UNIVERSITY OF NAIROBI

School of Engineering

APPLICATION OF GIS IN ROAD CLASSIFICATION
CASE STUDY: KIAMBU COUNTY

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F56/81741/2015

A project report submitted in partial fulfillment of the requirements for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial and Space Technology of the University of Nairobi

JULY, 2021

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DECLARATION

I, MATHIBU, BENSON MUGO, 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 university.

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ABSTRACT

Effective infrastructure is a key precondition for sustainable national economic and social growth. Roads play a significant role in economic development. Understanding the global road classification characteristics could help countries to efficiently manage their roads. Road classification has not been done adequately due to the many challenges that exists: the classification process has evolved or was developed as a one-off exercise. As a result, there is little available documentation guiding classification procedures.

In Kenya, the road classification guidelines were done in 2009 and after that a new constitution came into place and the guidelines and standards have not been revised. The guidelines and the manuals are implemented manually by officers in the relevant authority and hence road classification processes tend to be biased.

The main study objective was to carry out road classification using GIS. Specifically, it sought to identify the criteria used to do road classification, create a GIS model that will classify roads and finally compare automatically classified roads with the manually classified roads. The achieved results include a list of criteria for road classification and a GIS Model used to carry out road classification. Also, a map showing the classified roads and subsequent comparison maps showing road classes A to F have been created. A total of 1858 km were automatically classified in Classes A, B, C, D, E and F which accounts for 34.5% of the total gazetted roads. The results show that some roads automatically classified in Classes A, D and E had been omitted yet they met the criteria. Classes D and E were the most affected. Some roads automatically classified in Classes B, C and F had been elevated yet they did not meet the criteria, Class C being the most affected.

The results reveal that during manual classification there is either inclusion of roads that do not meet the criteria or omission of roads that meet the criteria. This was understood to mean that there is bias in the manual system since the judgement of classification is not scientific. The GIS spatial modelling techniques can be used to consider and integrate various criteria resulting into informed decisions which help avoid bias in the road classification process. To achieve sustainable development in the roads sector, the roads geodatabase should be updated and well maintained by road authorities since it is key in making informed decision.

DEDICATION

This project is dedicated to my loving wife and my beloved children

ACKNOWLEDGEMENTS

First and foremost, I give all the glory to the Almighty God for enabling me to complete my studies.

In a special way, I wish to acknowledge my supervisors, D. K. Macoco and Prof F. N. Karanja for their continued support and invaluable guidance and advice during the study.

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ACRONYMS

ADT	Average Daily Traffic
CIDP	County Integrated Development Plan
DoT	Department of Transport
ERS	Economic Recovery Strategy
GDP	Gross Domestic Product
GoK	Government of Kenya
GIS	Geographic Information System
KeNHA	Kenya National Highways Authority
KeRRA	Kenya Rural Roads Authority
KNBS	Kenya National Bureau of Statistics
KRB	Kenya Roads Board
KURA	Kenya Urban Roads Authority
KWS	Kenya Wildlife Service
PMSA	Primary Metropolitan Statistical Area
RISFSA	Road Infrastructure Strategic Framework for South Africa
UDD	Urban Development Department
USA	United States of America

CHAPTER 1: INTRODUCTION

1.1 Background

Operative infrastructure is a key prerequisite for sustainable development including economic and social growth (Srinivasu *et. al* 2013). Scholars including Ghosh et al (1998), Deng (2013) and Mbekeani (2007) all universally in their empirical work agree that development of infrastructure is crucial to enhancing market expansion and accessibility particularly in countries that are developing. Communications and transport cost can be reduced by investing in effective infrastructure hence enabling trade and creating wealth. The Kenyan transport sector contributes a range between 5 to 15 % to the Gross Domestic Product (GDP).

Roads play a remarkable role in social and economic development of every nation and it serves as the intermediary service to all sectors. National integration and growth are always associated with roads as their main enabler for they act as the link to the global economy. Understanding the global road classification characteristics could help countries to efficiently manage their roads, DoT (2012). A road network that is safe and efficient is an essential enabler of sustainable development in rural and urban areas of a country.

However, there are diverse issues encountered in the road transport sector in Kenya and consequently in the study area. These include lack of updated road policy and legislative framework, unsustainable funding for road development, rehabilitation and maintenance, lack of new road safety initiatives, lack of job opportunities, huge overall road maintenance backlog including in counties and constituencies which is increasing and the growing congestion and need for road network improvements.

1.2 Problem Statement

Road classification has not been done adequately in Kenya due to the many challenges that exist namely the rapid growth and urbanization of the population, the significant road network expansion, provision of special purpose roads through ad hoc addition of road classes, the existence of many unclassified roads that are calling for maintenance and development funding. In addition, progressive changes in administrative boundaries has affected the validity of the original functional classification which in turn affects the administrative centres. The promulgation of Constitution 2010 has made these issues more urgent and therefore there is need to realign the road management and development accordingly. In relation to these, a Kenya

Roads Bill 2017 was proposed to address these issues but unfortunately it has never been enacted into law. The Bill proposed establishment of the Public Roads Standards Board, classification of County and National trunk roads and re-establishment of Road Authorities among other things. Additionally, the criteria used for the road classification are subjective and relatively broad and it is sometimes difficult to relate the actual class assigned to the original classification system. The current system for road classification is seen to be fixed and unable to adjust to changing situations. Also, the implementing officers in the relevant Authority do the classification manually. A good road classification could outline the appropriate role of the road in the network and the responsibility of the associated relevant Authorities. Allocation of scarce funds and rational planning is now perceived to necessitate a more objective and quantifiable basis for prioritizing road classification than a simple functional classification system can provide. Road classification also helps countries to manage their roads efficiently and effectively.

In most countries and especially Kenya, the classification process has evolved or was developed as a one-off exercise. As a result, there is little available documentation guiding classification procedures. In Kenya, road classification guidelines were done in 2009 and after that a new Constitution came into place and the guidelines and standards have not been revised. Therefore, there is dire need for an update of road classification guidelines and standards and implementation of Geographic Information System (GIS) in the road classification process to achieve a better road classification system.

1.3 Objectives

1.3.1 Overall Objective

The main study objective to carry out road classification using GIS in Kiambu County.

1.3.2 Specific Objectives

i. To identify the criteria for road classification.
ii. To create a GIS model for road classification.
iii. To assess the manually and automatically classified roads.

1.4 Justification for the Study

Managing contemporary roads has proved to be a complex matter. To be able to achieve better results and efficiency in operations, GIS can help planners in the transportation sector to put together inter-agency information. GIS can yield higher efficiency in the infrastructure lifecycle which includes planning, design, survey, construction, maintenance and operations. GIS has proven to be of great help in desolations mitigation for all stakeholders in the transport sector.

By use of GIS technology, the planners can certainly detect potential problems that can be addressed more economically. GIS is a computerized system that can be utilized in accident analysis, highway maintenance, environmental assessment, route planning and construction management, transport safety, in addition to road development, rehabilitation and maintenance.

1.5 Scope of Work

The research will explore road classification using GIS. The research will entail identifying the criteria that is used for road classification and creating a model using those parameters that can automatically classify roads in the county. The research aimed to demonstrate how GIS can assist to enhance automation of the road classification process which currently is achieved through manual biased methods by roads authority.

1.6 Limitation of the Study

The research is limited in terms of availability of up-to-date traffic data and therefore this research intends to use simulated data. Also, lack of up-to-date road classification guidelines and standards that are in line with Constitution 2010 is another limitation.

1.7 Report Organization

This report has five chapters including:

Chapter One: This chapter comprises the introduction, problem statement, justification, scope and report organization.

Chapter Two: This chapter reviews literature on road classification, its importance, models used and how road classification has been done in Kenya and also in some sampled developed countries.

Chapter Three: This chapter has information on the study area, data used and sources and the methodology that was applied to obtain the results.

Chapter Four: It outlines results achieved and discussions.

Chapter Five: This chapter provides conclusions and recommendations that were draw from the study. References follow thereafter.

CHAPTER 2: LITERATURE REVIEW

2.1 Understanding Road Classification

2.1.1 Introduction to Road Classification

The main purpose of road classification is to group all road links in a network in a logical, hierarchical scheme that will promote rational planning, design, maintenance and use of the network. A road link and route identification / numbering system is a by-product of the classification system (Government of Kenya, 2007).

There are several objectives of a road classification system. The main ones are the promotion of efficient:

1. Road network planning which includes database development, management, maintenance, and allocation of resources.
2. Road design and construction, providing an appropriate level of service for the traffic volume and predominant trip characteristics.
3. Road maintenance and rational funding allocations.
4. Road management and jurisdiction.
5. Safe road use, including appropriate speeds, segregation of transport modes where relevant, and rational route identification.

2.1.2 Importance of Road Classification

Road Classification is the primary constituent in provision of a safe and pleasurable road network system as it improves living and working environment for citizens. At the same time, it assists in meeting the movement requirements of the broader economy (Bulai and Ursu, 2012). Road classification also provides a clear road signage and enhanced road infrastructure that leads to improvement of economic growth and support the county and the national governments in overcoming the present physical infrastructure impediments. The road classification system helps in expanding and improving existing road infrastructure, prioritizing road maintenance and rational funding allocation, provide an appropriate level of service in road design and construction, have optimal road management and jurisdiction and increase access of rural areas and contributes to environmental sustainability (Government of Kenya, 2009). Additionally, road classification helps to achieve efficient road network planning and also improving safety on our roads through inclusion of appropriate speeds, segregation of transport modes and rational route identification.

