a new approaches to road safety in Kenya will signify a shift in focus from reducing the number of crashes to minimising the probability of high severity crash outcomes.

The aforementioned critical statistics on the wrath of road carnage in Nairobi City and Kenya as whole as well as the guide to new approaches to road safety create potential ground for further studies in a bid to promote road safety in entirety. GIS as a tool has been used to promote road safety largely through mapping of crash zones (black spots) and occurrences. This study seeks to explore the use of GIS and geospatial techniques in a new paradigm to predict and calculate potential road accident zones and high risk areas. The success of the study will promote safer road systems and approaches and save nations of the burden that come as a result of road accidents.

1.6 Scope of Work and Basic Assumptions

This study aims at demonstrating the potential use of GIS and GIS techniques in predicting and identifying hot spot areas for road accidents. The study employs the use of GIS software and other software such ArcGIS, QGIS, AutoCAD and IDRISI Selva while employing concepts adopted from engineering, urban planning and mathematics. These concepts allow for the capturing of critical data and analysis of speed, curves and terrain which are key parameters of this study. The study focuses on approximately 40 kilometres of Thika SuperHighway from Thika town at the Thika - Garissa road interchange to Nairobi at Professor Wangari Maathai intersection.



Map 1-1 The Study Area (KARA, 2012)

The study works on the premise that road geometry, ceteris peribus, specifically high risk curves and speed interactions are major causes for road accidents in the Nairobi Metropolitan Region (NMR). The road geometry comprises of major road sections that include straights, curves and intersection. Here, it is assumed that the vehicle is in a sound state and the driver behaviour is proper, obeying all road rules. It is also assumed that the cause of major sources of deaths and injuries from road accidents include major highways connecting the city to other towns in other counties especially in off – peak hours, between 1700 hrs and 0600 hrs where high speeds are largely used. Also, the study assumes that high risk curves on highways continue to pose a risk to the safety of road users and therefore cannot be left in their current state.

1.7 Definition of Key Terms and Concepts

In order to better understand the study, key terms and concepts as defined in Noon (2006) and KiwiRAP (2008) have been discussed hereunder as adopted, used and applied throughout the project.

Advisory Speed - The recommended maximum speed at which a section of the road way should be negotiated for comfort and safety.

Alignment - The geometric form of the centreline of a carriage way in both horizontal and vertical directions.

Black spot - A particular known problem zone or hazardous area reached by consensus over time due to several occurrences.

Centerline - The line which defines the axis or alignment of the centre of a road. It may be defined by pavement markings on road delineating opposing traffic flow.

Collective Risk - Measure of the total number of fatal and serious crashes or deaths and serious injuries equivalents per curve/section of the road in a certain crash period

Design Speed - A speed fixed for the design and correlation of those geometric features of a carriageway that influence vehicle operation.

Desired Speed - The speed over a section of a road adopted by a driver(s) as influenced by road geometry and other environmental factors.

Fatal Injuries - Injuries that result in death within 30 days of the crash.

Horizontal curve - The culmination of bringing together the straights and curves on a plane view.

Hot Spot (road traffic accident hot spots) - A place on the road section where the likelihood of accidents to happen is high.

Personal Risk - Measure of the risk of death or serious injuries to each vehicle entering the curve/road section.

Risk - Road safety outcome to the amount of exposure.

Risk Mapping - Use of historical traffic and crash data to produce colour coded maps illustrating the level of risks on sections of the road network.

Serious Injuries - Fractures, concussion, internal injuries, crashes, several cuts and lacerations, severe general shock necessitating medical treatment and other injury involving removal to and detention in hospital.

Vertical Curve - Generally a parabolic figure in the longitudinal profile of a carriageway to provide a change in grade at a specified acceleration (Noon, 2016).

1.8 Organization of the Report

This study is comprised of five chapters where Chapter One provides the study background, introduces the problem statement, objectives of the study, justification of the study and key definitions of terms and concepts creating a better foundation going forward. Thereafter, Chapter Two follows with literature review on concepts relating to road safety, risk, speed, curves and the legislative framework which acts as a pillar on which this study is anchored. Chapter Three presents the study methodology and key data while Chapter Four discusses the results and findings of the study. Chapter Five finally lays out the conclusions and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter seeks to offer a comprehensive and advanced understanding of the subject matter of the study. This chapter defines the various concepts of the study, while digesting what has been done by other scholars in similar fields and builds on the same while also identifying the theoretical and legislative framework that the study is anchored on. Therefore, this provides the broad context of the study and sets the existing scholarly and historical context of the research.

2.2 The Concepts of Road Safety

2.2.1 Risk and Road Safety

Road safety assessment is usually evaluated on the basis of 'risk' which is associated with the number of accidents and casualties. This is known as road safety outcome. Related to road safety, is risk which can be defined as 'the road safety outcome to the amount of exposure' as shown in the equation 2.1:

$$\text{Risk} = \text{Road Safety Outcome} / \text{Exposure}$$

Equation 2-1; Risk Equation

Using different parameters, exposure can be measured, while comparing the performance of various road segments, as vehicle kilometres travelled with volume and number of trips. However, for countries, it can be passenger per kilometres travelled, population and number of registered vehicles. Risk assessment is recommended for road safety performance evaluation. Although risk can be analysed on the basis of direct calculation using outcomes by exposure, this can endanger the lives and property of individuals. Largely, risk can be estimated using three main methods; through recent history of fatal or serious crashes i.e reported risk, reported injury crashes i.e estimated risk and also predicted using physical and operational characteristics known to affect risk.

The level of risk on road safety can be further explained by the following metric assessments:

a) Collective Risk

b) Personal Risk

a) Collective Risk

Collective risk refers to the measure of the total number of fatal and serious injury crashes per kilometer over a segment/section of a road. This can be illustrated by the equation below:

$$\text{Collective Risk} = \frac{(\text{Fatal crashes} + \text{serious injury crashes}) / \text{number of years of data}}{\text{Length of Road section}}$$

Equation 2-2; Collective Risk

b) Personal Risk

Personal risk refers to the measure of danger to each individual using the state highway data being assessed.

$$\text{Personal Risk} = \frac{(\text{Fatal crashes} + \text{serious injury crashes}) / \text{number of years of data}}{\text{Distance travelled} / \text{number of years of data}}$$

Equation 2-3; Personal Risk

This metric shows the likelihood of a motorist, on average, being involved in a fatal or serious road crash on a particular road segment/section. It is of most interest to the public to understand the personal risk metric as it shows the risk to road users as individuals. It is believed that a risk aware driver is better informed and will therefore be more capable of modifying their behavior to respond to the various road conditions.

Identification of the riskiest sections of a road can be achieved by assessing a road section using a five category band that analyses the collective and personal risk as shown in table 2-1.

Table 2-1: Risk Rating Using Different Categories

RISK RATING	COLLECTIVE RISK Average annual fatal and serious injury crashes per km	PERSONAL RISK Average annual fatal and serious injury crashes per 100 million vehicle-km	COLOR
Low	≤ 0.039	< 4	
Low - Medium	0.04 ≤ 0.069	4 ≤ 4.9	
Medium	0.07 ≤ 0.10	5 ≤ 6.9	
Medium – High	0.11 ≤ 0.189	7 ≤ 8.9	
High	0.19 +	9 +	

Source: KiwiRAP Final Risk Mapping 2007 – 2011 Summary

2.3 Relationship between Speed and Road Safety

2.3.1 Brief History of Design Speed Concept

The early principles of road design were initially adapted from railways. Historically a road was given a design speed and curves were designed for safe operation at this speed. As vehicles increased in power they began operating at higher speeds resulting in an increased number of high severity accidents (Noon, 2016).

According to Vicroads (1994) in *"Validation of Operating Speed Model"*, researchers during the mid-20th century began questioning the design process and specifically the choice of one particular design speed for a road. Moreover, research by AARB in 1970's discovered that in places where a design speed of less than 100 km/hr was designated, for example, the drivers actual operating speeds were different from the design speed. It was therefore concluded that the use of a constant design speed does not guarantee consistency between design elements, motorists have no concept of design speed limit and drive at whatever speed they find comfortable. Since then, there have been several research attempts to redefine the design speed concept as shown in the table below.

Table 2-2: Evolution of Design Speed Definition

Source	Definition
Barnett 1937	Assumed Design Speed is the maximum reasonably uniform speed which would be adopted by the faster driving group of vehicle operations, once clear of urban areas.
American Association of State Highway Officials (AASHO) 1938	Design Speed is the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones.
AASHO, 1941	Assumed Design Speed is the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones. The approved speed classifications are 30, 40, 50, 60 and 70 mph. The assumed design speed for a section of highway will be based principally upon the character of the terrain though a road of greater traffic density will justify choosing a higher design speed than one of lighter traffic in the same terrain
AASHO, 1945	Design Speed: Topography — Minimum (mph) — Desirable (mph) Flat — 60 — 70 Rolling — 50 — 60 Mountainous — 40 — 50
AASHO, 1994	Design Speed is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern. The assumed design speed should be a logical

	one with respect to the topography, the adjacent land use, and the functional classification of highway.
Austroads, 2003,2010	A speed fixed for the design and correlation of those geometric features of a carriageway that influence vehicle operation. Design speed should not be less than the intended 85th percentile speed

Source: Adapted from Noon 2016

2.3.2 Effect of Speed on Road Safety

The interaction between the laws of physics and the driver behaviour assist in the management of vehicle speeds which have an effect on the risk of death and serious injury at high risk sections of a road. While approaching intersections, curves and bends, modest minimizing of travel speed can produce quite a significant reduction in risk of deaths and serious injuries, holding all factors constant.

Evidently, the time required to react to a conflict that happens at slower speeds is reduced giving the driver a high opportunity to avoid a collision, rolling over or hitting other objects on the road side. Therefore, it can be deduced that a modest reduction in approach speed can make such a significant change in impact magnitude.

2.3.3 Effects of Horizontal Alignment on Road Safety

There are numerous factors affecting operating speeds on the road. These may include the terrain, volume of traffic and road characteristics. One of the road characteristics that has a bearing on the operating speed and ultimately has an effect on road safety is the horizontal alignment.

According to J.R. Mclean, 1974 in his book "Driver Behaviour on Curves – A Review", drivers do not respond to super elevation and the associated friction factor when selecting the speed at which they will negotiate a curve. The curvature of the road itself appears to be the determinant factor.

Horizontal curve design principle was adapted from railway engineering practise and derived from kinematics equation. The equation is based on the side friction of a vehicle to traverse a constant radius curve at the design speed as in equation 2-4.

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

Equation 2-4 Radius of a curve

Where:

R = curve radius (m)

V = vehicle speed (km/hr)

e = pavement super elevation (m/m)

f = side friction factor (between tyre and pavement)

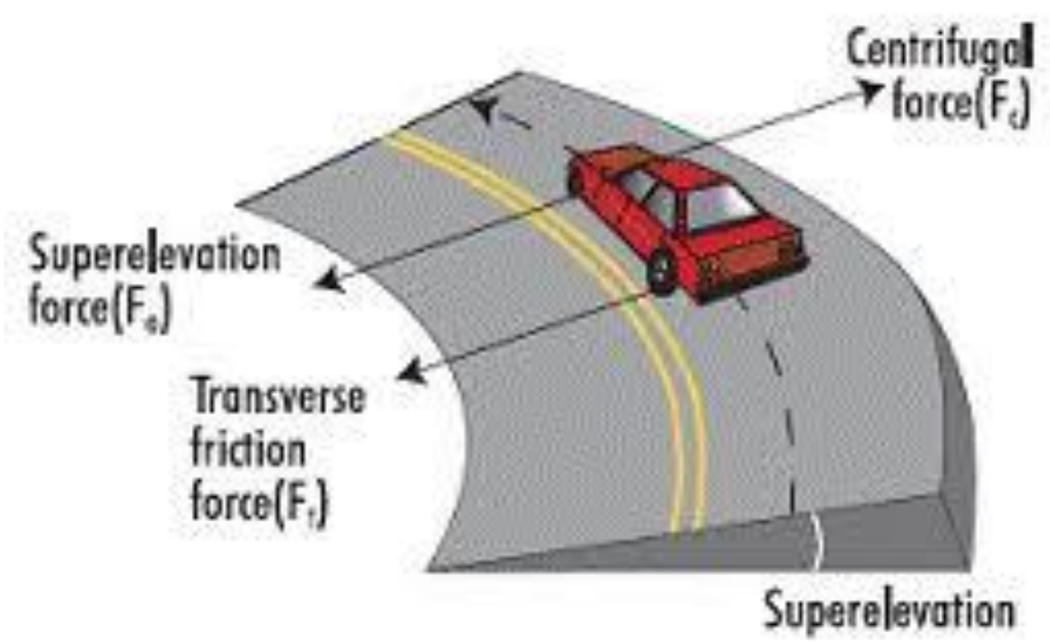


Figure 2-1 : Concept of Super Elevation (PIARC 2003)

Side friction factor refers to the force that is experienced between the tyres and road surface resulting in a change of direction and a centripetal acceleration when a vehicle is traversing a horizontal curve. If this force is insufficient the car will continue in motion tangentially to the horizontal curve. The side friction values adopted for cars in various countries or regions is usually tabulated.

In the year 2013, Hammonds among other researchers presented their findings in the investigation of speed and curve interactions. Their models commonly referred to as Hammonds model is widely applied in Australia and New Zealand.

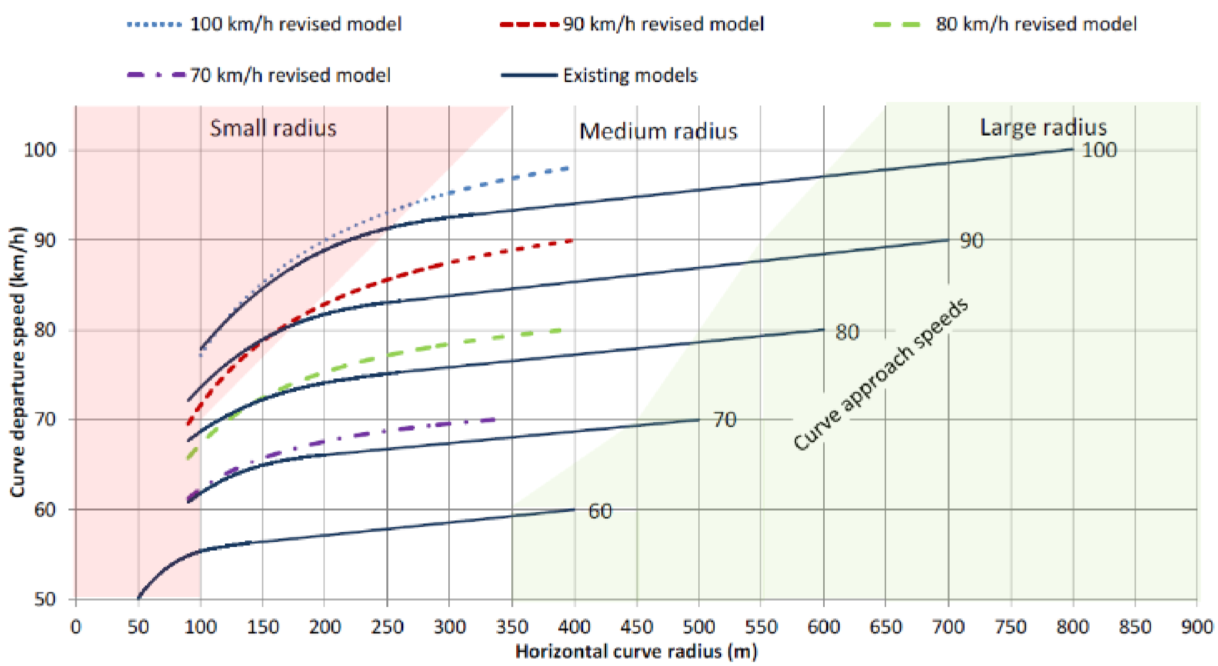


Figure 2-2 : Curve Model and Curve Departure Speeds (Hammonds et al 2013)

2.4 Use of GIS Techniques for Network Wide Study Efficiency

Although the calculation of a risk profile of an individual intersection is not a time consuming exercise, a smarter, more time-efficient method needs to be developed for the purpose of screening an entire network so all high-risk sites could be identified and prioritized.

Transport data by its nature is spatially referenced i.e. it is relative to a particular point or length of the transport network. Therefore, different sets of transport data can be brought together inside a geospatial environment and used for a variety of uses. Using Geographical Information Systems (GIS), a process has been developed where complex models are applied over a road center line dataset that contains all the necessary attributes and crash information to calculate the risk metrics for every intersection within a network.

The first part of the process involves the preparation of a base layer upon which the risk mapping models can run. The key element of the base layer is the road centerline dataset. This is typically obtained from national road mapping authorities such as KENHA, KURA and KERRA. It contains speed, intersection control and traffic volume attributes. The quality of this information varies from one local authority to the next, so some 'cleaning' is usually required to ensure the road centerline is fully connected, has a complete set of attributes, and accurately represents the geometry of the network.

Once the base layer has been prepared, crashes can be assigned to the road centerline network based on their geo-coded location. Models are then run using suitable techniques to assign crashes located within 50m of an intersection to an intersection. Complex models are run thereafter that apply severity indices to specific crash movement types for injury crashes at each junction/intersection. The sum of the death and serious injury (DSi) casualty equivalents for each crash are thereafter summed up together to give the overall DSi casualty equivalent value for the intersection, which is known as the Collective Risk (Durdin, 2010).

2.5 A Road Safety Risk Prediction Methodology for Low Volume Roads, A Case of New Zealand Eastern Bay

During the 2015 Australasian Road Safety Conference a team of researchers presented their paper on the road safety prediction methodology for low volume roads such as those in New Zealand's Eastern Bay of Plenty region. Roads in this region have relatively low traffic volumes and witness a number of rural road safety issues which include inappropriate speed, use of drug and alcohol and young/inexperienced drivers.

Since the roads in Eastern Bay of Plenty region experience low traffic volumes, crashes tend to be few and difficult to predict using risk assessment techniques that rely on the crash history.

Therefore, to solve this menace, the researchers in the conference prepared a paper that employs a new risk prediction methodology that identifies high risk curves without relying on crash history.

Methodology

It was discovered that many rural road crashes, approximately 57.9% of all fatal and serious rural road crashes between 2004 and 2013, in the area of Eastern Bay of Plenty region occur on curves. Approximately 1500km of road in the study area was identified to establish a new methodology for prediction of high risk areas.

The first step was to identify curves using a high quality road centerline. Using GIS linear referencing tools, the road centerline was divided into 10 meter sections and the rolling 30 metre average radius calculated for each arc section and thereafter extracting discrete curve sections.

Secondly, according to Austroads 2009, it is possible to predict the operating speed (85^{th} percentile) of cars traveling in each direction along a section of rural road. Once curves had been identified, each corridor was divided into a series of curves with known radii, and straights with known lengths (Dale Harris, Paul Durdin, Colin Brodie, Fergus Tate and Robyn Gardener, 2015).

Working along the corridor, speed behavior was modelled to reveal either:

(a) Acceleration on straights longer than 200 metres where approach speed is less than the operating speed of the curve.

(b) Speed maintenance on straights less than 200 metres or where the speed falls within the section operating speed range.

(c) Deceleration on curves where the approach speed is higher than the operating speed for the curve(s).

Results

The study revealed 6,985 curves across the study area using the curve identification methodology. The curves were identified and classified by design speed limit and then categorized as shown in the table below.

Table 2-3: Horizontal Curve Radii Categorization

Curve Category	Total Curves	% of all Curves
Unacceptable	600	8.6%
Undesirable	815	11.7%
Desirable	941	13.5%
Within Limit	4629	66.3%

Since the curve identification methodology utilized in this study was new and untested, the results were compared against an existing Transport Agency curve dataset for the Eastern Bay of Plenty. The results were plotted on a graph to develop a curve analysis model which was later developed through a mapping website "SignatureNET" which displayed the risk metrics alongside contextual road safety data including administrative boundaries and crash locations.

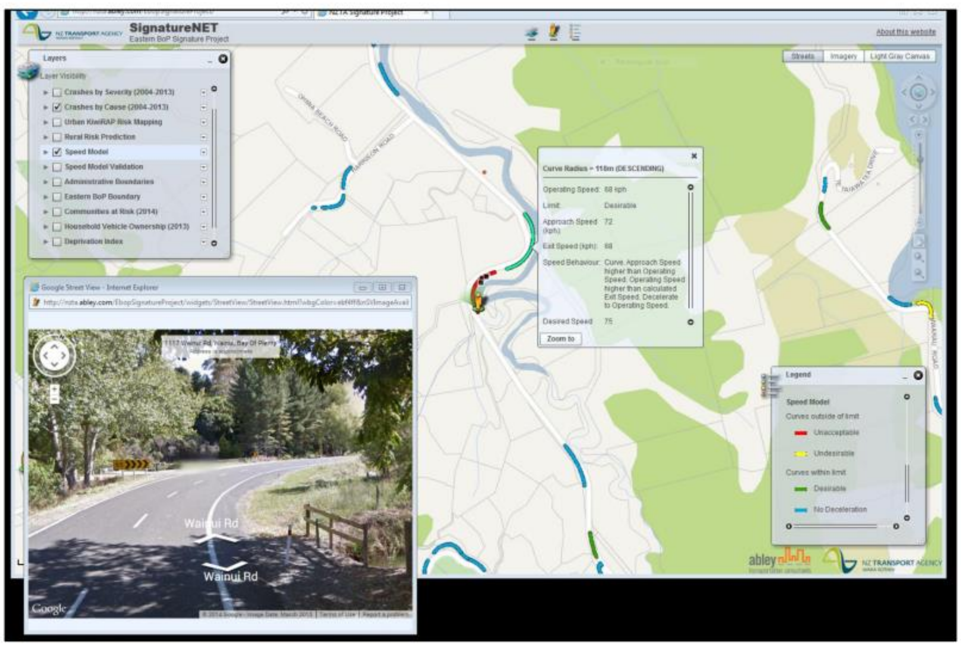


Figure 2-3 : Risk Map Model

2.6 Policy and Institutional Framework

The study is founded on some fundamental principles and guidelines rooted in the legislation of Kenya.

2.6.1 Kenya Vision 2030

Kenya Vision 2030 is the new long-term development blueprint for the country where the Kenyan society envisions "a globally competitive and prosperous country with a high quality of life by 2030". It aims to transform Kenya into "a newly-industrializing, middle-income country providing a high quality of life by 2030.". Urbanization is projected to occur at a rapid rate; by 2030, it is estimated that more than 60% of Kenyans will be living in cities and towns. These changes are likely to impact adversely on the road networks and road safety in Nairobi City as well as the entire country. Therefore, in line with the Vision 2030 and Sustainable Development Goals (3.6), there is critical need to promote road safety and minimize deaths and serious injuries through road carnage by half.

2.6.2 Traffic Act Cap 403

This is an Act of Parliament in Kenya for the governing of traffic vehicles and for intended purposes. This Act provides for regulation of traffic in Part VI which include the highway code and other traffic regulations key to this study. Other important chapters to this study include Part VII on Accidents and Part X which discusses in detail other provisions for road users.

2.6.3 National Transport and Safety Authority Act, 2012

This is an Act of Parliament to provide for the establishment of the National Transport and Safety Authority (NTSA); to provide for the powers and functions of the Authority and for connected purposes. This Act provides for the functions of the NTSA as follows:

a) Advise and make recommendations to the Cabinet Secretary on matters relating to road transport and safety.

b) Implement policies relating to road transport and safety.

c) Plan, manage and regulate the road transport system in accordance with the provisions of this Act'

d) Ensure the provision of safe, reliable and efficient road transport services.

To ensure that NTSA achieves its functions in section 4 (1), the Authority is required to also undertake; registration and licensing of motor vehicles, conduct motor vehicles inspections and certification, develop and implement road strategies, facilitate the education of members of the public on road safety, conduct research and audits on road safety and compile inspection reports relating to accidents among others.

Therefore, NTSA is a vital state organ in Kenya that seeks to promote and facilitate road safety through various means. This Act and its dictates are key in enriching and guiding this study.

2.6.4 Road Design Manual Part 1 - Geometric Design of Rural Roads, 1979

This manual provides guidelines and recommendations to be considered during road design and construction. It also offers general standards to be adhered to as well as certain special conditions to be taken into consideration. This manual provides for road safety considerations, road design criteria and controls. The manual dicsusses "Road Alignment" in Chapter 5 and gives the minimum radii for horizontal curve (Table 2.6) with R min values based upon a maximum super elevation e = 6%.

Table 2-4: Minimum Radii for Horizontal Curves

Design Speed V_D(km/h)	40	50	60	70	80	90	100	110	120	140
Min.hor. radius, R min(m)	60	100	160	250	350	450	600	750	1000	1400

It is recommended that radii of consecutive curves should be within particular limits given in the graph below.

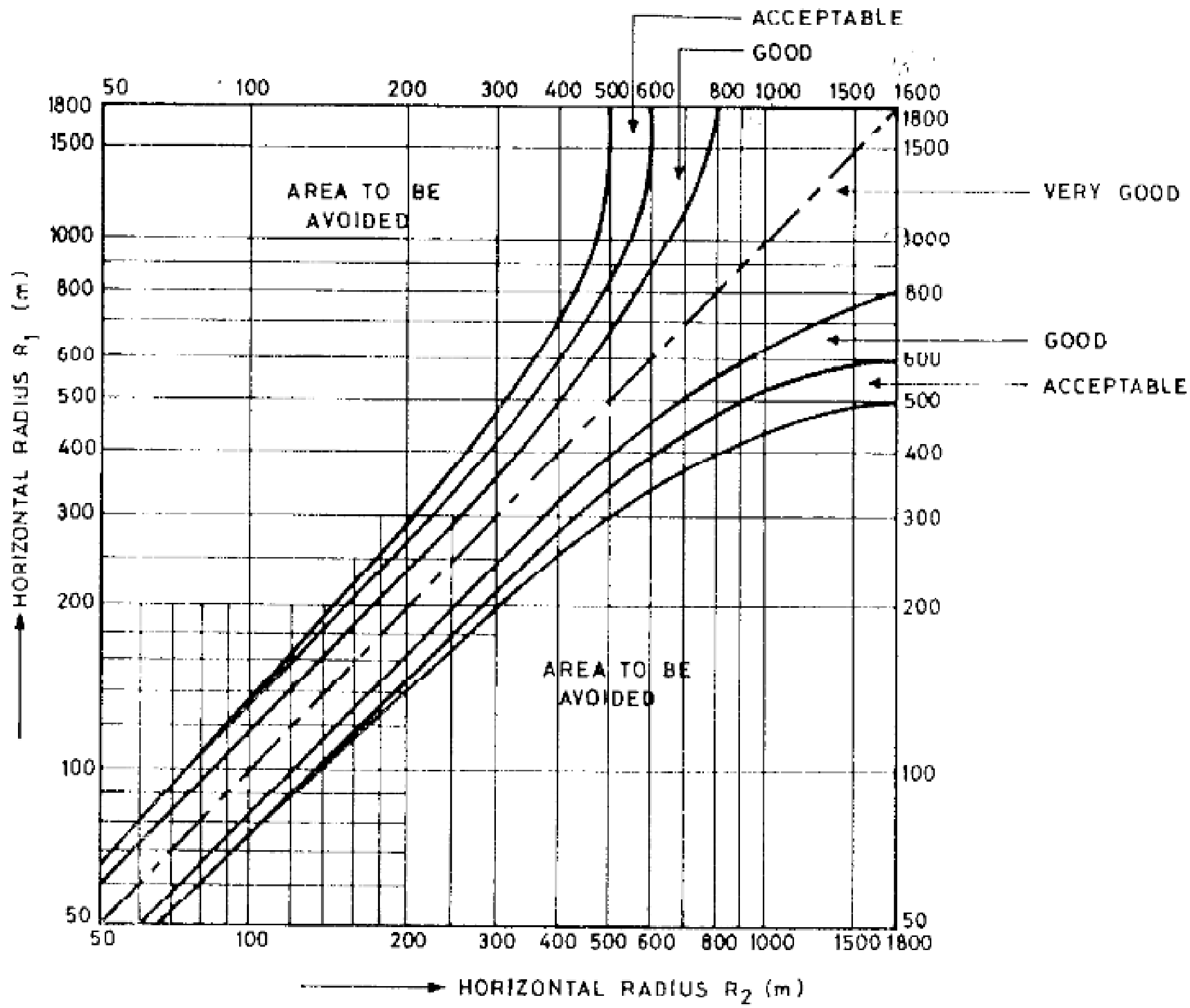


Figure 2-4: Acceptable Combinations of Radii for Consecutive Curves

From review of the various literature, the best methodology for identification of road traffic accident hotspots is through use of an integrated GIS approach of identification of curves, generation of operating speed models and assessing of road accident high risk areas. The results of the approach can be validated using road traffic accidents crash data. This can be achieved through of acquisition and use of relevant spatial datasets such as types of curves on road sections, radius of curvature of the road curves, designated speed limits for road sections, operating speeds along road sections and road traffic accidents crashes data.

CHAPTER THREE

MATERIALS AND METHODS USED

3.1 Study Area

The study area covers Thika Super Highway that connects the City of Nairobi and industrial town of Thika. This is an 8-lane controlled access dual highway measuring approximately 40 kilometres that originates from down town Nairobi forming part of the international trunk road A2 Highway which links Kenya- Ethiopia at Moyale town and Tanzania-Kenya at Namanga town. This road is important as it links the Great North Trans-African Highway (Cape Town to Cairo).

The study area is situated in the larger Nairobi Metropolitan Region (NMR). The NMR is an area that extends about 32,000 square kilometres that substantially depend on the city of Nairobi for

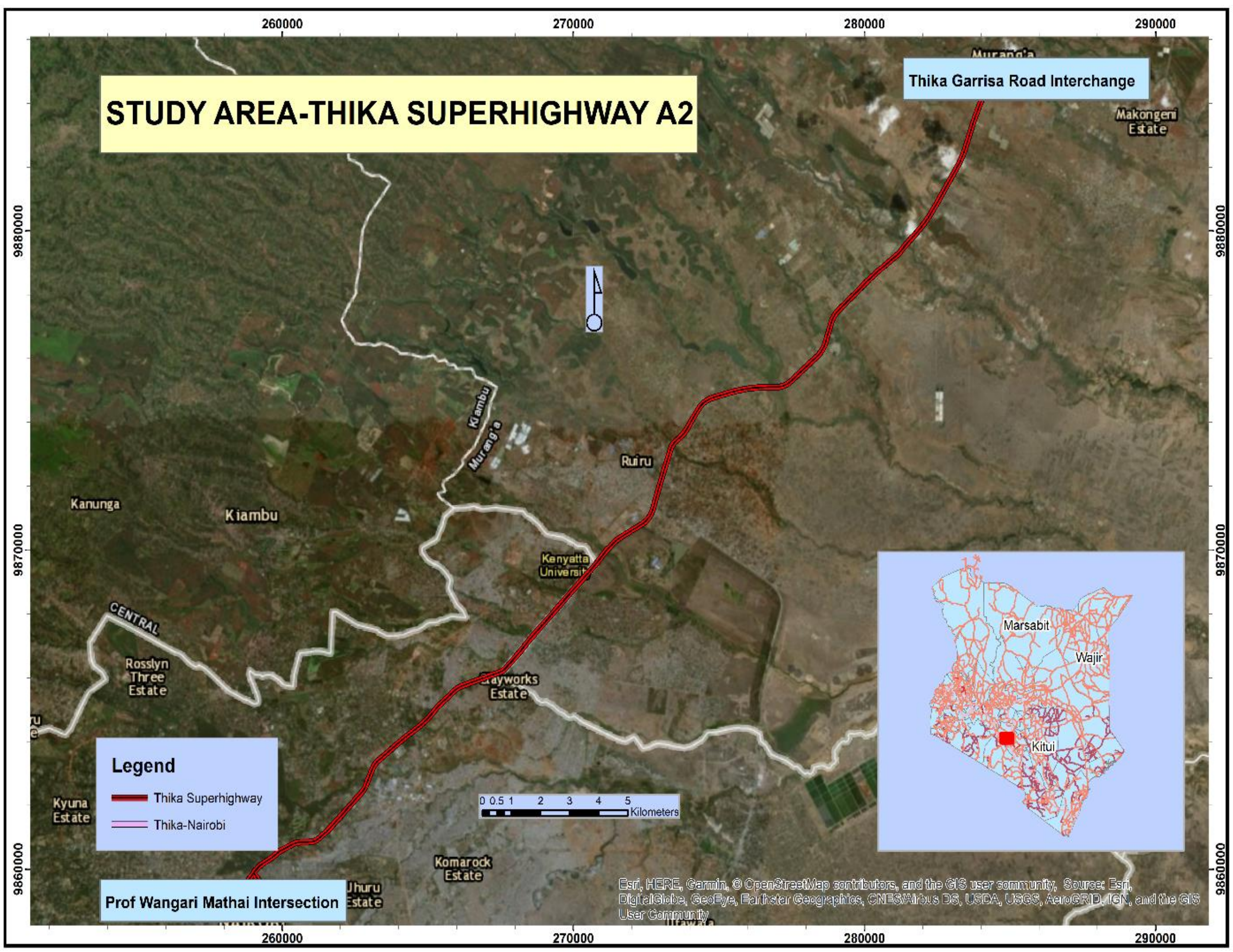


Figure 3-1; Study Area from Professor Wangari Mathai Intersection to Thika Garissa Road Interchange

employment and social facilities. This region has also been spurred by the rapid population in the surrounding counties such as Kiambu, Muranga, Machakos and Kajiado. The NMR is the most dynamic engine of growth in Kenya which accounts for more than 30% of the national GDP.