2.1.3 Criteria for Road Classification

The development of any road classification system should consider the social, economic and environmental issues. The social aspect relates to the role of roads in providing access to social facilities and amenities, whereas the economic aspect of roads relates to the role of roads in terms of providing linkages to economic opportunities and job creation. The environmental aspect on the other hand involves the environmental impacts of roads and the same time the mitigation measures that can be adopted.

Road classification systems comprise defined hierarchies, which set different types of roads or streets in relation to each other, in terms of allowable connections between them in the network. Most are structured as simple linear rankings from major to minor, incorporating a variety of themes, but most commonly relate to a combination of jurisdiction and function defined in terms of the relative scale of urban centres connected.

Mainly all classification systems have adopted an international functional road classification system that defines roads as either arterials, connectors or local roads.

The main indicators that form the criteria include administrative level, descriptive terms, level of target urban linkage, catchment population, town size, average daily traffic, target surface type and design standards (carriageway, reserve and design speeds).

The criteria mainly used in Kenya are categorized into criteria for classification of rural roads and criteria for classification of urban roads shown in Tables 2.1 and 2.2, respectively.

Table 2.1: Criteria for Classification of Rural Roads: Minimum Class Requirements

Functional Class	Road Class	Administrative level Indicator	Present Descriptive Term	Functional Class	Alternative Descriptive Term	Level of Target Urban Linkage	Catchment Population Indicator	Town Size Linked**	Traffic Indicator ADT*	Target Surface Type	Indicative Design Standards: Width in metres, m		Indicative Design Standards: Design speed (kph)
											Carriage-way	Reserve	
ARTERIAL OR TRUNK	S	NA	NA	Super Highway	Auto route, Motorway, Expressway	Capital, Cities	NA	NA	> 3,000	Paved	Dual cwy of min 2 lanes	Min. 60	90 – 120[2]
	A	International	International	Major Arterial	Trunk Road	Capital, Cities, Provincial HQs	NA	NA	> 2,500	Paved	7 - 14	40 - 60	70 - 110
	B	Inter-Provincial	National	Minor Arterial	Trunk Road	Capital Provincial + District HQs	NA	> 25,000	> 1,500	Paved	7(-14)	40 - 60	70 - 110
COLLECTOR	C	Inter-District	Primary	Major Collector	District	District towns, Other towns		> 10,000	> 500	Paved	6.5	40	60 - 110
	D	Inter- Divisional	Secondary	Minor Collector	Divisional	Division centres, Major Markets	> 13,500	2,000 to 10,000	> 150	Paved / Gravel	6	25	50 - 80
LOCAL	E	Inter-Location	Minor	Major Local	Major Feeder	Location centres, Markets	> 4,500		> 50	Gravel	5	9 - 20	50 - 80
	F	Inter-Sublocation	NA	Minor Local	Minor Feeder	Sub-location Centres / Markets	< 4,500		< 50	Improved Earth	4	9 - 10	40 - 50
	G	Intra-Sublocation	NA	Local Access	Farm to Market	NA	< 2,500		< 30	Improved Earth	4	9 - 10	40 - 50

(Source: Kenya Roads Classification Manual, 2009)

Table 2.2: Criteria for Classification of Urban Roads: Minimum Class Requirements

Functional Class	Road Class	Functional Class	Alternative Descriptive Term	Other Typical Features	Target Mobility	Target Access Restriction	Target NMT Provision		Smaller Town ADT	Traffic Indicator ADT	Indicative Design Standards			
							Cyclist Track	Walking track			Width in metres, m		Speed (kph)	
											Reserve	Carriage-way	Design	Target
ARTERIAL	H	Major Arterial	Highway	Express-way, Ring Road	High	High	Separate track	Separate track		17 - 18,000 per lane	60 - 80	3.5 m per lane 4-6 lanes	70 - 90	60
	J	Minor Arterial	Principal Arterial	Principal Bus route	Moderate	Moderate	Separate track	Separate track	2,000 - 5,000	10 -12,000 per lane	20 – 45	3.5 m per lane 2-4 lanes	50 - 60	30 - 40
COLLECTOR	K	Major Collector	Primary Distributor	Radial / spine roads, Bus routes	Moderate	Low	Separate track	Separate track		9,000 per 2 lanes	18 - 40	7	30 - 50	20
	L	Minor Collector	District Distributor		Moderate	Low	Separate track	Separate track			15	7	30 - 50	20
LOCAL	M	Major Local	Shopping / Local street		Low	None	Lane next to MT lane	Separate track			12 – 15	5 - 7	30 - 50	20
	N	Minor Local	Non-residential access (industrial / government / commerce, etc)		Low	None	None	Separate track			9 – 12	5	30 - 50	20
	P	Local Access	Residential access		Low	None	None	Separate track		400 per 1,000 population.	9 – 12	3 - 5	30 - 50	20

(Source: Kenya Roads Classification Manual, 2009)

2.1.4 Process of Road Classification and Re-Classification

Existence of Acts of parliament, gazette notices, policies, classification manuals and guidelines which are well laid out guides the whole road classification process. Also, any stakeholder in the transport sector can initiate the road classification process.

Finally, ratification of proposed classification and numbering should be done. The ultimate custodian of the road geodatabase is the Kenya Roads Board (KRB) and thus any changes in road class and numbering shall ultimately be effected by KRB. The road authorities will, on behalf of the road agency, apply to KRB for change of road class. KRB will subsequently carry out road class analysis. If the requested class change merits, KRB will give new class and allocate a number to the road. These changes will be incorporated into the road geodatabase.
Development of the road classification process entails eight main stages or components:

1. Refinement Stage: This entails Screening and testing of procedures through desktop trials and pilot surveys. Also, at this stage comments from stakeholders are obtained.
2. Investigation stage: This entails carrying out Pre-survey investigations at division, district and town levels.
3. Data Collection Stage: This stage involves collection of all survey data that may be relevant to road classification.
4. Analysis Stage: This stage entails Core Procedures whereby the classification analyst does desk-based analysis of all finalized survey maps.
5. Stage five is the follow-up stage that is mainly done in towns
6. Consultation Stage: This involves consultation with stakeholders who include urban and district Authorities
7. Road classification finalization stage.
8. Guidelines preparation stage which entails preparation of reclassification guidelines for future use.

2.2 Road Classification Models

Most classification systems comprise between four and seven classes, but often tiers have been further subdivided in a pragmatic way. Most of the systems adopt functional classification method.

A common cross-frontier feature of most systems is a pyramidal structure, where the highest level roads in the hierarchy comprise only a small proportion of the total road network length, but account for a disproportionate amount of the traffic in terms of annual vehicle km; conversely, the lowest level of the hierarchy typically comprises two thirds of the network but only a small part of the traffic volume.

2.3 Road Classification in Other Parts of the World

Kenya road classification guidelines prepared in 2009 is a mixture of road classification systems in the US, South Africa and in Australia as follows:

The United States of America functional method attempts to tie the classification more explicitly to the traffic or trip function, distinguishing between arterial, collector and local road functions and the associated dual role of roads in providing mobility and access. The American system is the most robust conceptually and is widely replicated across the world.

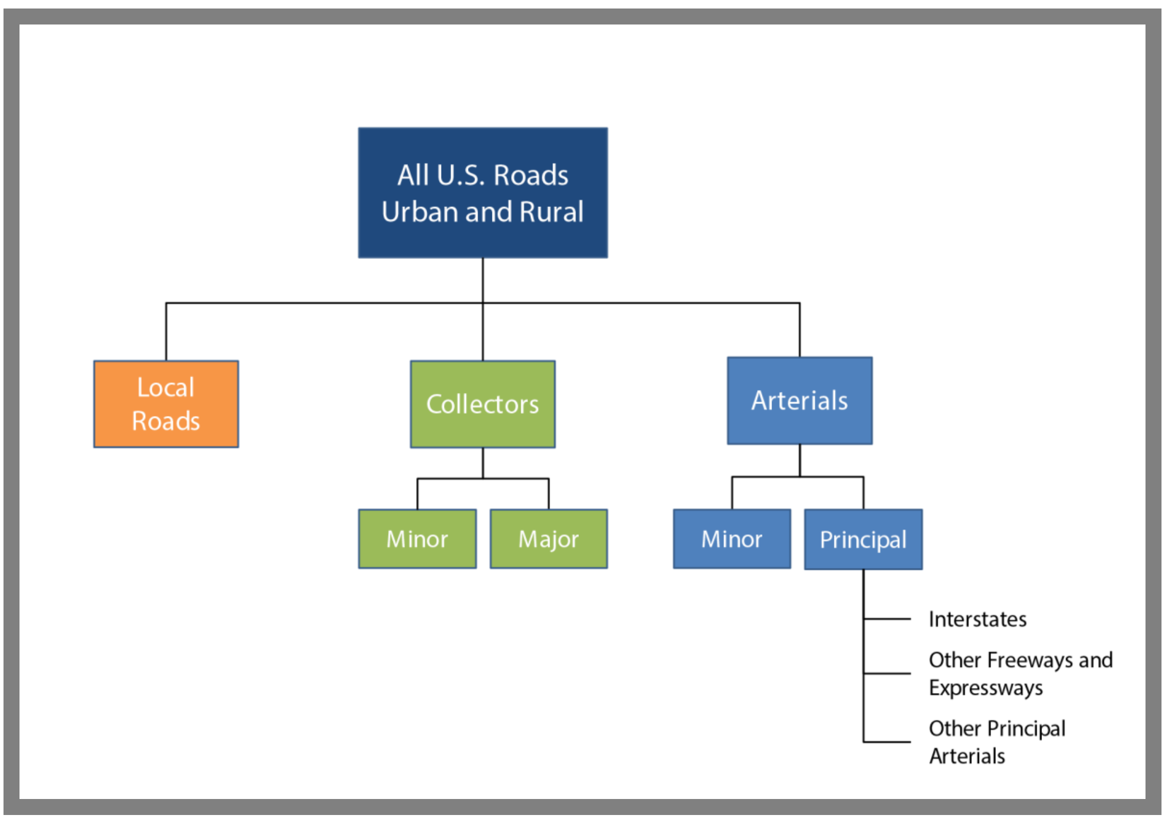

Figure 2.1: US Highway Functional Classification System Model

Source: U.S Department of Transport, Federal Highway Transportation website: https://www.fhwa.dot.gov/policy/2015cpr/chap2.cfm accessed 08012020 at 1.15am

Roads in South Africa are classified in terms of broad function and jurisdiction:

- *National Roads (N roads):* roads providing mobility of national importance, normally associated with longer travel distances and minimum interference to the free flow of traffic; principally to support economic activity and growth.
- *Provincial Roads (R roads):* These are roads providing both access and movement in a regional context; typically, they link towns that are not situated on national roads.
- *Urban Roads (M roads):* These are category of roads providing movement and access in urban spaces
- *Rural Roads*: These are roads providing access to remote communities and areas.

Road Classification System in Australia is as shown in Table 2.3.

Table 2.3: Road Classification System in Australia

Australia: PMSA (Map Authority) Road Classification System	
Nationa/State Highways	Roads which are important in a national sense, and/or are major intrastate through routes, and /or principal connector roads between Capital and/or major regional and/or key towns.
Arterial Roads	Well maintained and widely used roads which are major connectors to National Highways and/or State Highways, or have major tourist importance or have main function to form the principle avenue of communication for city traffic flows.
SubArterial Roads	Roads acting as connectors between highways and/or arterial roads, or principal avenues for massive traffic flows.
Collector Road	Roads connecting sub-arterial to local roads or distributing traffic to local street systems.
Local Road	Road providing access to properties.
Track - 2 wheel drive	Unimproved roads which are generally only passable in 2 wheel drive vehicles during fair weather and are used predominantly by local traffic.
Track - 4 wheel drive	Unimproved roads which are generallu only passable in 4 wheel drive vehicles.

(Source: Road Classification Guidelines Report, 2007)

2.4 Road Classification in Kenya and in the Study Area

The Kenya Roads Act No. 2 of 2007 stipulates that all public roads to be classified using first schedule of the Act. Additionally, each road shall have unique number, name or description for ease of its identification among all other roads of its class within the country. The relevant authorities will be required to keep and maintain a current roads inventory for all the roads under its management; this includes keeping the required format and details which include but not limited to road categorization, identity details, as may be approved by the Minister (now Cabinet Secretary).

2.5 Kenya Road Network

Road classification in Kenya was done in the 1970s or earlier and since then there has been only one reclassification which was in 2016. Table 2.4 shows road classes that existed and the new classification that was done in 2016.

Table 2.4: International System of Road Classification

Functional system	Level of service provided	Class of Rural Road	Class of Urban Road
Arterial Roads	These roads has greatest speed and service levels with access controls and the same time they have the longest interrupted distance	S	-
		A	H(Au)
		B	J(Bu)
Collector Roads	These are roads with lower speed limits for shorter distances and has less highly developed service level.	C	K(Cu)
		D	L(Du)
Local Roads	They predominantly offers entry to industrial, residential and commercial areas with little or no through movement	E	M(Eu)
		F	N(Fu)
		G	P(Gu)

(Source: Kenya Gazette 2016)

2.5.1 Description of Rural Road Classification Hierarchy

The rural road network comprises of three wide categories:

1. Arterial or Trunk roads which consists of Superhighways or S roads, which are toll roads or motorways with full access controls, the International or class A roads, and the National Roads or B roads.
2. Collector roads which comprises of the Primary inter-district or otherwise class C roads and Secondary roads also referred as intra-district class D roads.
3. Local roads, which comprises of Minor E, F and G class roads

2.5.2 Description of Urban Road Classification Hierarchy

All the roads or sections of roads that lie within urban boundary are called Urban Roads. This definition only applies to rural road classes D, E, F and G, but does not apply to major roads class A, B, and C. The broad functional groups of urban roads are subdivided, as in the case for rural roads, to give a similar range of seven road classes for urban roads (H to P). These are broadly consistent with the proposals in the urban roads draft design guidelines, though some terms and criteria have been adjusted to maintain consistency with the proposals for the rural roads. Higher class rural roads will, however, retain their classes and numbers as they pass through urban areas, and responsibility for the maintenance of the sections in the urban areas will be borne by the relevant Road Authority.

Similar concepts are adopted in the urban road network Classification as used for rural roads hierarchical groupings. The urban road network comprises of three functional groupings as shown in Table 2.4 which in addition provide the urban class hierarchy.

With promulgation of the new Constitution in 2010, there was need to realign the road development and management accordingly. Kenya Roads Bill 2017 proposed establishment of the Public Roads Standards Board, classification of National Trunk and County roads, re-establishment of road Authorities among other things.

The Bill suggested that sections of higher class rural roads (A, B, C) that pass through municipalities will retain their classes and numbers. Maintenance and management of such sections that are within the municipal boundaries will fall under jurisdiction of the Kenya National Highways Authority (KeNHA). Road classes A, B, C are national trunk roads while D, E, F, G and others are county roads.

CHAPTER 3: MATERIALS AND METHODS

3.1 Area of Study

The area of Study is the Kiambu County located in Central Kenya: The County has a total area of 2,544 square kilometres with approximately 476.3 square kilometres under forest cover and a population of 2.42 million people. Kiambu County is 40% rural and 60% urban. The county has extremely distributed topography. Three wide categories of soils cover the county which include plateau, volcanic footbridges and high level upland soils. There are two principal sources of water which include surface and sub- surface sources. Kiambu County experiences bi-modal type of rainfall whereas it has 26^{o} C as the mean annual temperature (CIDP 2018-2022).

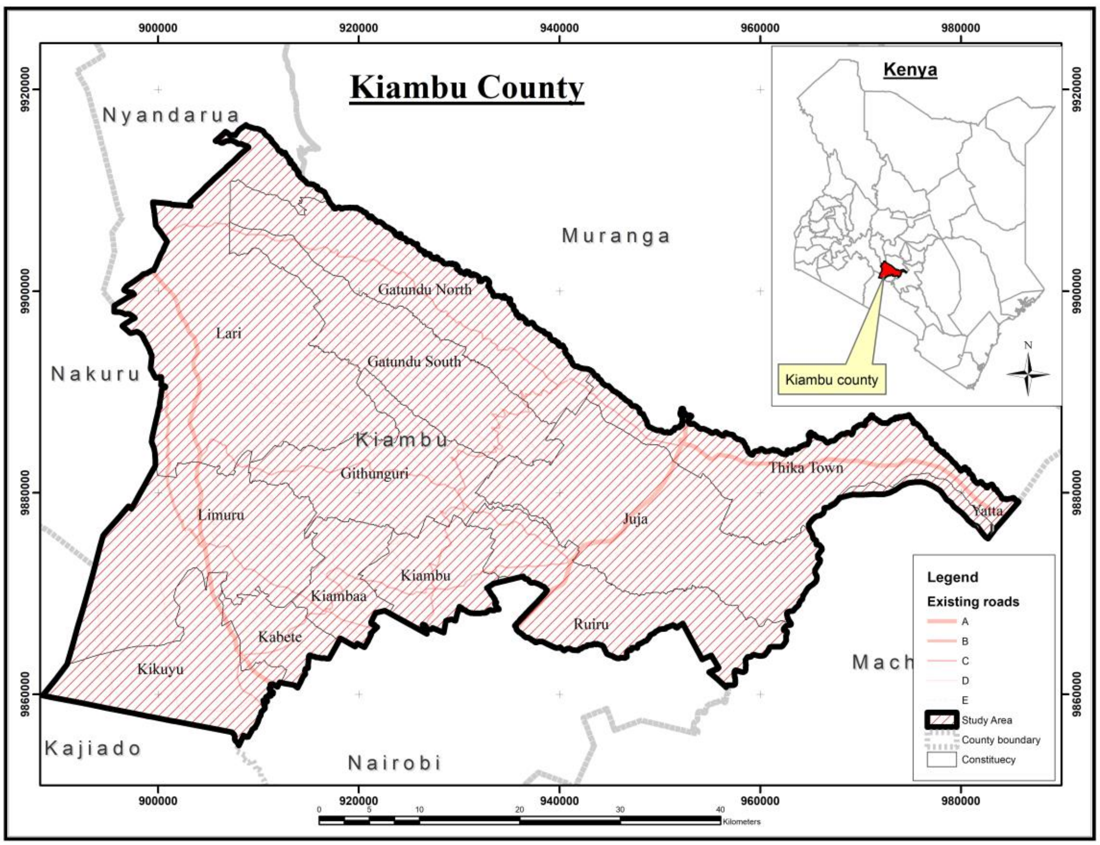

Figure 3.1: Area of Study Map

3.2 Datasets and Sources

Data, mostly soft copy was used during this study, gathered from different institutions. The data types used for the study plus the sources where they were obtained from are as listed in Table 3.1.