3.2 Methodology

This study seeks to achieve the overall objective of identifying potential road accident hot spots on Thika Superhighway through use of geospatial models and techniques. The use of ArcGIS, QGIS and programming languages offer the right tools for analysis while GPS, imagery and photographic equipment are essentials for data capture. The approximately 40 kilometres Thika Superhighway in one direction (from Thika to Nairobi) would normally take a longer period to assess and analyse the risk of the road sections since the processes can be time-consuming and cost-prohibitive. Therefore, some of the data for the study was generated and automated using GIS methods which allowed for identification of curves, generation of designated speed models along Thika Superhighway and assessing of road accident high risk areas. The data requirements and procedures followed in this study are expounded further under each of the study objective parameters (speed, curve, terrain and crash data).

3.2.1 Designated Speed Modelling

Designated speed herein refers to the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway allow. KeNHA in collaboration with NTSA have established various designated speed limits in the study area. The process of developing a speed model for use in this study is described below.

a) Data Requirements

Speed is a critical parameter for prediction of road accident hot spots. The speed attributes necessary for this study include the following:

Table 3-1 Speed Attributes

Data Type	**Characteristic/Format**	**Source**
Designated Speed Location	Point Location/Coordinates along Thika Superhighway	Field work on 28 April 2019 using Garmin etrex 30 GPS hand held GPS
Traffic Volume & Time	Attribute Text Speed odometer	KeNHA Field work for validation

b) Designated Speed model data collection and analysis

The data for designated speed was collected by a Garmin etrex 30 GPS at an accuracy of ± 3m. This data was downloaded into the external drive of a computer in the format of Comma Separated Values (CSV). The CSV file was imported into the ArcGIS Desktop application for mapping of designated speed models. These models were developed for the entire study area from Thika to Nairobi. In addition, geotagged photographs of various speed signs for various sections of the Thika Superhighway were taken using iPhone 6 S Camera. The camera uses GNSS and cellular network positioning to locate the position of the required data. It offers the advantage of taking high resolution images at low cost. The geotagged images were viewed in Google Photos and their X and Y coordinates were extracted and incorporated into the designated speed model. The coordinates of the geotagged photographs are in Geographic Coordinate System (GCS). To transform them into Projected Coordinate System, Global Mapper software was used by specifying parameters shown in figure 3-2 to 3-4.

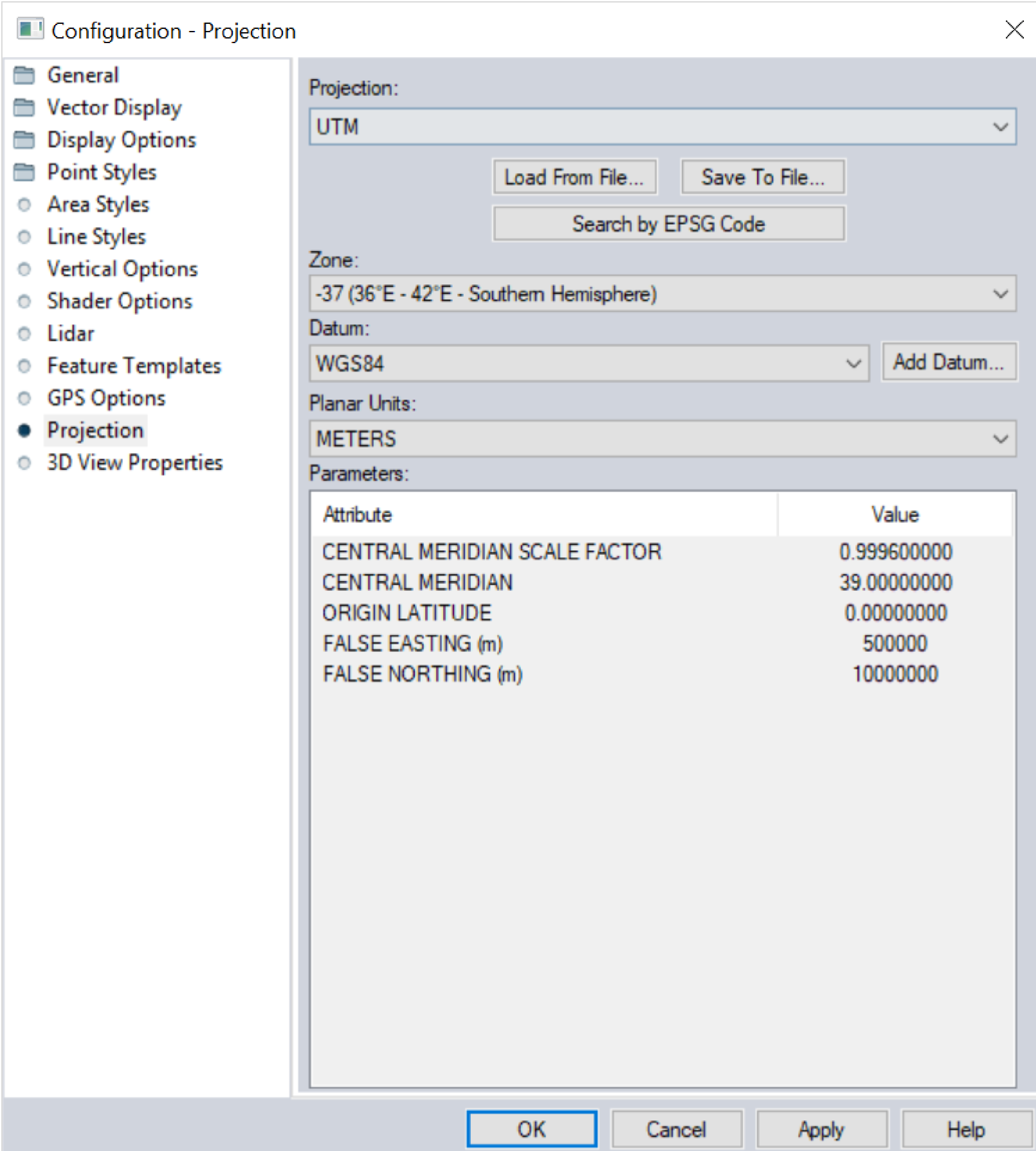


Figure 3-2; Coordinates transformation from Geographic to Projected Coordinate System

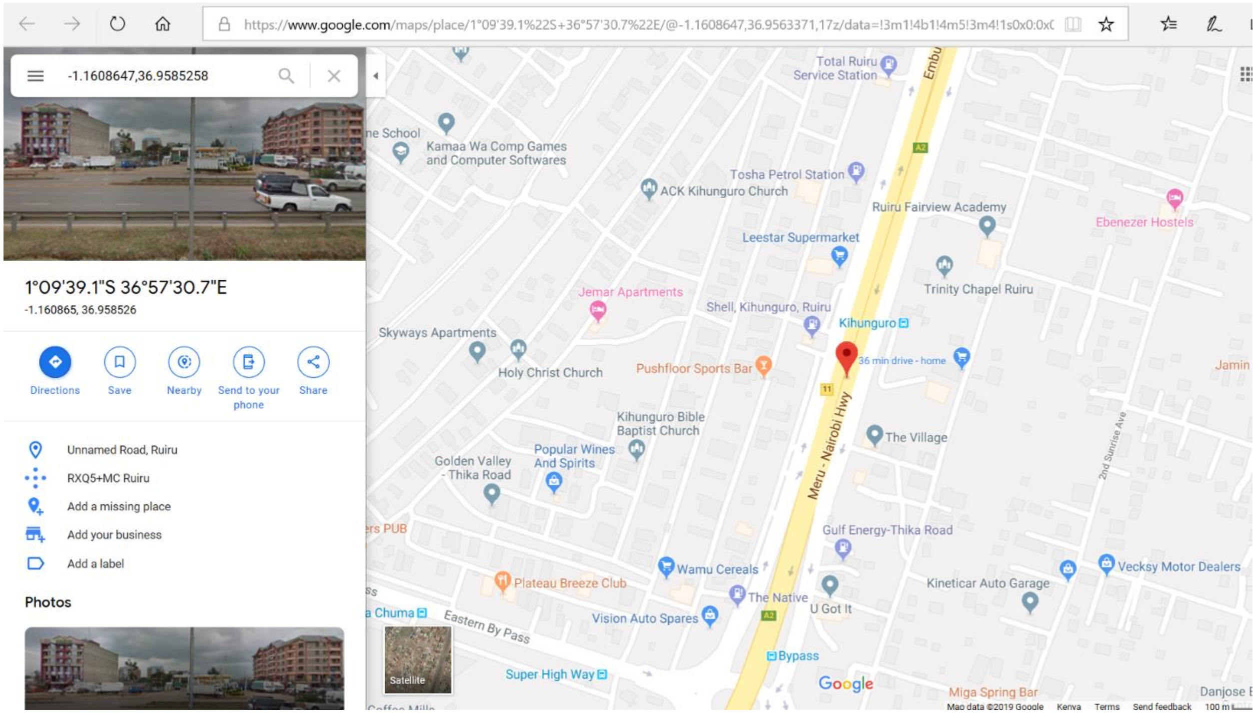


Figure 3-3: Extracting Coordinates of Designated Speed Limit Sign

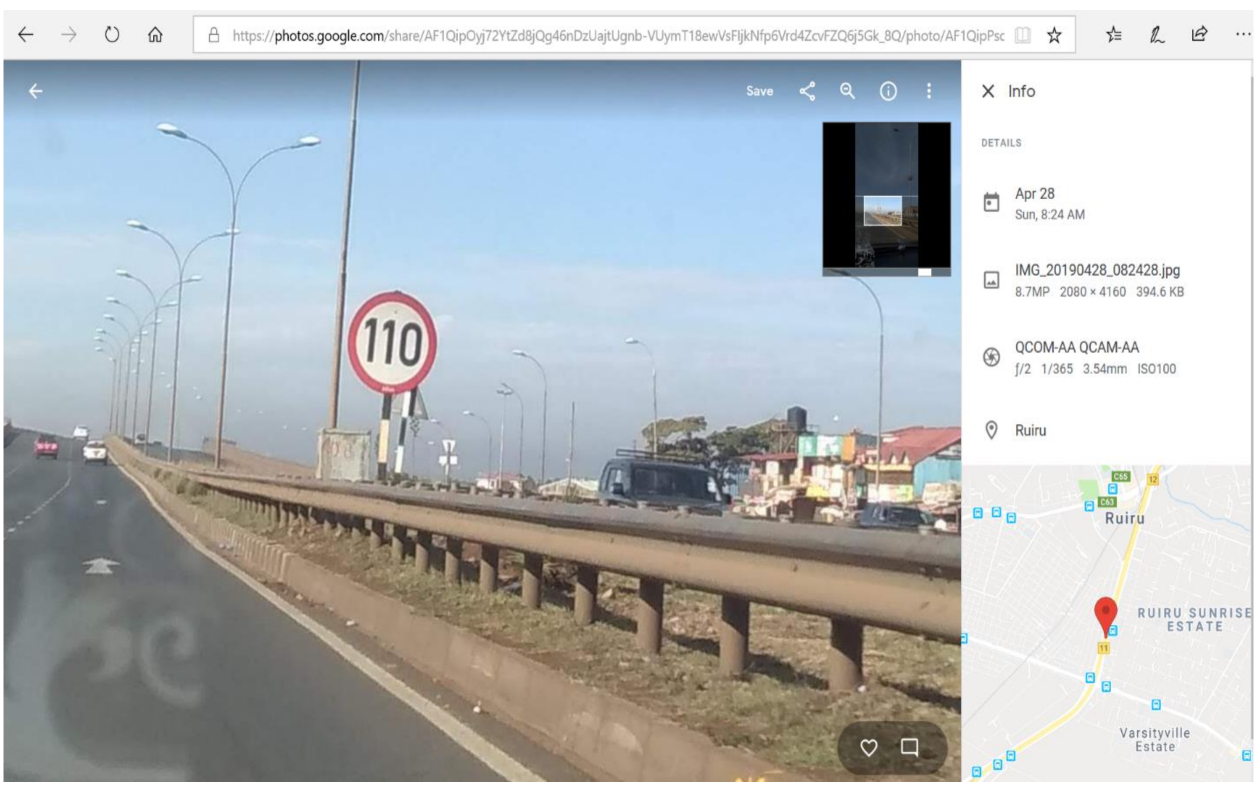


Figure 3-4: Geotagged photograph of Designated Speed Limit on Thika-Nairobi section of study area

3.2.2 Horizontal Curve Identification

This process required first to identify curves using a high quality road centreline. The spatial road dataset utilized in this methodology closely matched the actual centreline of the road when compared.

(a) Data Requirements

Horizontal curves have been critical road sections used in the identification of road accident hot spots according to various studies. The curve attributes necessary for this study include the following:

Table 3-2; Horizontal Curve Attributes

Data Type	**Characteristic/Format**	**Source**
Road Profile/Alignment	High spatial resolution aerial image of Thika Superhighway 40km,road centerline shapefile	Digitizing of the road centreline using ArcGIS 10.3 using Digital Globe's WorldView-1/2/3 at 0.5m spatial resolution
Horizontal Alignment	Spatial format, attribute table	Automated using ArcGIS/ Roca tool
Form/Type of Curve	Spatial format	Mapping techniques, mathematical constructs

(b) Horizontal Curve Analysis

To acquire a quality road centerline, a high spatial resolution (0.3m) Landsat 8 of Thika Superhighway was downloaded from USGS in Geotiff format. The image is then ready for use as input into the digitization process.

Coordinates of six salient features that are well spread out in the study area (N-S, E-W, NW and SE directions) were captured from Google Earth and input into the Georeferencing process of the Unzipped Geotiff image.