Table 3.1: Datasets and Sources

Data Type	Description of Characteristics	Source
Administrative Boundaries	Shape files	IEBC
Topo Maps	Scanned maps Scale 1:50000	Survey of Kenya
Towns	Shapefiles	KRB
Attributes of Roads	Soft copy	KRB
Roads	Shapefiles	KRB

3.3 Methodology

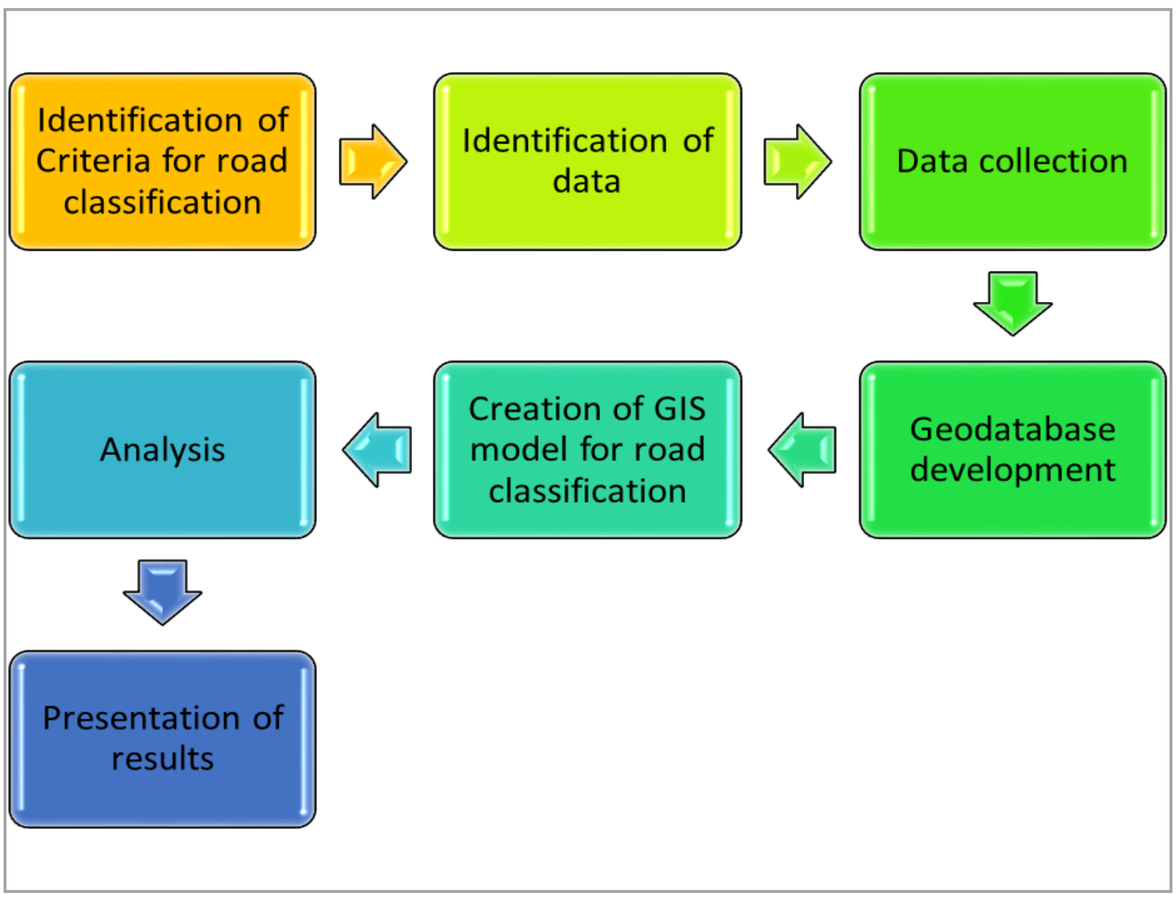

Figure 3.2: Methodology Overview

3.3.1 Identification of Road Classification Criteria

Criteria can be defined as a set of guidelines or requirements utilized as basis for decision making. Careful selection of criteria was done after a comprehensive evaluation of available literature and also consultation with experts. The criteria were sourced from the Kenya Roads Classification Manual, 2009. Due to unavailability of traffic data and inadequate population data, Traffic indicator ADT and catchment population indictor as well as town size linked criteria were not incorporated.

3.3.2 Geodatabase Development

For the purpose of this project, a Geodatabase can be well thought-out as the store of geospatial data, which mainly uses a database management system (DBMS). These Geodatabases have an all-inclusive information model which is fit for representation and management of geographic data. To achieve a comprehensive information model, use of tables was implemented. File Geodatabase approach was preferred due to its possibilities of having more than one editor work on the same geodatabase same time but on different datasets.

Figures 3.3 and 3.4 show how the new geodatabase was done.

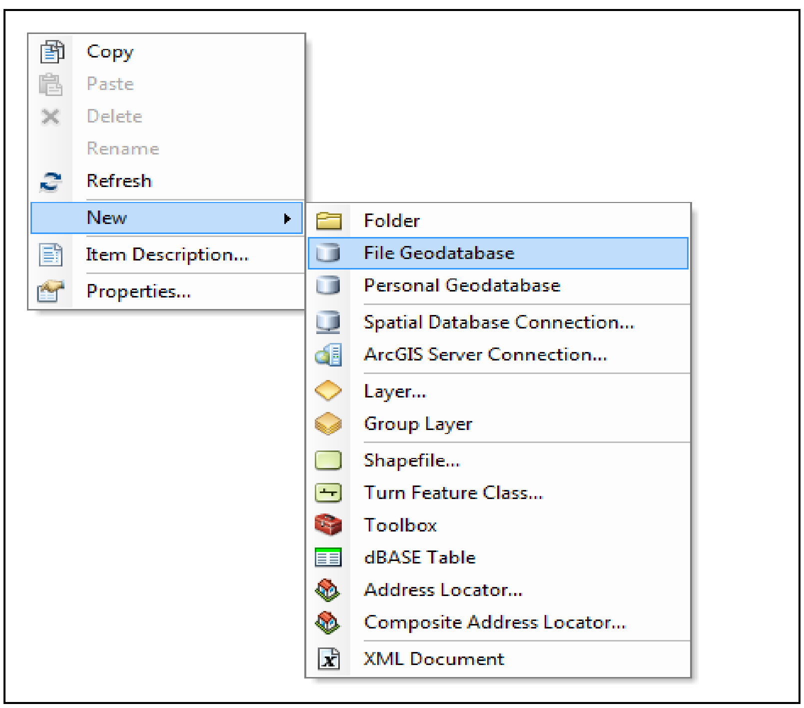

Figure 3.3: Creating Geodatabase in ArcGIS Environment

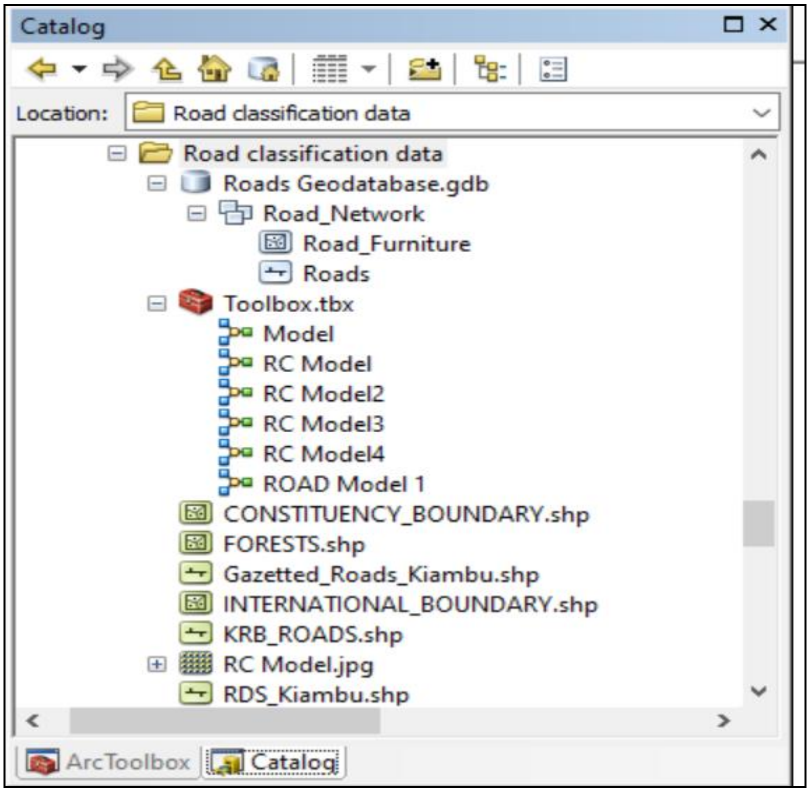

Figure 3.4: Created Geodatabase in ArcGIS Environment

3.3.3 Database Design and Implementation

Database design can be defined as a process of selecting the specific data that will be represented into the Geodatabase and identifying the best way of representing it. All the activities that will be performed in the database using available GIS tools depends on the database as a foundation. The main things that inform database design process are the available datasets and the final products required by the users. The final database is ensured to fulfill the user needs, has well-organized retrieval mechanisms and data structures. At the same time, it should ensure consideration of normalization and data sharing principles, multiuser access, editing, update and maintenance.

The database design phases involve:

a) External model (User needs).
b) Conceptual model.
c) Logical model.
d) Physical model.

a) External Model (User needs)

This model identifies the user needs of the potential users of the Roads Geodatabase. The needs of the user were assessed through informal means by primarily talking to officers working with the Kenya Roads Board and the Road Authorities. The potential users of the roads database include County and National governments, Roads Authorities, Public and Private Sector as demonstrated in Figure 3.5.

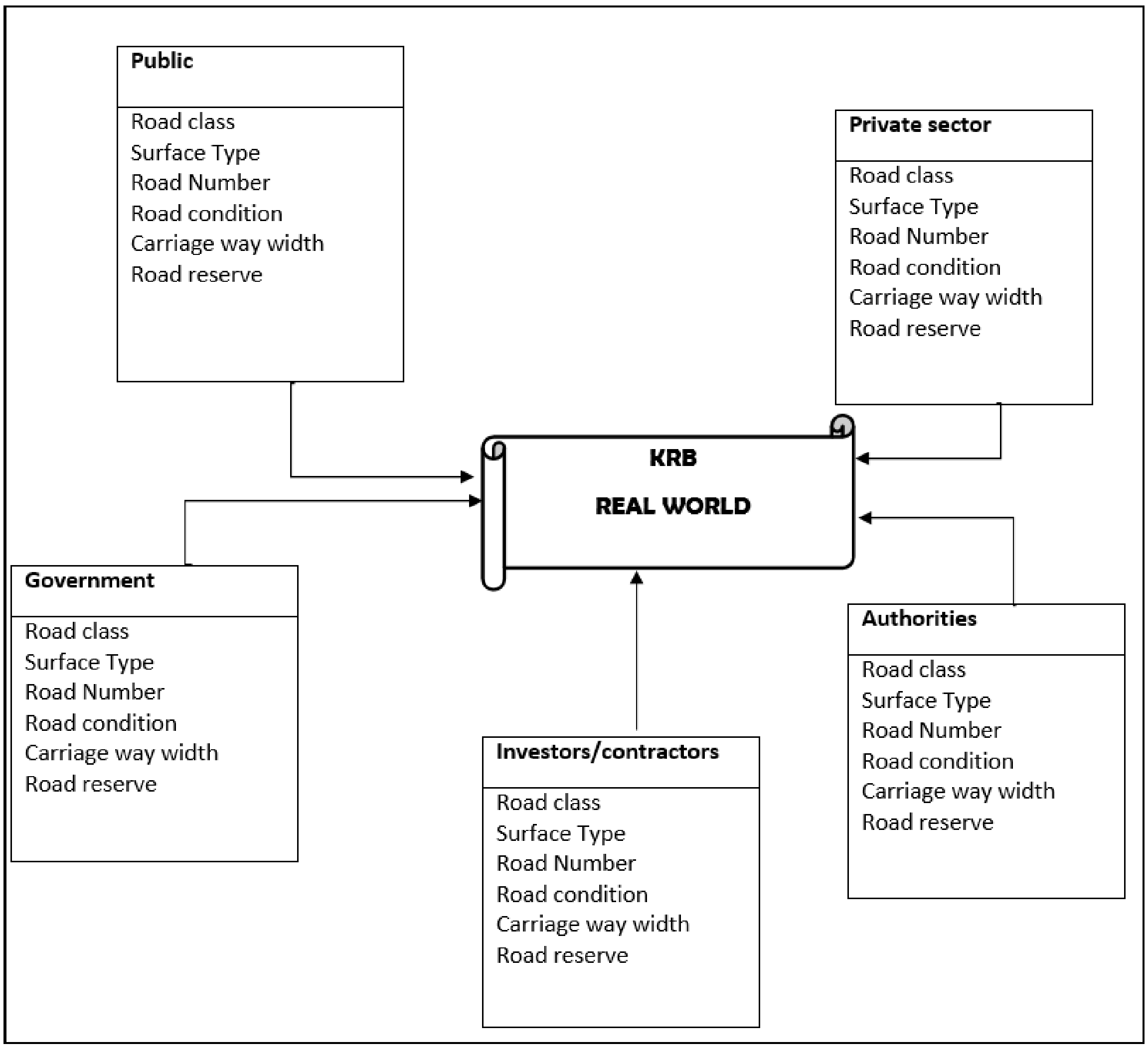

Figure 3.5: External Model for Road Network

b) Conceptual Model

This model synthesizes the external models into an Entity-Relational (E-R) diagram. An ER diagram is a blueprint for a database structure and stipulates the kind of data categories to store in any given entity along attributes and any associations (relationships) between them as shown in Figure 3.6.

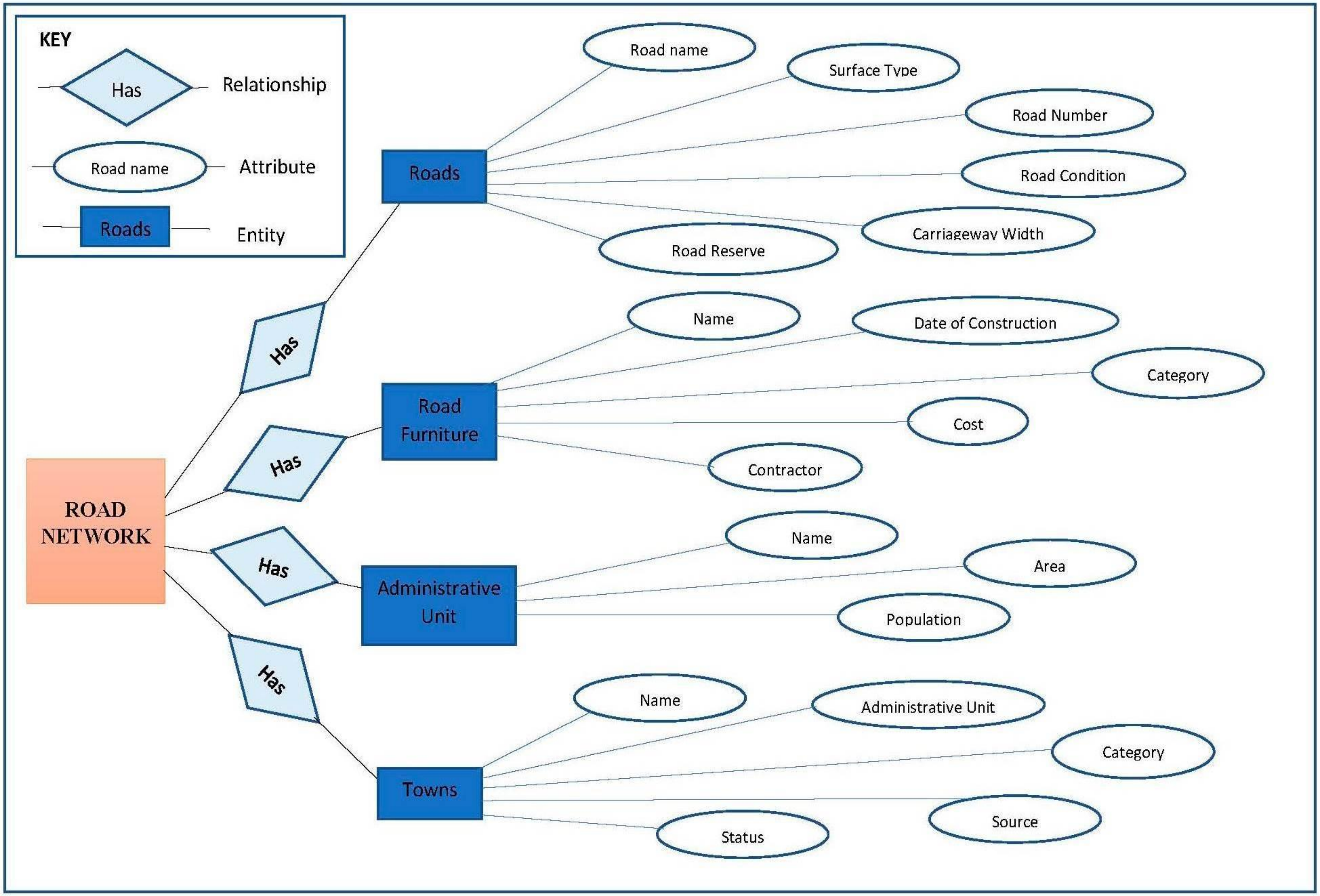

Figure 3.6: Conceptual Model for Road Network (Source: Author Conceptualization)

c) Logical Model

This model shows how to represent the E-R diagram into the Geodatabase. The entities (feature classes in this case) and their attributes include:

Roads [FID, Name, Class, Surface Type, Road number, Condition, Carriageway Width, Road reserve width………………………………..]
Road furniture [Name, DoC, Category, Cost, Contractor, Length/Area…………….]
Administrative unit [Name, Area, Population, …………….]
Towns [Name, Administrative unit, Category/Type, Source, Status, …………….]

d) Physical Model

Physical model is both software and hardware specific and it requires careful consideration on file structuring for efficient access from the storage space. The resulting model should provide efficient physical data storage structures. The empty schemas created in ArcGIS environment are shown in Figure 3.7.