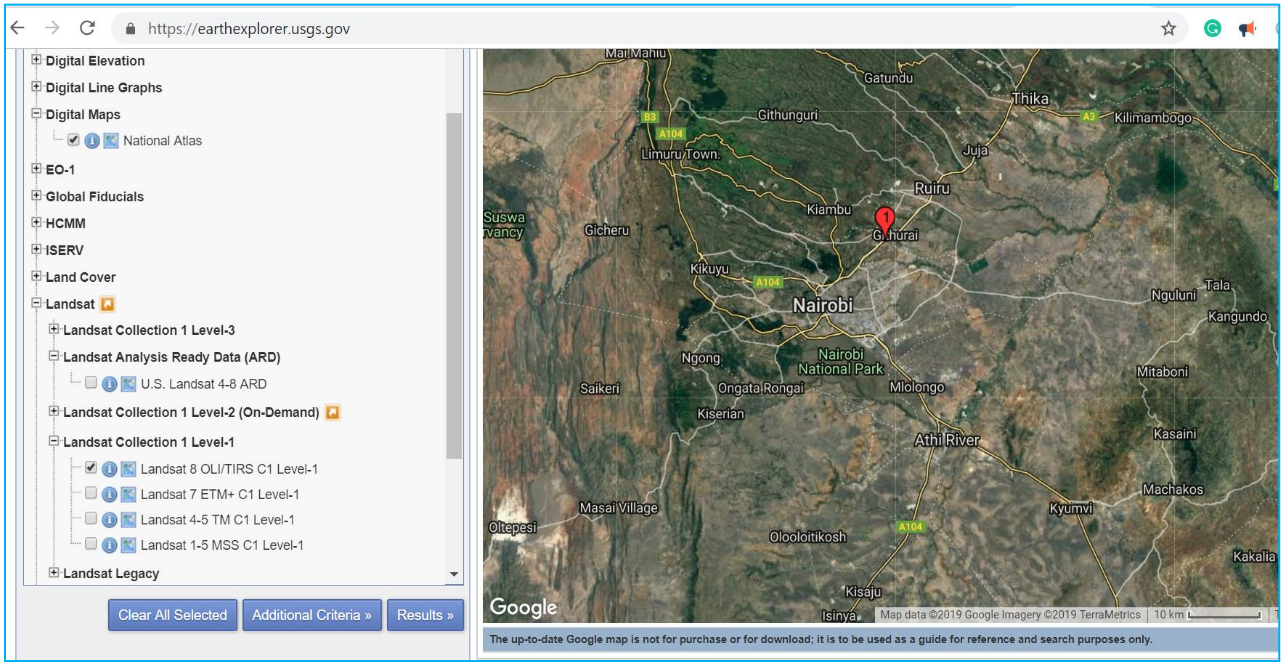


Figure 3-5: Downloading Satellite Imagery from USGS

The Georeferenced image was rectified to acceptable Root Mean Square (RMSE) error of ±0.02m using First Order Polynomial (Affine) transformation.

A line type geometry shapefile was digitized as a polyline for road centreline using photo interpretation techniques of using colour, shape, association and size were used to help digitize accurately the road centreline.

The road centreline was digitized in 5 segments 7.5km each in length and were named Segment A-B, B-C, D-E and E-F starting from Thika towards Nairobi.

The next step was to identify the various curves along the road profile of the study area. Road Curvature Analyst (ROCA) toolbox from CDV – Transport Research Centre was then used to analyse and compute various curve geometries of the road centreline. The tool was developed for automatic identification of road from digital vector data. It is capable of efficiently identifying circular curves with their radii and tangents (straight sections), which are output as linear features. It also offers the option to calculate curvature attributes (Average Deflection Angle, Detour ratio and the Number of turns) for each input line features as new attributes. The inputs to the tool are the line feature class of road network sections and user predefined input as training data comprising of coordinates of road section vertices and user-defined geometry classification.

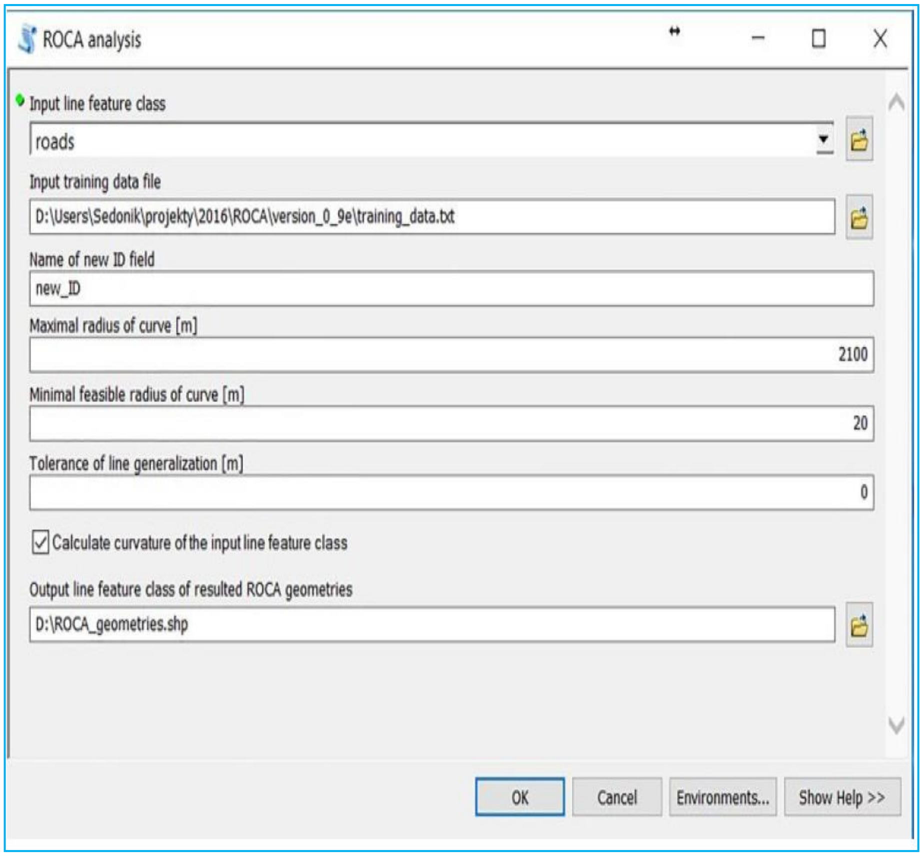


Figure 3-6; Road Curvature Analyst Toolbox In Use

3.2.3 Vertical Curve/Terrain Modelling

(a) Data Attributes

Table 3-3;Vertical Curve Attributes

Data Type	Characteristic/Format	Source
Slope Analysis	Contours, DEM	SRTM DEM

(b) Slope Analysis

A 1-arc second Digital Elevation model from SRTM was used to analyse slope and elevation profile of the Thika Superhighway alignment to understand slope variation with terrain. The result was an elevation profile superimposed road formation level and a slope analysis map shown in Chapter Four.

The SRTM DEM has the following product specification specified in table 3-3

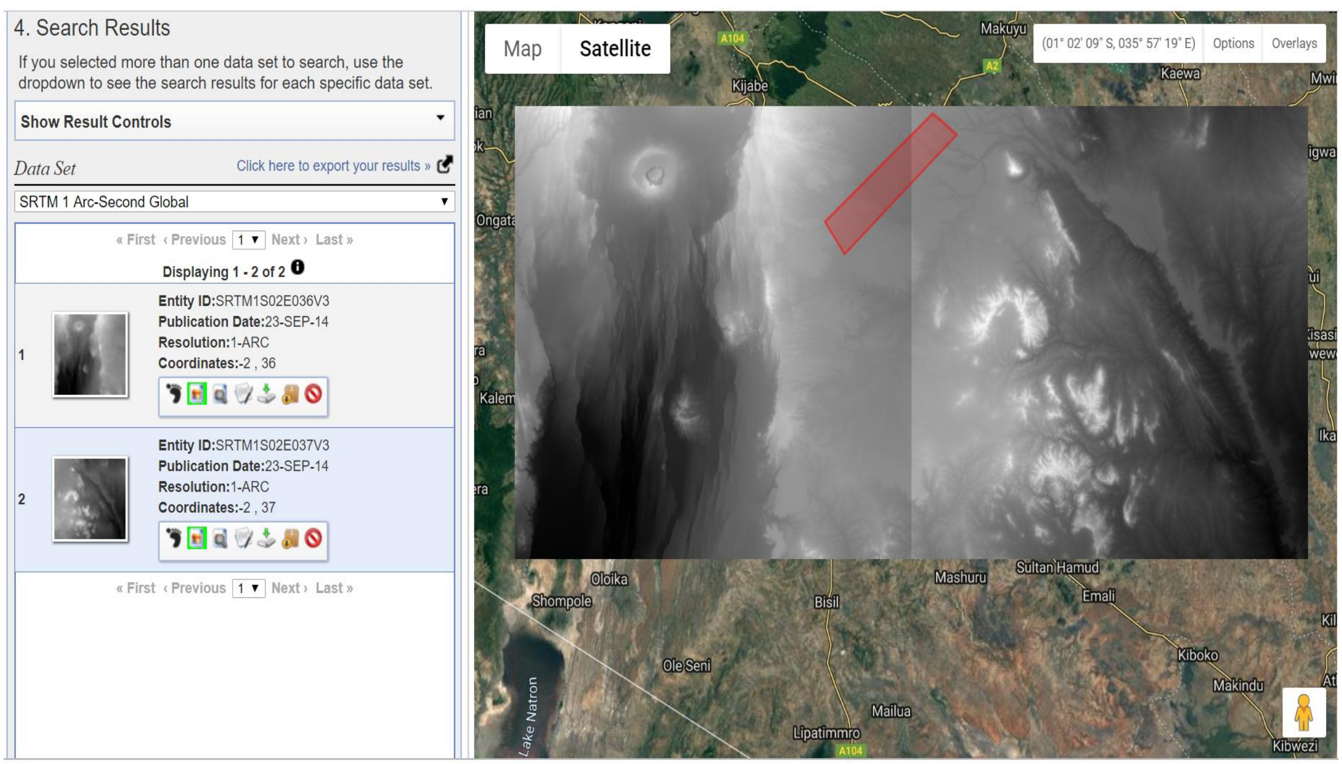


Figure 3-7; Acquisition of DEM

Table 3-4 SRTM product specification

Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Meters
Spatial Resolution	1 arc-second for global coverage (~30 meters) 3 arc-seconds for global coverage (~90 meters)
Raster Size	1 degree tiles
C-band Wavelength	5.6 cm

The downloaded DEM Geotiff images were extracted and imported into ArcGIS for slope analysis using to slope tool shown in figure

Input raster is where you input the downloaded DEM (surface raster).

Out raster is the slope output raster

Output measurement determines the measurement units (degrees or percentages) of the output slope data.

DEGREE — The inclination of slope will be calculated in degrees.

PERCENT_RISE — Keyword to output the percent rise, also referred to as the percent slope.

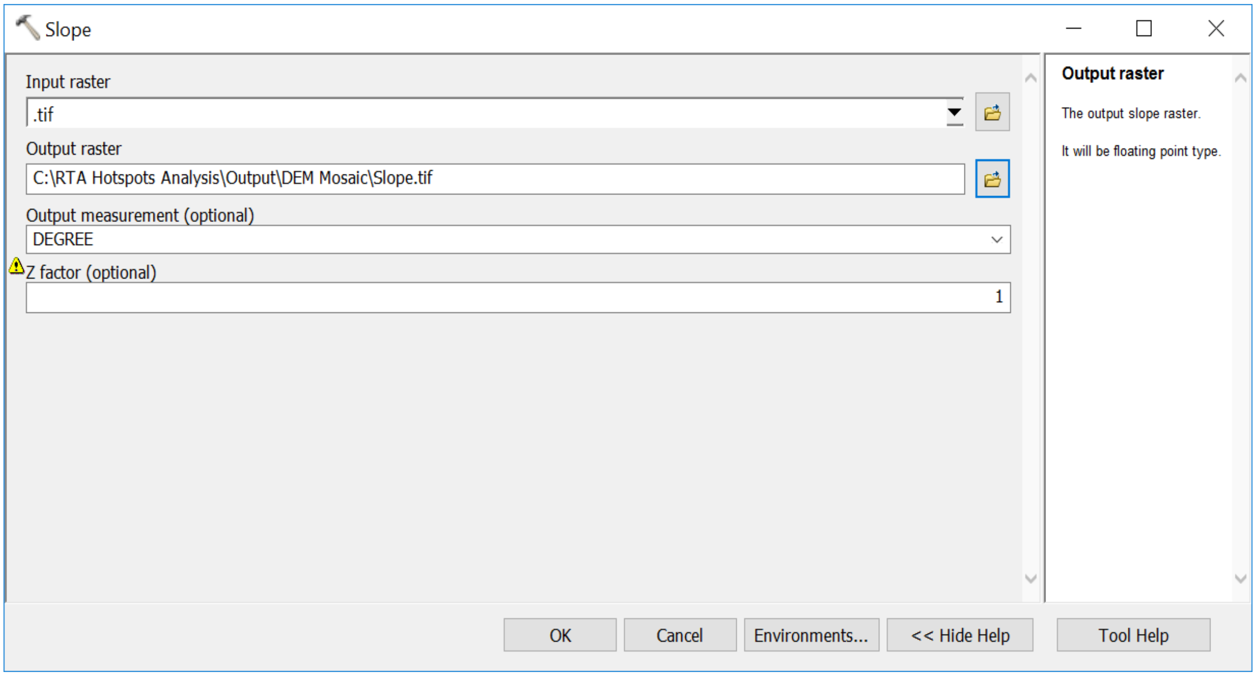


Figure 3-8; Slope Analysis Tool

Z factor is the conversion factor between 2D coordinate (xy) unit and the elevation (z) units. Since the coverage for the study area was in two footprints, Mosaic to New Raster tool was used to combine the rasters into one seamless image before the slope analysis tool was invoked.

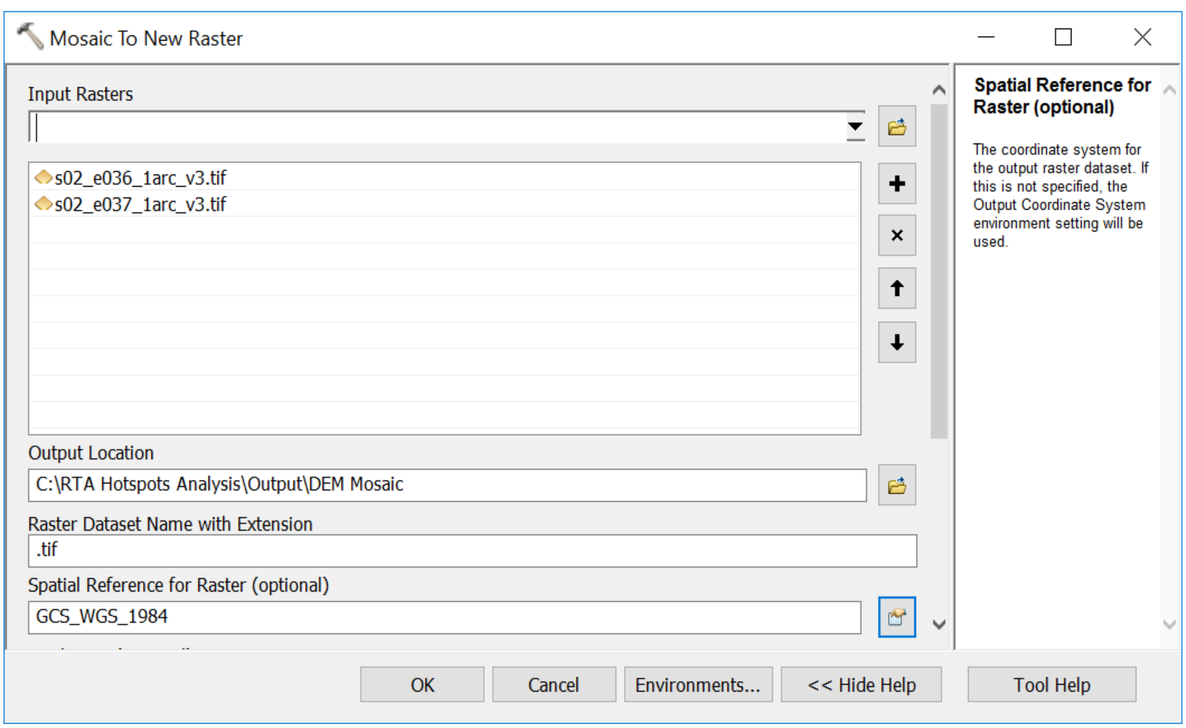


Figure 3-9; Mosaic to new raster tool for combining rasters

3.2.4 Road Traffic Accident Crash History Data.

(a) Data Requirements

The crash data attributes required for this study is shown in the table below:

Table 3-5; Crash Data Attributes

Data Type	Characteristic/Format	Source
Location	Coordinates, attribute text, excel sheets	NTSA Road Accident Reports
Crash Severity (fatal/serious injury/minor injury)	Excel Sheets, attribute text	NTSA Road Accident Reports
Movement Type and Road Users	Attribute Text, Excel Sheets	NTSA and validation field work

(b) Crash History Analysis

This was obtained from the NTSA in form of monthly fatal road accident Excel files for the year 2018 and 2017. This data had attributes for date, time in 24 hours' format, traffic base/sub base, county, road, place, Motor Vehicle involved, details of the accident, name of victim(s), age, gender, type of victim (Pedestrian, Passenger, Driver, Motor cyclist). (*see Appendix A*)

This data was summarised into Fatal Accidents report detailing; category of injury (whether fatal, serious or slight), victim involved (whether pedestrian, driver, passenger, passenger-passengers or passenger to cyclist).