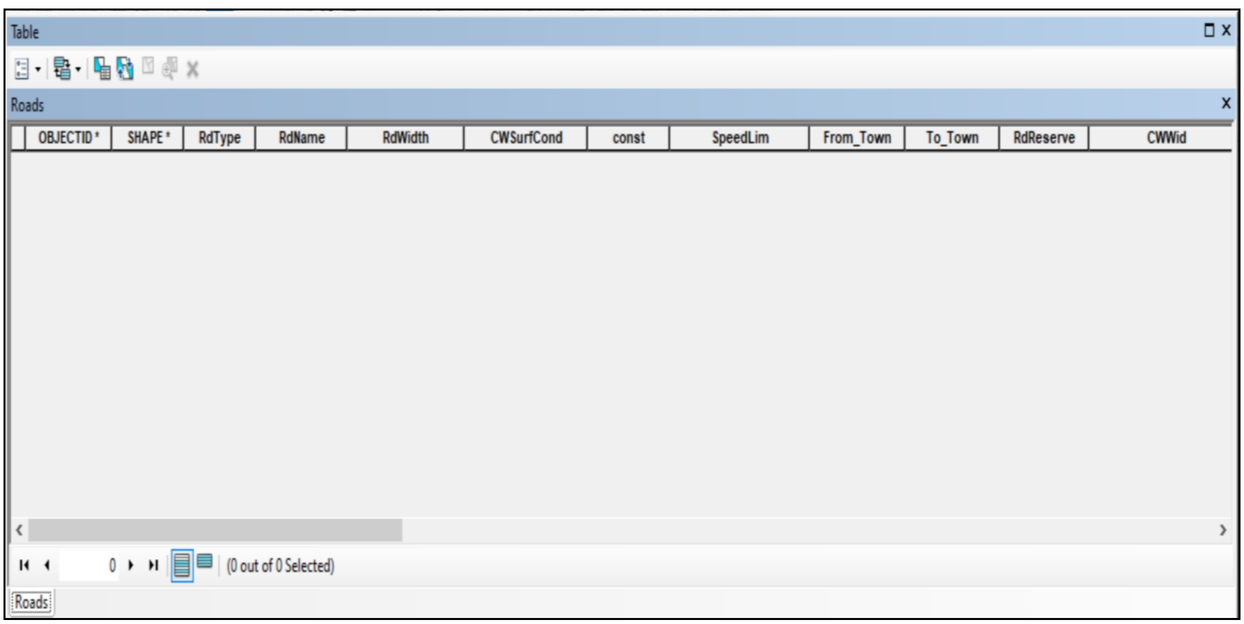

Figure 3.7: Created empty schemas for road feature class

The empty schemas were then populated through importation of data into the geodatabase. Figure 3.8 shows a populated relation in the database.

Roads

FID	RdType	const	SpeedLim	RdReserve	CWWid	NumLanes	Admin_levi	Surf_type
14271	Single Carriageway	Kiambu	70	40	7	0	Interprov	Paved
14272	Single Carriageway	Kiambu	70	40	7	0	Interprov	Paved
14365	Single Carriageway	Kikuyu	80	40	6.5	0	Interdist	Paved
14366	Single Carriageway	Kikuyu	80	40	6.5	0	Interdist	Paved
14454	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14455	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14456	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14457	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14458	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14459	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14460	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14461	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14462	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14463	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14464	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14465	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14466	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14467	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14468	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14469	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14474	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14475	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14476	Single Carriageway	Limuru	80	40	7	0	Interprov	Paved
14556	Single Carriageway	Githunguri	70	40	7	0	Interprov	Paved
14557	Single Carriageway	Githunguri	70	40	7	0	Interprov	Paved
14558	Single Carriageway	Githunguri	70	40	7	0	Interprov	Paved
14723	Single Carriage	Gatundu South	20	40	4	1	Intrasubloc	
14724	Single Carriage	Gatundu South	80	40	7	1	Interprov	Paved
14725	Single Carriage	Gatundu South	80	40	7	2	Interprov	Paved
14726	Single Carriage	Gatundu South	80	40	7	2	Interprov	Paved

16832 (0 out of 18307 Selected)

Roads

Figure 3.8: Populated relation for road feature class

3.3.4 Creation of GIS Model for Road Classification

After identifying the Criteria, creating and populating the geodatabase, the model was then created. This model is an automatic workflow that combines all the criteria; it contained the inputs datasets, and outputs that can be graphically displayed as a map.

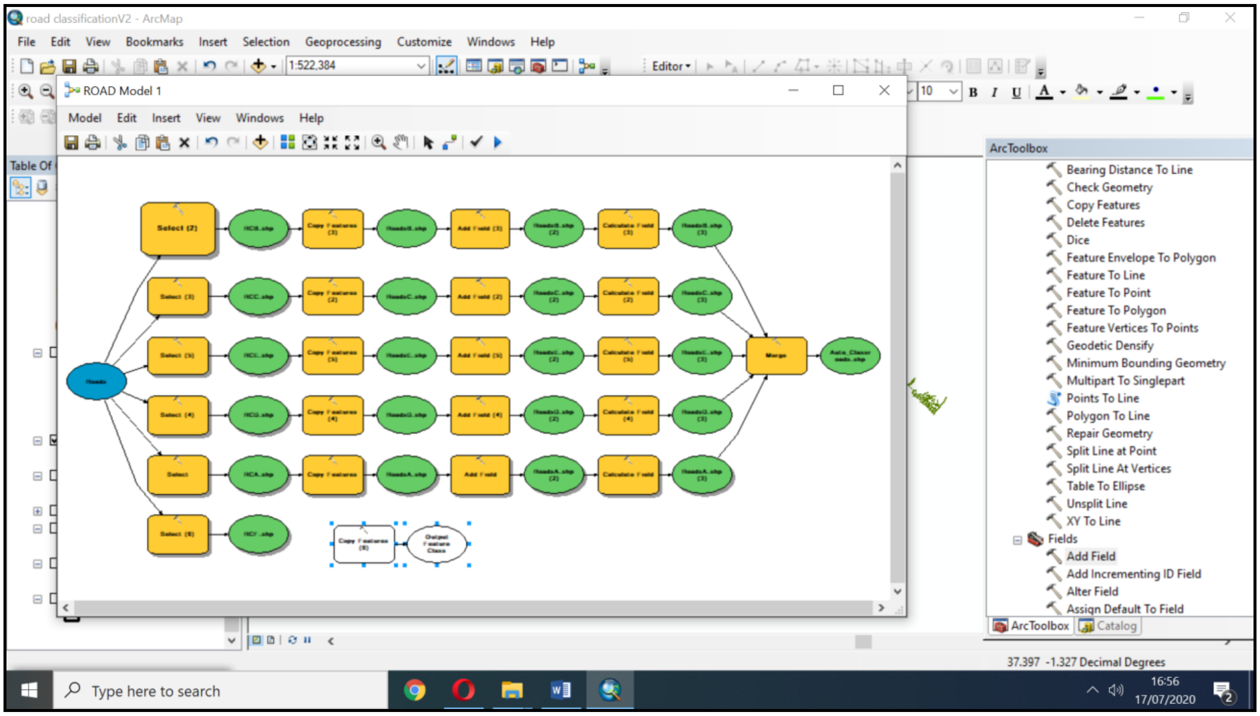

Figure 3.9: Adding tools in the model

The main tools used in the model are: Select tool for applying the criteria, copy features tool, add field tool and merge tool for combining all the classified roads together in one layer.

Using Select tool to apply the Criteria

Criteria was applied using SQL queries for each road class. 'Select by Attributes' tool was used which prompts the GIS to provide an expression that is used to output features that match the criteria. A sample query used to classify class A roads is shown in figure 3.10.

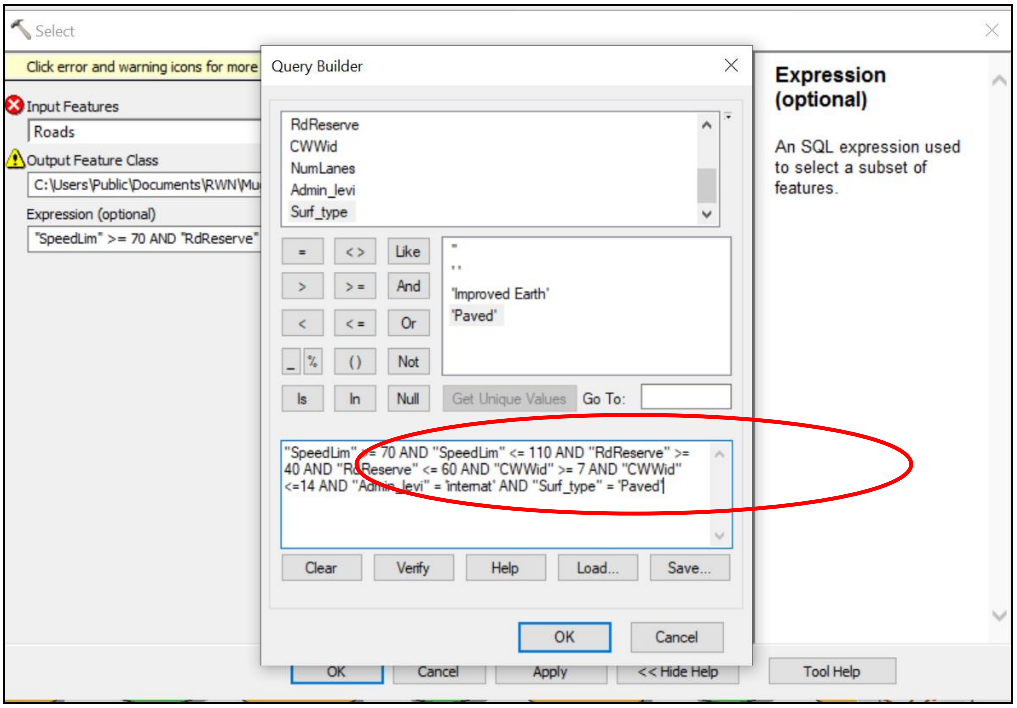

Figure 3.10: Sample query – SQL Query for Class A roads

Copying features: This option assist in copying features of an input layer to a new layer. If the features of the input layer are selected, only the selected features of that layer will be copied.

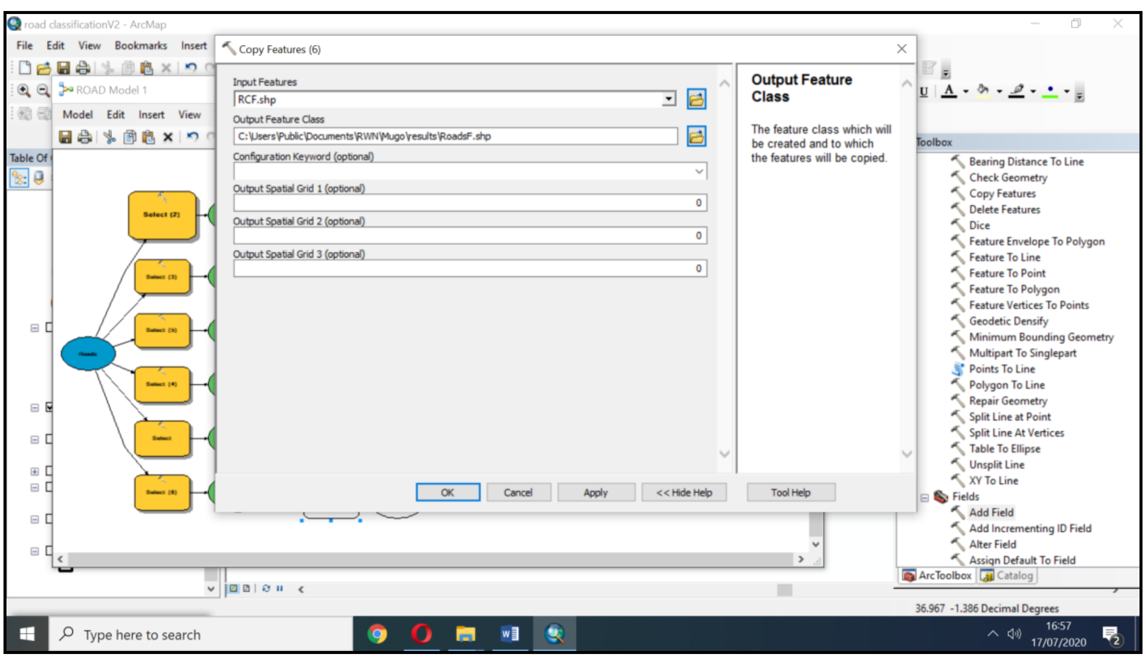

Figure 3. 11: Creating a new layer of a specific class of road

Adding field: This option helps to Adds a new attribute to a standalone table or a feature class table.

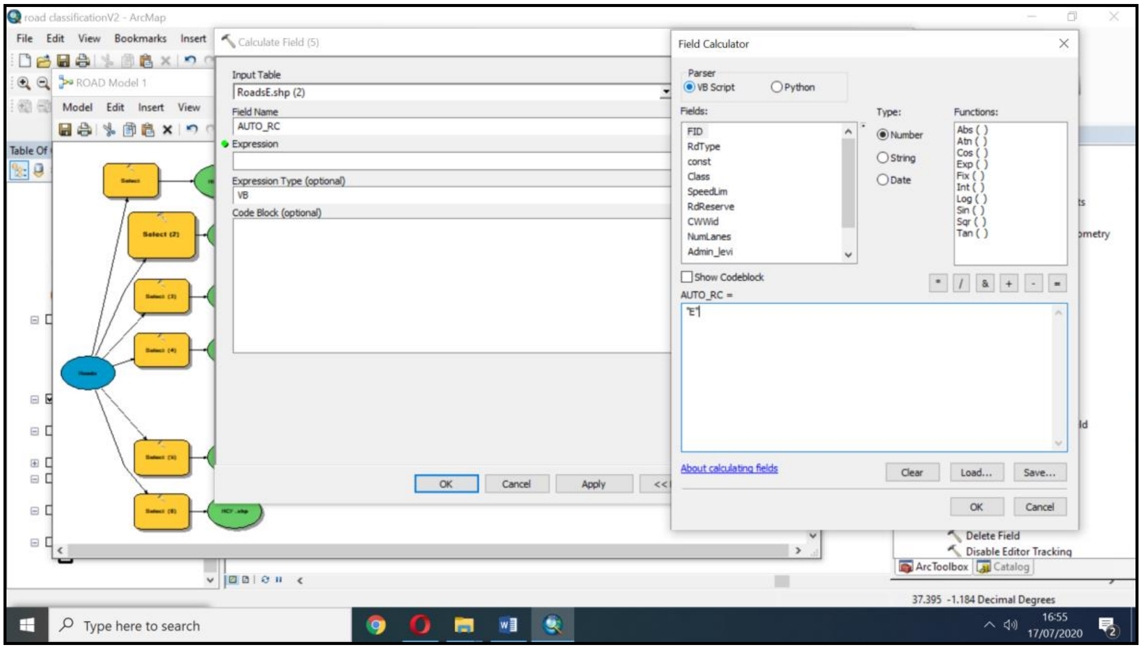

Figure 3.12: Adding a field in the classified roads layer inside model

Merging all the classified roads:This option allows combination of multiple input layers into a new single output layer. The tool can combine either line, point or polygon feature classes or tables.

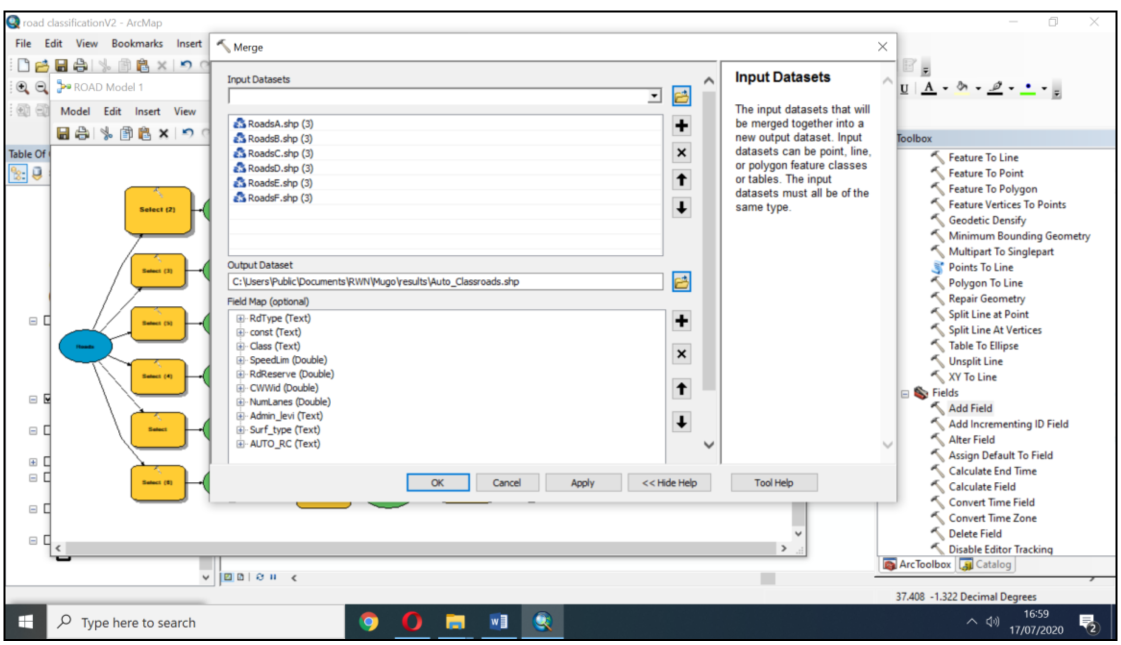

Figure 3.13: Merging classified roads in ArcGIS model builder

Running the Model

Models can be run from different views including the Python window, model tool dialog box, stand-alone script or even within Model Builder. Once a model has been run, the model variables are automatically validated and tools in ready-to-run mode are executed. Consequently, the outputs should be added to the display.

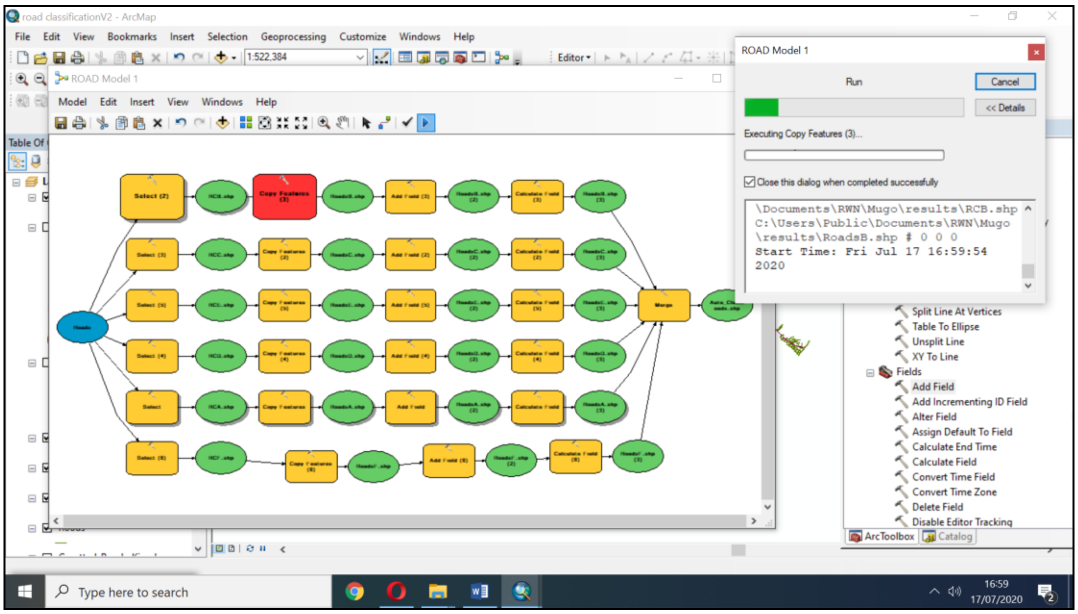

Figure 3.14: Running the model in the ArcGIS environment

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results

The results that were obtained were in line with the objectives. They include the following:

4.1.1 Criteria for Rural Road Classification

The road classification criteria used were as shown in Table 4.1.