This summary report data was used to create visualization that would be in cooperated into the validation model for assessment of accuracy of prediction of road traffic accident hotspots. The charts facilitated drawing of important conclusions from the prediction model.

Table 3-6; Excerpt of Road Traffic Accidents data for Thika Superhighway

Crash Spot	V-V	V-P	L-C
Muthaiga-Kiambu road	8	19	5
NYS/Utalii Drift	13	6	13
Survey of Kenya		1	0
Drive Inn	3	12	
Mathare North Road		5	2
GSU/Allsops Drift	1	2	
Garden Estate Road		4	17
Homelands Area		5	4
Safari Park Area		14	1
Kasarani/Kamiti Road	4	15	
Kenya Tents	15	11	5
Clay Works Area		1	0

Key

V-V = Vehicle to Vehicle accident

V-P = Vehicle hitting Pedestrian

LC = Loss of Control

3.2.5 Integrated Road Traffic Accidents Hotspot identification model

The Road Traffic Data was analysed together with the curves data generated in a Multi Criteria Decision tool to generate hotspots which were validated using the crushes data from the NTSA.

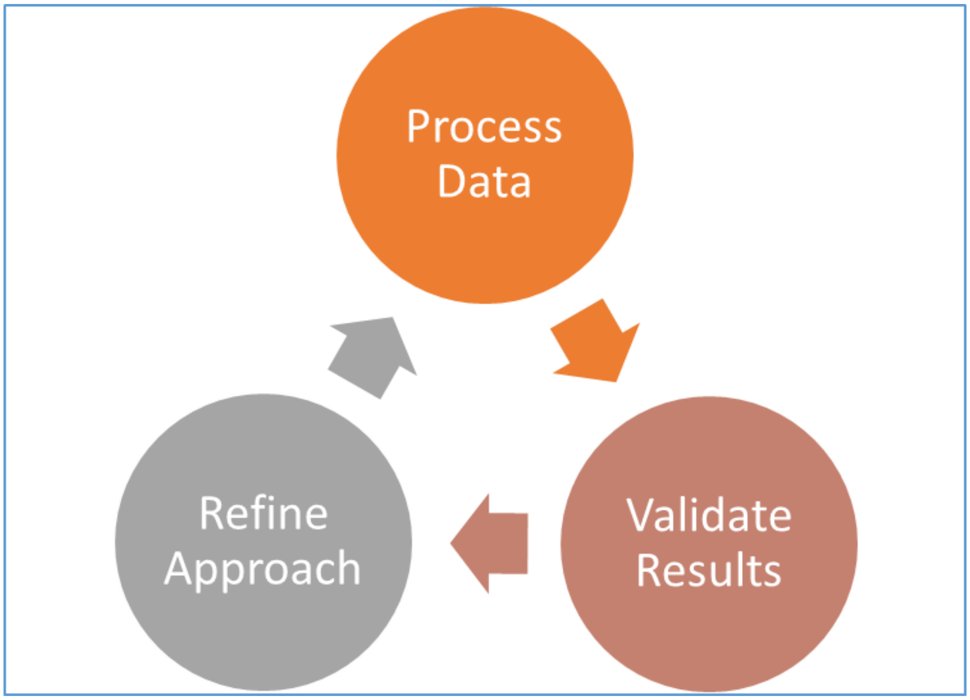


Figure 3-2; Integrated RTA Hotspots identification Model

Designated Speed models, horizontal context curves and terrain data were combined in a multi critetia decision tool to be used in automatic identification of Road Traffic Accidents hotspots. The identified hotspots were validated using the Road traffic accidents crash history data.

The results of the study are shared online to a wide range of users for development of an online near realtime RTA reporting system with integration to feedin live tweets

3.3 Preparation of Data Sets

This section of the study allows for preparation of the pillars on which the project was anchored. This section discusses the technical support and processes that were used to achieve the project objectives. These include:

a) Hardware Components

The table below shows the hardware components used in the study, their specific usage and feature components.

Table 3-7; Hardware Requirements

Hardware	Usage	Features
Laptop	Work station for storage, analysing, distributing and presenting of data collected.	HP Pavillion X360, CORE i5 7^{th} generation, 8GB RAM, 5.2 GHz, 1TB Hardisk
Mobile Hand Held GPS	Collect point data for designated speed and other location data needs	Garmin etrex 30 with accuracy to within +/- 3 metres
Personal car (odometer)	Travel the study distance noting the designated speeds, especially along curves	Subaru Legacy 2009 model
Camera	Capturing geotagged photographic images of the nature of curves and video recording for driver behaviour along curves.	iPhone 6 S Camera
External Hard Disk	External storage for transfer of data	Transcend Store Disk Jet 1TB
Printer and Scanner	Printing of reports, maps and photographs as well as scanning of hard copy maps	HP LaseJet M506

b) Software Components

The table below shows the software programmes utilized in the study.

Table 3-8; Software Requirements

Software	**Usage**
ArcGIS 10.3	Georeferencing, digitizing, data manipulation and analysis, mapping and presentation
Global Mapper	Map Projection, detailing of map elements and terrain analysis
AutoCAD	Profiling of sections
Ms Word & Nitro PDF	Report writing

The afore mentioned data needs and attributes as well as the hardware and software all interact under one system to achieve the envisaged objectives. The interaction is summarised in the illustration below.

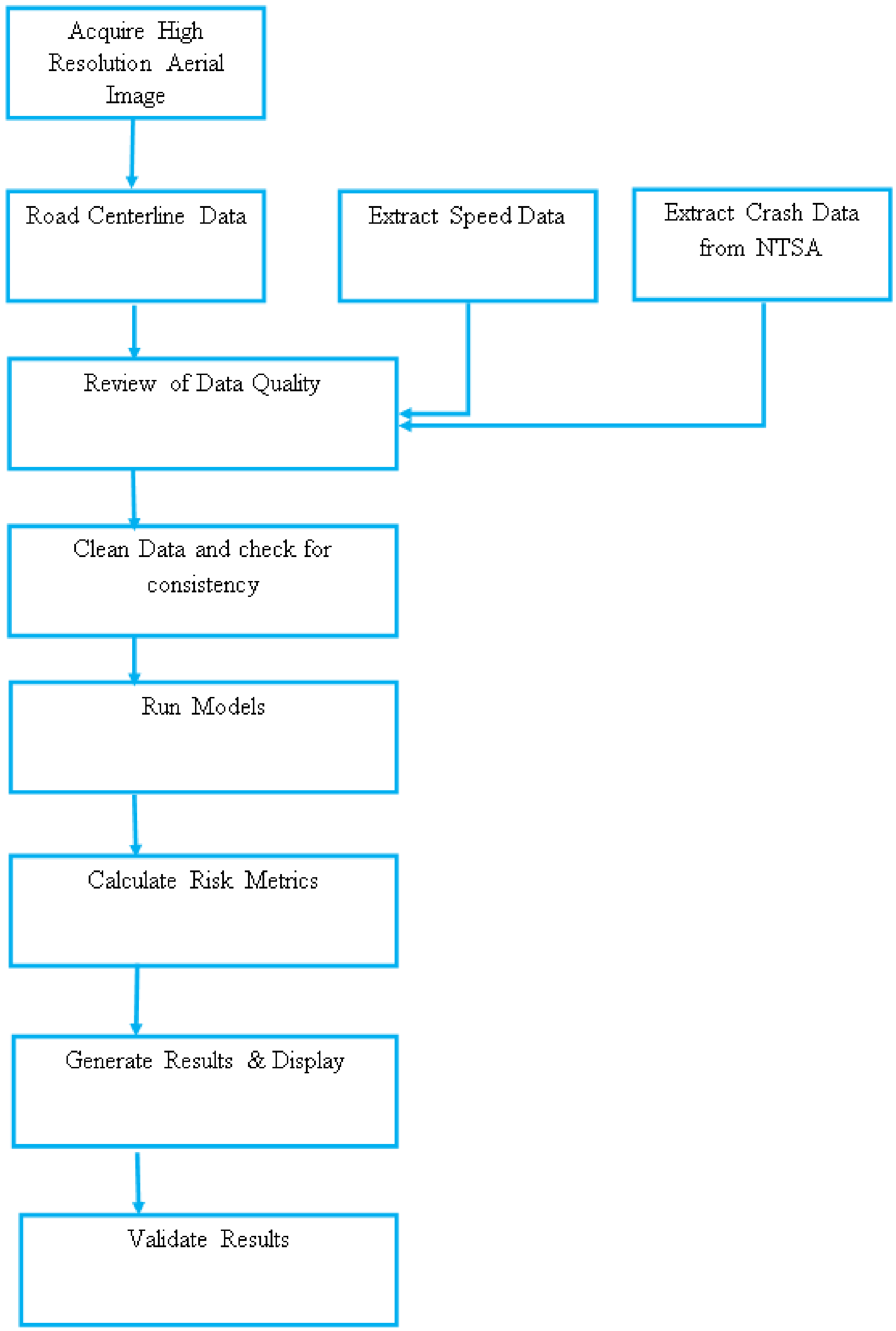


Figure 3-11; Methodology Flowchart

Table 3-9; Summary of Methodology

Objective	**Methodology**	**Expected Result**
1. Design and develop spatial speed models	-Collect data on designated speeds by KeNNHA/NTSA on Thika Super Highway using handheld GPS and geotagged images -Map the point location for the start and end of each designated speed -Design and map the findings using ArcGIS using a base satellite image of high resolution	- Speed model of the current situation
2. To identify the effect of horizontal (radius) and vertical (terrain) curves on road safety through designing of curve models.	-Acquire high resolution quality satellite images of the study area. -Collect precise road centre-line data and plot on the image. -Divide the road center line data to appropriate segments to fit the scale i.e 7.6 km sections -Analyse the data using suitable Roca analysis tool to identify different types of	- Horizontal Curve Model

	curves. -Identify, label and map the curves	
	-Acquire elevation data along the road profile of the study area. -Analyse slope using DEM	-Vertical Curve (terrain) Models
3. Design a suitable integrated geospatial model using speed and curve in prediction of road accident hot spots.	- Use a mathematical construct based on the afore mentioned Hammonds Model to evaluate the speed, horizontal curve and terrain to identify potential hot spots and high risk areas. -Integrate the speed models and curve models using GIS	-Geospatial model that identifies potential road accident hot spots
4. Compare and validate findings and results	-Collect data on fatal accidents/crash history on the study area (NTSA). -Analyze the data and prepare a map of road crash history -Overlay of the geospatial high risk prediction model on to the existing crash history data.	-Validation of results -Integrated map of black spots and potential hot spots for road accidents

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Designated Speed models

Designated speed is a function of radius of curvature and the way a curve is being approached by a driver. The data collected using the GPS and geo-tagged photos (table 4-1) were mapped onto a georeferenced image to reveal the patterns in the speed model.

The designated speed model from Thika-Nairobi mapped from KeNHA data with their specific location is as shown in figure 4-1.

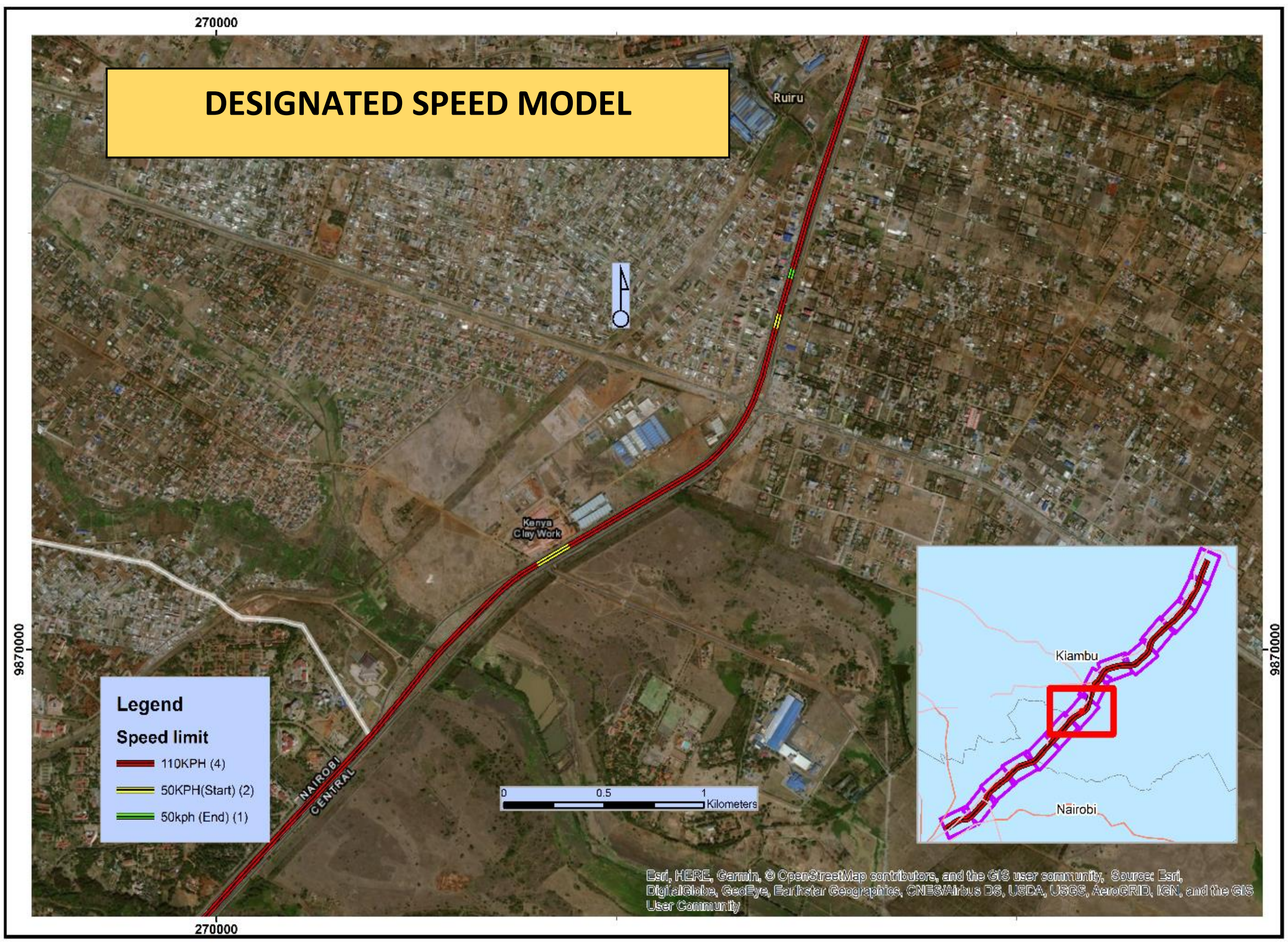


Figure 4-1; Designated Speed model for Thika Superhighway section from Thika towards Nairobi

The maps reveal that Thika Superhighway is designed largely for speed limits of 110 kph. In some sections, close to urban centers, advisory speeds of 50 kph are designated. The maps of the designated speed generally give a uniform visual impression with scattered changes of 50 kph in some sections. The

Table 4-1; Sample Designated Speed Limits data

X	Y	Speed Limit
259032.00	9859927.00	110KPH
268557.00	9867271.00	110KPH
269077.00	9867802.00	110KPH
271610.00	9870395.00	50KPH

4.2 Types Curve along Thika Superhighway

The road centreline was used to create strip index features in ArcGIS 10.3 to produce 14 maps along the road alignment at a scale of 1:10000. The various types of curves along the road alignment were similarly mapped and yielded the results shown in figure 4-2.

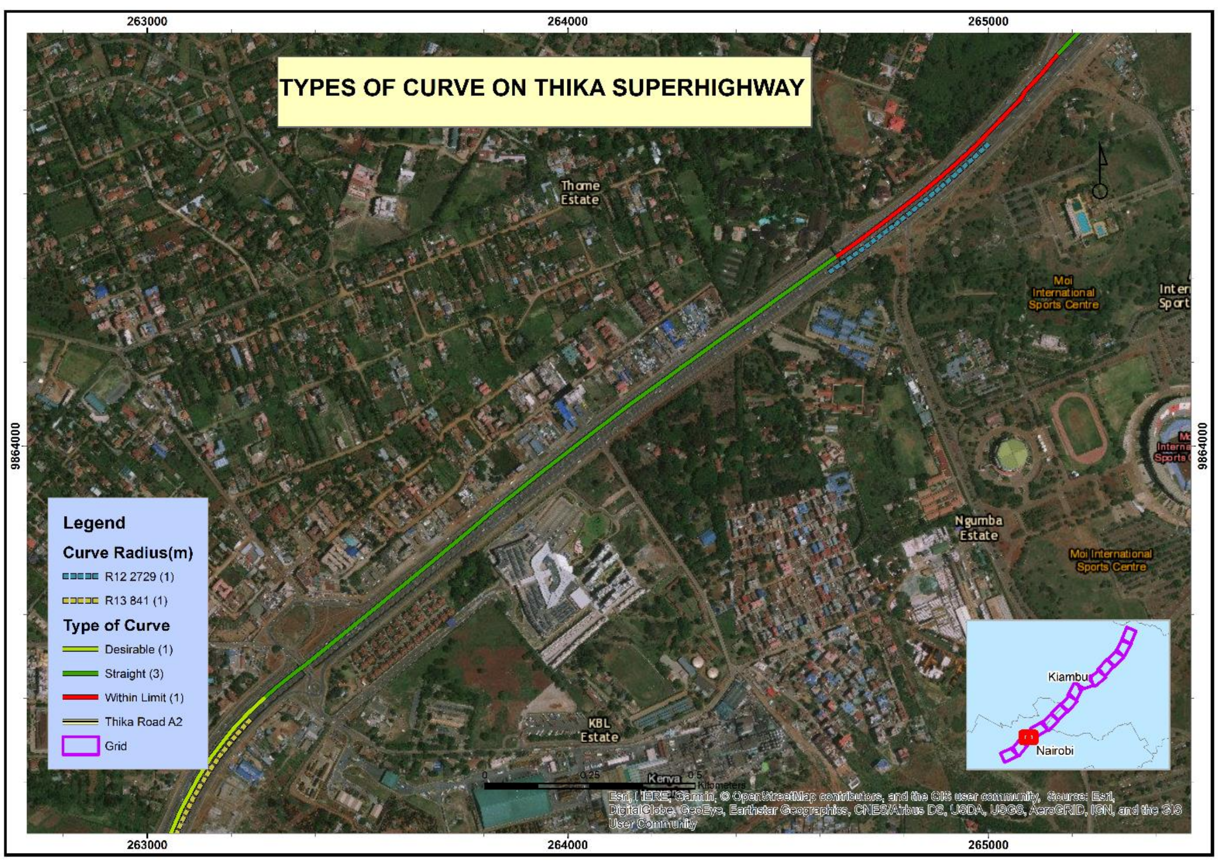


Figure 4-2; Horizontal Curve Model of a section of Thika Superhighway

The ROCA tool derived seventeen (17) automated curve sections on Thika Superhighway as shown in table 4-2. The least curve radii were observed to be around Ruiru – Kamiti area (530 m) while the highest curve radii were observed to be around Kenyatta University Mall (3920 m). The length (l) and radii (m) were used to categorize the road sections guided by the Road Manual (1976) dictates. The road sections above were categorized into straights, desirable curves, curves within limit and unacceptable or out of context curves. These categories were given colour codes and mapped to give the bands in figure 4-2 above.

Table 4-2 Curve Radii for Thika Superhighway

CURVE RADIUS TABULATION		
Curve	**Radius (m)**	**Area**
R1	1758	Red Rose Gardens
R2	1604	Juja
R3	1033	Kalimoni
R4	1003	Mugutha
R5	982	Kimbo
R6	885	Kenya University Ruiru
R7	530	Ruiru Kamiti Road
R8	847	Eastern Bypass
R9	3920	Kenyatta University Mall
R10	756	Githurai
R11	1060	Kasarani
R12	2729	Safari Park Area
R13	841	Rosters
R14	865	Allsops
R15	711	Utalii
R16	585	Muthaiga
R17	1040	Pangani

The photographs in figures 4-3 and 4-4 show the horizontal curves at the Juja Bridge and Githurai respectively. These show the different types of curves from a visual perspective.

Figure 4-3; Curve at Juja Interchange

Figure 4-4; Githurai Curve

The curve identification criteria identified a total of 17 curves on the Thika Superhighway. This was based on the criteria specified in table 4-3.

Table 4-3 Horizontal Curve Categorization

Curve Category	Total Curves	% of Total Curves	Criteria (Decelarion Design Limit)
Unacceptable	2	11.76	Out of context
Undesirable	5	29.41	Out of context
Desirable	3	17.65	Within context
Within Limit	7	41.18	Within context

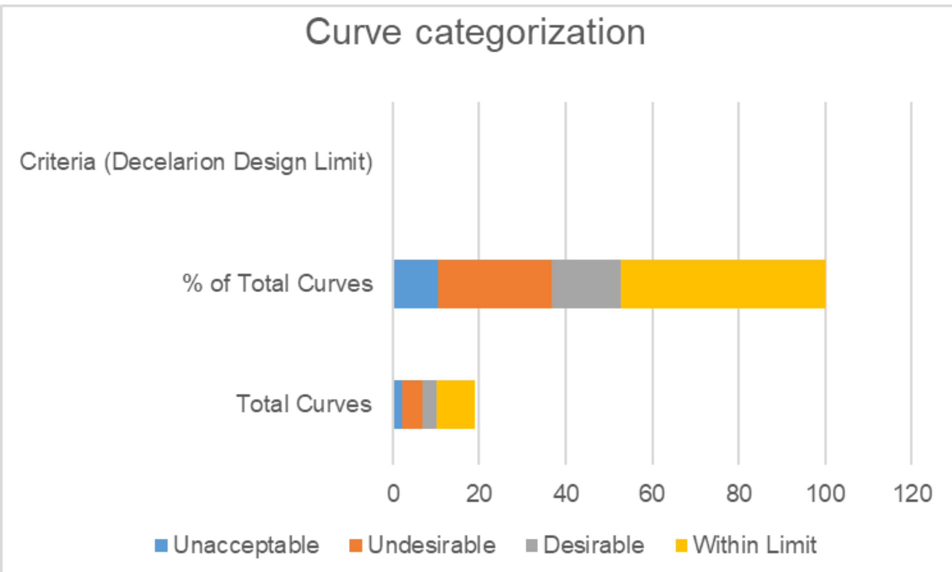


Chart 4.1 Curve Categorization

4.3 Crash Data Mapping

The crashes that have occurred along Thika Superhighway were mapped capturing details on type of crash, severity and cause. Figure 4-5 and 4-6 show the crash history map and a section of Thika Superhighway with mapped crash spots respectively. The crash spots map revealed, for example, that Mathare North Road experienced 0 Vehicle-Vehicle crashes, 5 vehicle-person and 2 loss of control crashes. This can accessed on ArcGIS online at https://tinyurl.com/y6sxcv8k

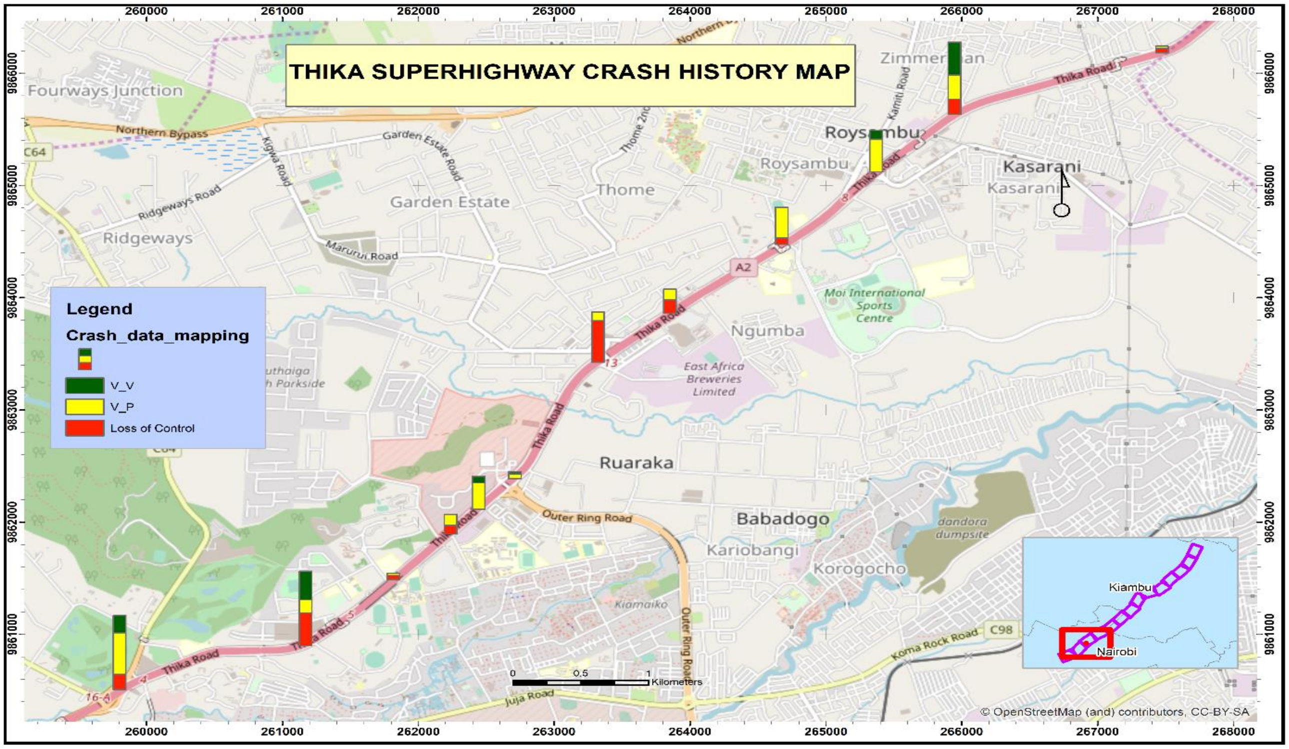


Figure 4-5: Crash History Map for Mathare – Roysambu Section of Thika Superhighway

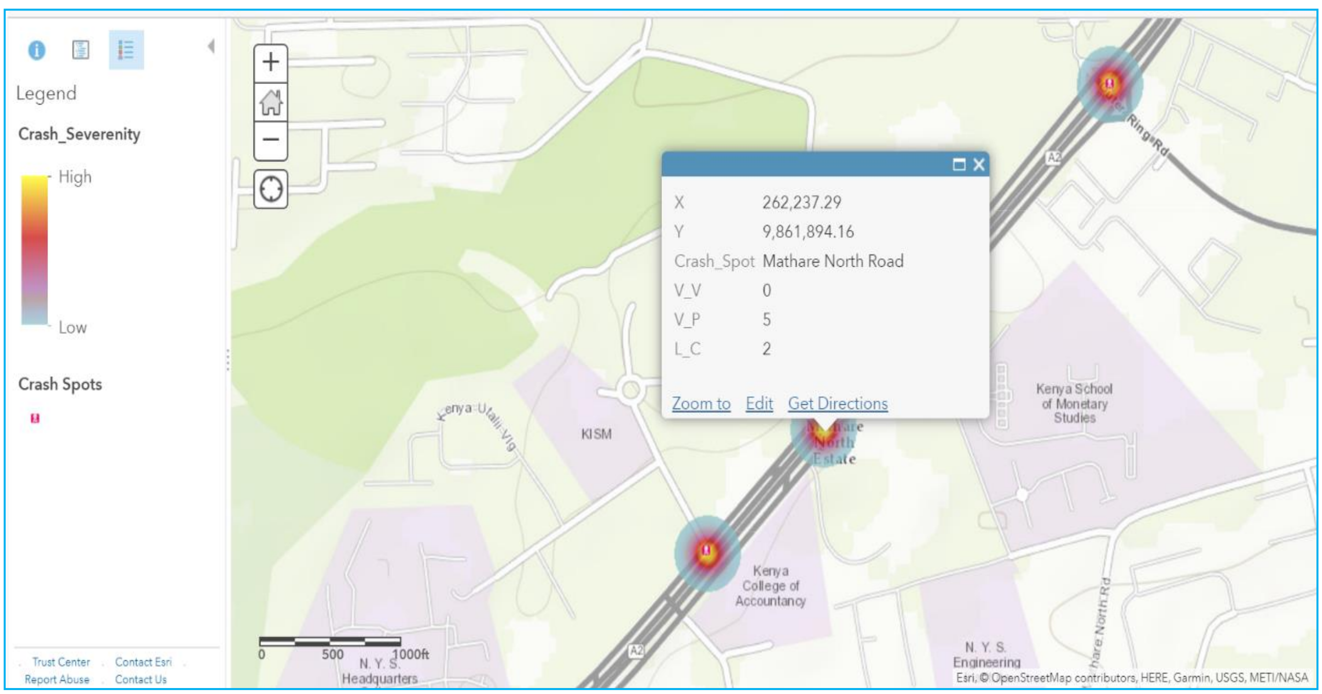


Figure 4-6; Crash Data Mapping on ArcGIS Online

4.4 Thika Superhighway Elevation and Slope analysis

The analysis of the DEM for a section of the Thika Superhighway generated a slope analysis map in figure 4-7. The slope map conformed to the elevation profile shown in figure 4-8. Detailed segment elevation profiles have been attached in Appendix C.

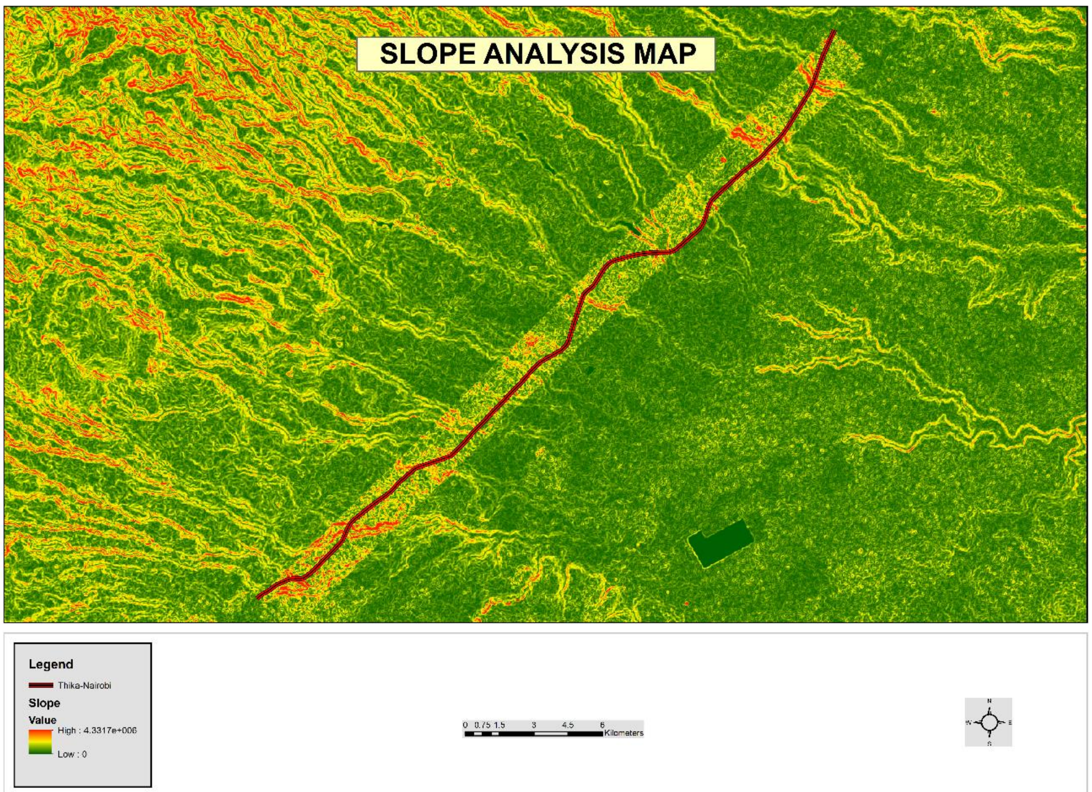


Figure 4-7; Slope Analysis Map for Thika Superhighway

Figure 4-8; Thika Superhighway Elevation Profile

4.5 RTA hotspots Prediction

The RTA hotspots prediction model was based on the rationale that incorporated mathematical and logical interaction of horizontal curves, vertical curves, design speed speed shown in table 4-4.

Table 4-4; Desirable operating speeds for combined horizontal and vertical curves

		Terrain (Slope)			
		Flat {<2%)	Undulating (2-4%)	Hilly (5-7%)	Mountainous (>=8%)
Curvature	Straight	110 km/hr	110 km/hr	95 km/hr	90 km/hr
	Curved	110 km/hr	100 km/hr	95 km/hr	90 km/hr
	Winding	90 km/hr	90 km/hr	85 km/hr	80 km/hr
	Tortuous	75 km/hr	75 km/hr	75 km/hr	70 km/hr

The designated speed model, horizontal curve model and the terrain model were gathered in a mathematical formula and logical (programming) construct (table 4-5) to identify the road accident hot spots for the study area.

Table 4-5; Integrated Model for Identification of Road Accident Hot Spots for Thika Superhighway

S/No	Location	Curve Radius (m)	Designated Speed Limit (km/hr)	Terrain (Slope(%))	Terrain	Standard Speed (km/hr)	Type of Curve	If function	Results
R1	Red Rose Gardens	1758	110	2.3	Undulating	110	Straight	Acceptable	
R2	Juja	1604	110	2.4	Undulating	110	Straight	Acceptable	
R3	Kalimoni	1033	110	1.4	Flat	140	Curved	Acceptable	
R4	Mugutha	1003	50	3.4	Undulating	140	Curved	Acceptable	
R5	Kimbo	982	110	0.9	Flat	120	Curved	Acceptable	
R6	Kenyatta University Ruiru	885	110	1.7	Flat	120	Curved	Acceptable	
R7	Ruiru Kamiti	530	110	1.3	Flat	100	Winding	Acceptable	
R8	Eastern Bypass	847	110	1.9	Flat	120	Curved	Acceptable	

R9	Kenyatta University Mall	3920	50	4.1	Hilly	110	Straight	Unacceptable	
R10	Githurai	756	110	0.4	Flat	120	Winding	Acceptable	
R11	Kasarani	1060	110	5	Hilly	140	Curved	Unacceptable	
R12	Safari Park	2729	110	1.3	Flat	110	Straight	Acceptable	
R13	Rosters	841	50	0.4	Flat	120	Curved	Acceptable	
R14	Allsops	856	110	0.8	Flat	120	Curved	Acceptable	
R15	Utalii	711	110	5.6	Hilly	110	Winding	Unacceptable	
R16	Muthaiga	585	110	3.3	Undulating	100	Winding	Acceptable	
R17	Pangani	1040	110	3	Undulating	140	Curved	Acceptable	

For example, at Utalii area (NYS) where radii is 585 m then logical construct will be: =IF (OR (F17="Flat", F17="Undulating", G17<110), "Acceptable", IF (F17="Hilly" &(G17>=110), "Undesirable", "Unacceptable"))

From the analysis, some of the identified hot spots on Thika Superhighway (Thika - Nairobi) occur on some of the undesired curves. The results were mapped onto the base map for the study area for visualization and interpretation. These hot spots include the general area of NYS bend/curve, Githurai and Juja curve (see Appendix D).

4.6 Thika Superhighway Traffic Hotspots

The RTA Crash history data yielded the following results which were used to validate RTA hotspot prediction model. Figure 4-10 shows the Kenya Tents (Githurai) as a hot spot with undesirable curve having 15 V-V crashes, 11 V-P and 5 crashes due to loss of control.

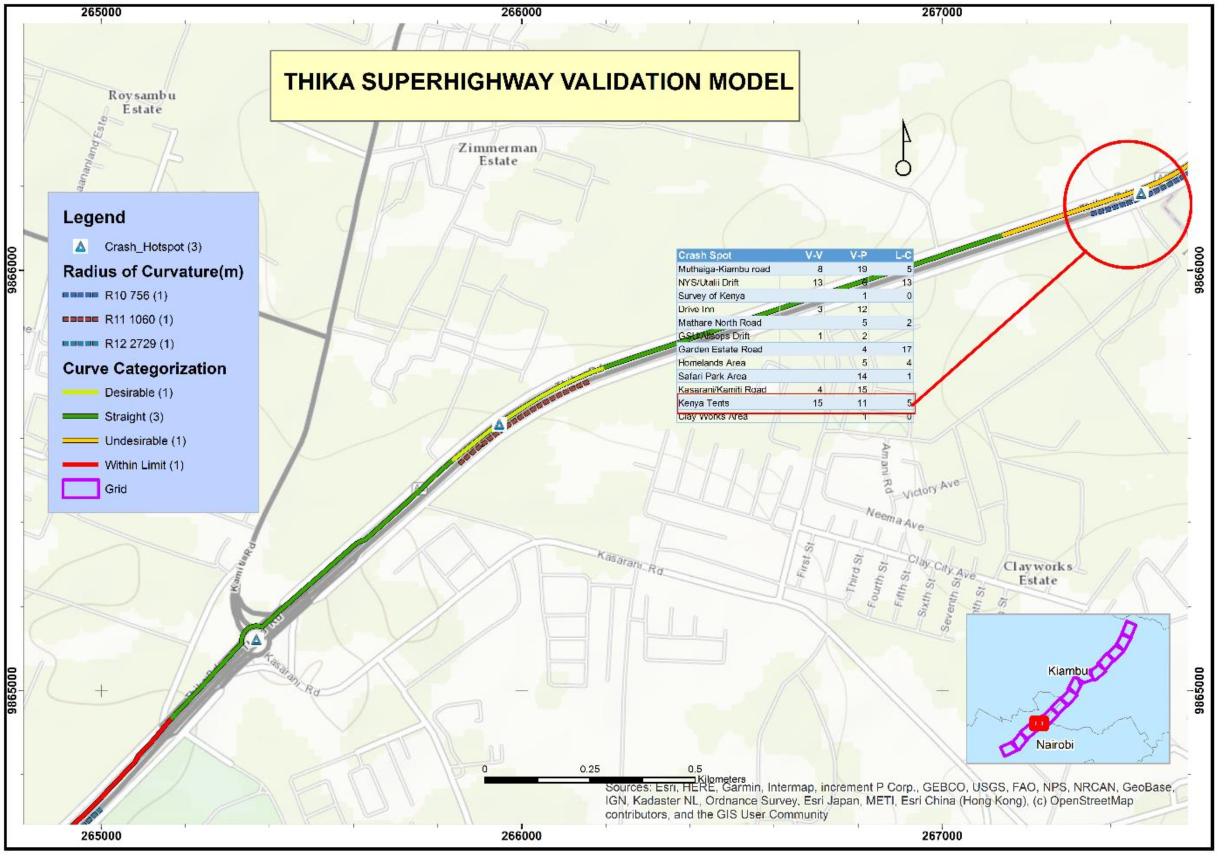


Figure 4-9: RTA Crash Validation Model

CHAPTER FIVE

CONCLUSION AND RECCOMENDATION

5.1 Overview

This section discusses the overall findings and results of the whole study in respect of the study. It provides a summary of the results and further proposes the way forward on addressing the issue of road safety through prediction of road accident hot spot areas.

5.2 Conclusion

It has been observed that the traditional approaches to road safety may have overlooked the importance of curves to road safety, because of their overall crash history which may not have been sufficient to warrant further investigation. However, from the prediction model, it is critical to consider these important road segment in road engineering in order to save lives and to prevent loss of lives through road crash.

This study achieved the objective of modelling the designated speed on Thika Superhighway as envisaged by the regulating body. The speed limit for the entire road is largely given at 110 km/hr with exception close to urban areas and town where the speed limit is 50 km/hr. The speed limit signs are far apart giving a fairly consistent designated speed map. However, car condition and driver behaviour on Thika Superhighway has given rise to operating speeds. Numerous studies have been done on the operating speed on the study area without giving the point location data for speed attributes.

The horizontal curve and vertical curve data for the study area were achieved using ROCA tool and terrain models derived from satellite image. The horizontal curves were identified to seventeen (17) in number and were later analysed and categorized into unacceptable, undesirable and desirable curves when integrated with the terrain and speed models.

The interaction of speed model, horizontal curve model and terrain were compared and contrasted with the NTSA crash history data for 2017 and 2018. The crash history data was mapped and overlayed onto the hot spot prediction model which showed consistency of the historical data and identified hot spots.

This prediction tool and GIS techniques used can therefore be adopted and replicated, with necessary adjustments where appropriate, for other similar studies to identify and predict road accident hot spots.

5.3 Recommendation

The study recommends the use of GIS techniques and geospatial high risk prediction model in identifying hot spots for other urban roads and rural roads as well. The study recommends more effort and resources be directed toward the study of operating speeds with point location data on major highways of the country in order to promote road safety.

The study further recommends the following for the identified hot spots (curves) on Thika Superhighway:

a. Application of High Prediction Model on to Interactive Maps

This refers to the creation of a plug-in onto already existing interactive maps for travel and navigation such as Google Maps. This will offer the driver ample time to plan for a trip and mark out dangerous curve and other road accident hot spots. Also, advance audio warnings can be issued when the driver is approaching these road accident hot spots.

b. Application of Intelligent Warning Signs

Road engineers can incorporate the study findings to road safety approaches and use electronic intelligent warning signs at dangerous curves and identified hot spots on Thika Superhighway. These warning signs are activated by approaching vehicles based on a number of variables such as approaching speed, surface condition and presence of other vehicles. This application is intended to reduce speed and raise awareness along undesirable curves.

c. Transverse Markings/Rumble Strips

Use of transverse markings provide enhanced visual sense of speed while rumble strips are changes in the surface leading to vibration or noise within a vehicle. These can be applied in close proximity to undesirable curve sections of the road in order to raise awareness and allow drivers to reduce speed way before approaching a dangerous curve.

d. Coloured High Friction Surface

This refers to a high skid resistance surface which can be combined with change of colour of surface in order to raise the driver's awareness. This can be augmented with marking of the speed limit on the coloured surface.

e. Enhanced Signage

This refers to improvement to signage and conspicuously through use of gating, larger road signs, and providing coloured background sign boards.

Further, the key to improve on road safety using the geospatial high risk prediction model is undertaking of a county/country-wide study for network analysis. Geospatial techniques can be used to analyse and map out the identified hotspots for road users. Also, further analysis using operating speeds by the drivers throughout the network can be used to add value to the study.

Road authorities for example NTSA and KeNHA can employ the use of technology and social media platforms such as twitter to collect real time updates on occurrences. This study recommends the integration of the geospatial high risk prediction model on to interactive maps and plug-in onto platforms such as Google navigation systems in order to warn drivers in advance of the identified hot spots in advance.

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APPENDICES

A. NTSA Summary of Accident Report (2017-2018)

B. Road Centerline Segmentation

C. Study Area Road Elevation Profiles (5)

D. Road Traffic Accident Hotspots

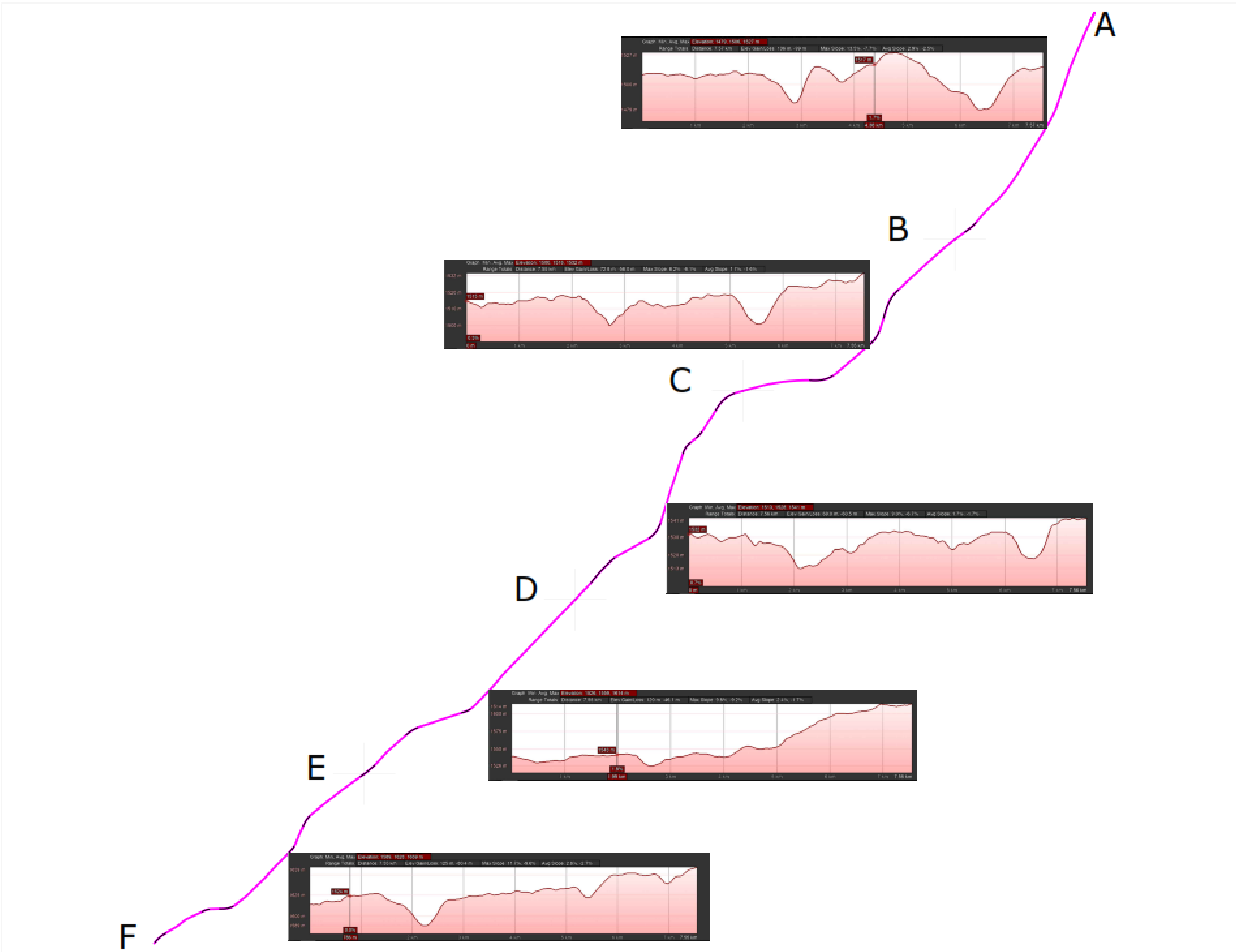
APPENDIX A: NTSA SUMMARY OF ACCIDENT REPORTS

S/NO	DATE	**TIME 24 HOURS**	**BASE/SUB BASE**	**COUNTY**	**ROAD**	**PLACE**	**MV INVOLVED**	**BRIEF ACCIDENT DETAILS**	**CAUSE CODE**	**VICTIM**	**NO**
1	14-Feb-18	700	THIKA	KIAMBU	THIKA ROAD	TAJ GARDENS	UNKNOWN	HIT & RUN	69	PEDESTRIAN	1
2	3-Jan-18	450	JUJA	KIAMBU	BOSTON QUARRY	NDARUGO AREA	KBW 931R FAW LORRY	THE VEHICLE LOST CONTROL HITTING THE PERIMETER	26	DRIVER	1
3	12-Apr-18	2045	JUJA	KIAMBU	NAIROBI THIKA	THIKA BOUND SERVICE LANE AT NIBS COLLEGE	KBU 589R/ZE 1484 MERCEDES BENZ TRAILER	THE VEHICLE KNOCKED DOWN THE VICTIM	68	PEDESTRIAN	1
4	12-Mar-18	900	JUJA	KIAMBU	THIKA HIGHWAY	NEAR CENTURION HOTEL	KCC 672D MITS LORRY	THE VEHICLE KNOCKED DOWN THE VICTIM	37	P/PASSENGER	1
5	19-May-18	2330HRS	KERUGOYA	KIRINYAGA	KERUGOYA-KAGUMO	WAIGIRI AREA	KMDM 391E DAIYUN & KBY455M TOYOTA VITZ	HEAD ON COLLISION	37	MOTORCYCLIST	1
6	23-Jan-18	620	JUJA	KIAMBU	KIMBO RUIRU SERVICE LANE	NEAR KENYATTA UNIVERSITY RUIRU CAMPUS	KBR 326A T/MATATU & KCA 043Q HINO BUS	THE KCA KNOCKED DOWN THE VICTIM AND WAS HIT FROM BEHIND BY MATATU	78	PEDESTRIAN	2
7	23-Jan-18	745	KASARANI	NAIROBI	OUTERING	NEAR GSU GATE	UNKNOWN M/V	HIT AND RUN	58	PEDESTRIAN	1
8	25-Jan-18	500	PANGANI	NAIROBI	NORTH VIEW	NORTH VIEW	UNKNOWN	HIT AND RUN. THE M/V HIT AND UNKNOWN PEDESTRIAN WHO DIED	7	PEDESTRIAN	1

								ON THE SPOT.			
9	25-May-18	1730HRS	PANGANI	NAIROBI	THIKA SUPERHIGHWAY		KBN234N ISUZU BUS	DRIVER LOST CONTROL, HIT THE PAVEMENT AND WAS THROWN OUT OF THE VEHICLE	26	DRIVER	1
10	26-May-18	0200HRS	JUJA	KIAMBU	THIKA-NAIROBI	HIGH POINT P/CROSSING	KCD183F TOYOTA FIELDER	VEHICLE KNOCKED DOWN PEDESTRIAN	14	PEDESTRIAN	2
11	27-May-18	1635HRS	JUJA	KIAMBU	NAIROBI-THIKA	GSU CAMP KIMBO	KCN205N ISUZU MINIBUS & M/CYCLE KMDZ737T	HEAD ON COLLISION	11	P/PASSENGER	1
12	12-Dec-18	1730	KAHAWA SUKARI	KIAMBU	KAHAWA WENDANI	GITHURAI	KCE 354B T/HIACE MATATU & PEDESTRIAN	THE MATATU KNOCKED DOWN THE PEDESTRIAN	PEDESTRIAN		1
13	17-Feb-18	2200	JUJA	KIAMBU	THIKA-super highway	NIBS INSTITUTE	KCF 199A	THE SAID M/VEHICLE KNOCKED DOWN A PEDESTRIAN WHO WAS COSSING THE ROAD KILLING HIM INSTANTLY.	68	PEDESTRIAN	1
14	8-Jan-18	820	DTEO STAREHE	NAIROBI	THIKA	NEAR MUTHAIGA FOOT BRIDGE	KBP 431E I/M/BUS(USAFIRI SACCO)	THE VEHICLE KNOCKED DOWN THE VICTIM	63	PEDESTRIAN	1
15	6-Sep-17	1530	KASARANI	NAIROBI	THIKA SUPER HIGHWAY	NEAR ROASTERS	KWN 383 ISUZU LORRY,KCJ 424L ISUZU BUS & KCJ 431M TOYOTA MATATU	THE LORRY GOT A TYRE BURST AND LOST CONTROL HITTING THE BUS WHICH VEERED OFF THE ROAD AND HIT THE MATATU	79	DRIVER	1
16	10-Oct-	2245	THIKA	KIAMBU	THIKA	TROJAN	KCF 675B	THE VEHICLE KNOCKED	63	PEDESTRIAN	1

	17				SUPERHIGHWAY		NISSAN TIIDA	DOWN THE VICTIM			
17	11-Aug-17	430	JUJA	KIAMBU	NAIROBI THIKA	JUJA FLY OVER	KCA 105M ISUZU CANTER	THE VEHICLE KNOCKED DOWN THE VICTIM	60	PEDESTRIAN	1
18	11-Sep-17	1700	RUIRU	KIAMBU	THIKA NAIROBI	GITHURAI	KCA 277W ISUZU BUS	THE CONDUCTOR FELL FROM THE MOVING VEHICLE	73	PASSENGER	1
19	13-Sep-17	1730	THIKA	KIAMBU	THIKA SUPER HIGHWAY	TROJAN PETROL STN	KMEC 478U TIGERS	THE CYCLE LOST CONTROL AND ROLLED SEVERAL TIMES	54	P/PASSENGER	1
20	21-Jun-17	2030	RUIRU	KIAMBU	THIKA SUPERHIGH WAY	WAKI STAGE	KBX 398S TOYOTA HIACE	THE VEHICLE HIT ANOTHER M/V	60	PASSENGER	1
21	28-Jul-17	1750	THIKA BASE	KIAMBU	NGOIGWA-THIKA ROAD	THIKA FLY OVER	KAX 366P TATA LORRY & KMEE 316M	THE M/CYCLE RAMMED INTO THE RARE OF THE LORRY	10	M/CYCLIST	1
22	12-Dec-17	620	KASARANI	NAIROBI	THIKA SUPER HIGHWAY	NEAR KASTIRMIL	KAL 467L ISUZU LORRY & KAH 273W V/WAGEN	THE LORRY WAS HIT FROM THE LORRY	98	DRIVER (1) & PASSENGER (3)	4
23	21-Nov-17	1800	KASARANI	NAIROBI	THIKA SUPER HIGHWAY	NEAR SAFARI PARK	KBM 347N TOYOTA IPSUM	THE VEHICLE KNOCKED DOWN THE VICTIM	60	PEDESTRIAN	2
24	3-Aug-17	320	RUIRU	KIAMBU	THIKA SUPER HIGHWAY	KWA KAIRO	KAQ494X TOYOTA LEXUS AND KAH042X TOYOTA LAND CRUISER	LOST CONTROL AND RAMMED INTO THE OTHER M/V	26	DRIVER 2 PASSANGERS	3
25	4-Jul-17	430	RUIRU	KIAMBU	THIKA SUPER HIGHWAY	NEAR KU UNIVERSITY	KAC 775S T/ALLION & KMCW 475D BOXER	THE VEHICLE HIT THE M/CYCLE	29	M/CYCLIST	1

26	14-May-17	1730	STAREHE	NAIROBI	THIKA SUPERHIGHWAY	NEAR MUTHAIGA FOOT BRIDGE	KBB 181J TOYOTA PRADO	M/V KNOCKED DOWN UNKNOWN M/A PEDESTRIAN KILLING HIM ON THE SPOT.	63	PEDESTRIAN	1
27	20-May-17	600	DTEO STAREHE	NAIROBI	THIKA SUPERHIGHWAY	NEAR JUBILEE HOUSE	UNKNOWN M/V AND M/A/PED	M/V HIT UNKNOWN M/A/PEDESTRIAN WHO WAS CROSING THE ROAD FROM L-R KILLING HIM INSTANTLY.	98	PEDESTRIAN	1
28	21-May-17	1700	RUIRU	KIAMBU	THIKA SUPERHIGHWAY	KIHUNGURO OVERPASS	KBZ 080D SCANIA BUS	BUS DRIVER KNOCKED DOWN M/A PEDESTRIAN SUSTAINED SERIOUS INJURIES AND DIED IN HOSPITAL	60	PEDESTRIAN	1
29	22-Feb-17	2145	DTEO KASARANI	NAIROBI	THIKA RD	CAR WASH AREA	KCH 357W T/IST & M/A/PED	THE VEHICLE KNOCKED DOWN A PEDESTIRAN	98	PEDESTRIAN	1
30	24-Mar-17	1230	STAREHE	NAIROBI	THIKA	SURVEY	KBQ 251P ISUZU M/BUS	THE M/V OVER RUNED A PASSENGER WHO JUMPED DOWN WHILE THE BUS WAS ON MOTION KILLING ON THE SPOT.	98	PASSENGER	2
31	28-Feb-17	930	THIKA	KIAMBU	THIKA SUPERHIGHWAY	KANDARA FLYOVER	KBQ 578L TOYOTA HIACE	THE VEHICLE KNOCKED DOWN THE VICTIM	10	P/CYCLIST	1
32	29-Jun-17	2050	RUIRU	KIAMBU	THIKA SUPER HIGHWAY	CLAYWORKS AREA	KBY 113K T/MATATU	THE VEHICE KNOCKED DOWN A VICTIO\M	60	PEDSTIRAN	1
33	30-Jun-17	820	STAREHE	NAIROBI	THIKA SUPERHIGHWAY	MUTHAIGA FOOTBRIDGE	UNKNOWN	HIT AND RUN	63	PEDESTRIAN	1
34	23-Jun-17	30	STAREHE	NAIROBI	THIKA SUPERHIGHWAY	SURVEY AREA	KAC 212C CANTER AND KMDU 225K BOXER	THE CYCLE RAMMED INTO THE STATIONERY VEHICLE	26	M/CYCLIST	1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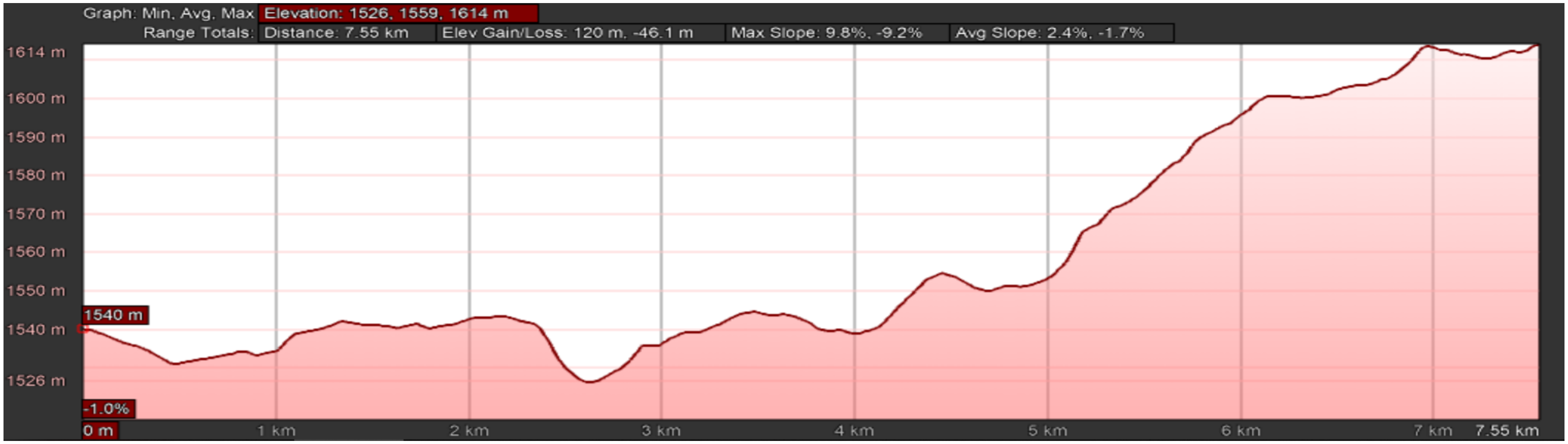
SECTION A - B

SECTION B - C

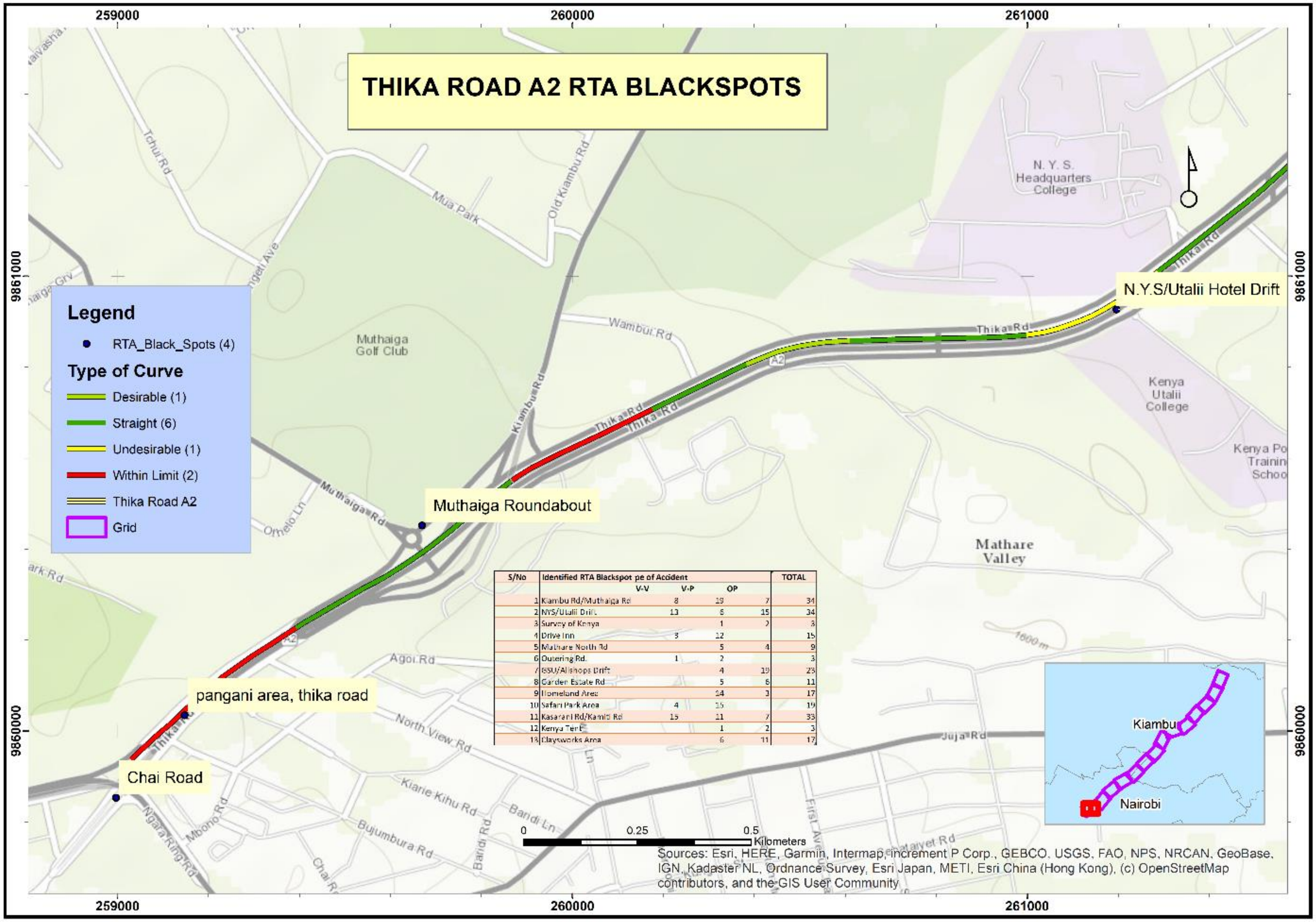


SECTION C – D

SECTION D – E

SECTION E – F


Graph: Min, Avg, Max
Elevation: 1479, 1506, 1527 m
Range Totals:
Distance: 7.57 km
Elev Gain/Loss: 106 m, -99 m
Max Slope: 13.5%, -7.7%
Avg Slope: 2.9%, -2.5%
1527 m
1522 m
1515 m
1508 m
1500 m
1492 m
1485 m
1479 m
1508 m
-0.9%
779 m
2 km
3 km
4 km
5 km
6 km
7 km
7.57 km



S/No	Identified RTA Blackspot pe of Accident	V-V	V-P	OP	TOTAL
1	Kiambu Rd/Muthaiga Rd	8	19	7	34
2	NYS/Utalii Drift	13	6	15	34
3	Survey of Kenya		1	2	3
4	Drive Inn	3	12		15
5	Mathare North Rd		5	4	9
6	Outering Rd.	1	2		3
7	GSU/Allshops Drift		4	19	23
8	Garden Estate Rd		5	6	11
9	Homeland Area		14	3	17
10	Safari Park Area	4	15		19
11	Kasarani Rd/Kamiti Rd	15	11	7	33
12	Kenya Tent		1	2	3
13	Clayworks Area		6	11	17