Table 4.1: Criteria for Classification of Rural Roads: Minimum Class Requirements

Road class	Admin level indicator	Descriptive term	Alternative Descriptive term	Functional class	Level of target urban linkage	Surface type	Carriage way width	Road reserve	Design speed
A	International	International	Trunk road	Major arterial	Capital, Cities, provincial Hqs	Paved	7-14	40-60	70-110
B	Inter-provincial	National	Trunk road	Minor arterial	Capital, provincial and District Hqs	Paved	7-14	40-60	70-110
C	Inter-district	Primary	District	Major collector	District towns, other towns	Paved	6.5	40	60-110
D	Inter-division	Secondary	Divisional	Minor collector	Division centres , major markets	Paved/Gravel	6	25	50-80
E	Inter-location	Minor	Major feeder	Major local	Sublocation centres, markets	Gravel	5	9-20	50-80
F	Inter-sub location	N/A	Minor feeder	Minor local	N/A	Improved earth	4	9-10	40-50

(Source: Adapted from Kenya Roads Classification Manual, 2009)

4.1.2 Road Classification Model

A Road classification workflow model developed using ArcGIS software is shown in Figure 4.1.

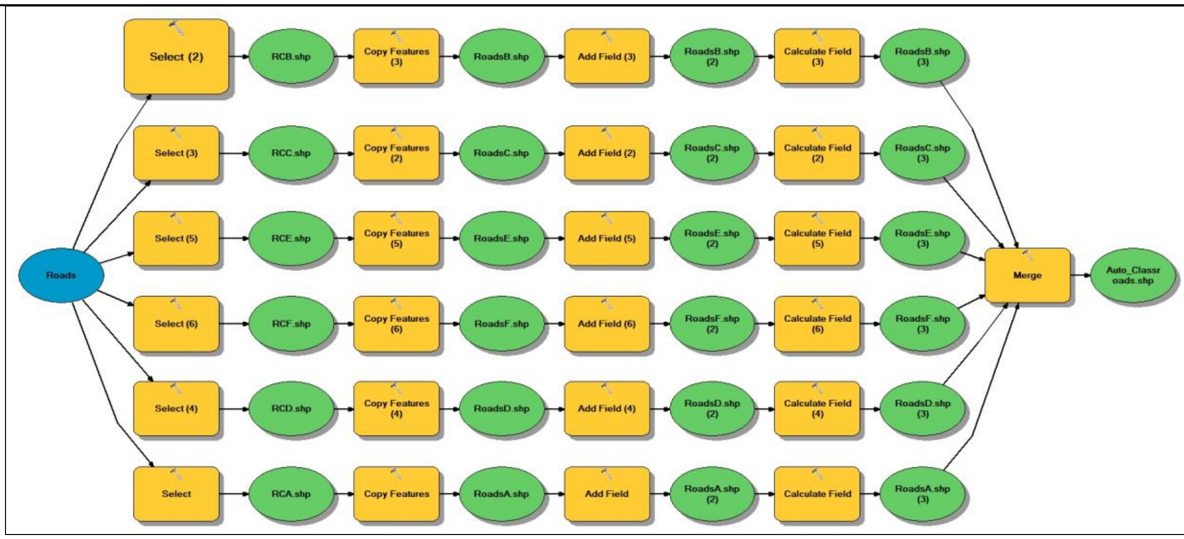

Figure 4.1: Road Classification model

4.1.3 Composite map for all automatically classified roads

After running the model, roads were classified and a map prepared as shown in Figure 4.2.

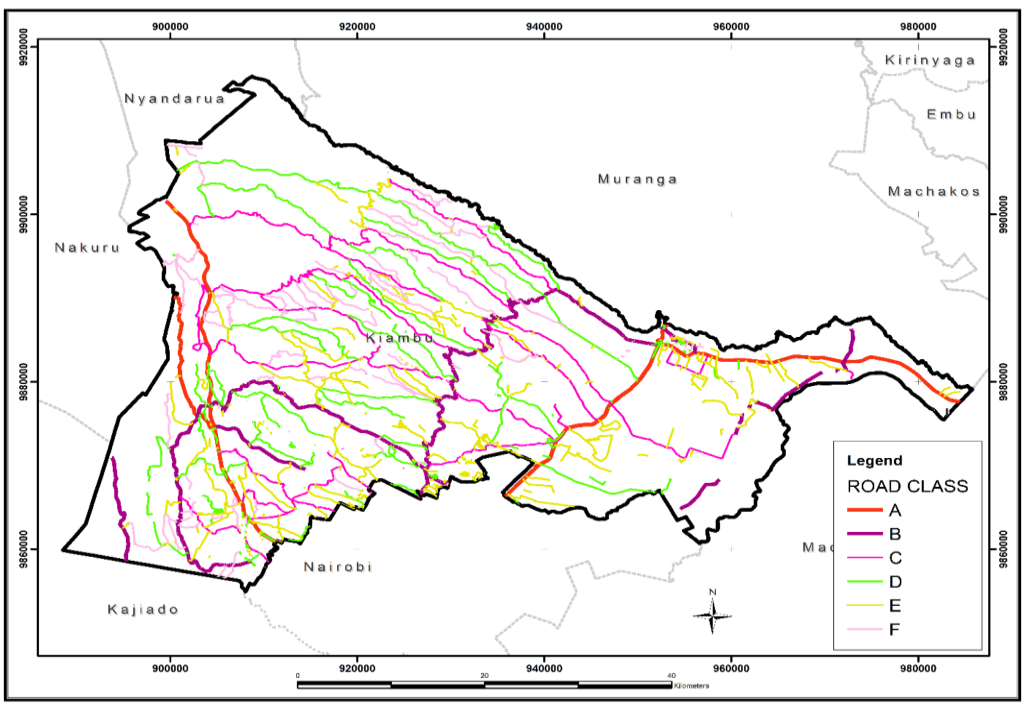

Figure 4.2: Composite map showing all automatically classified roads

4.1.4 Comparison of Class A roads

A composite map showing manually (2016) and automatically classified roads of class A category is shown in Figure 4.3

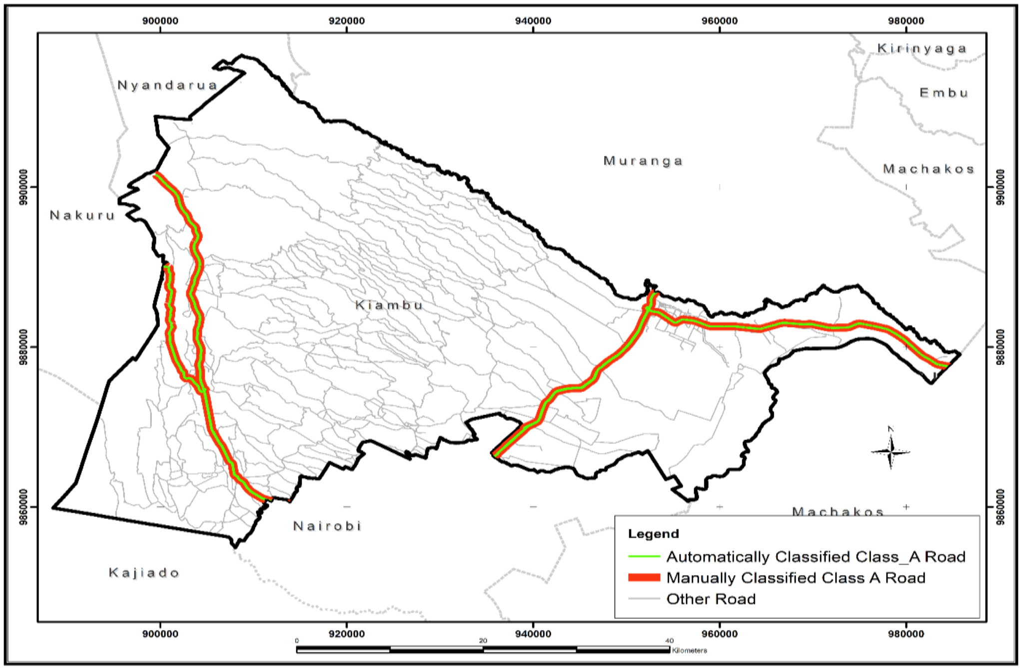

Figure 4.3: Map showing a comparison of Class A roads

4.1.5 Comparison of Class B roads

A composite map showing manually and automatically classified class B roads is shown in Figure 4.4.

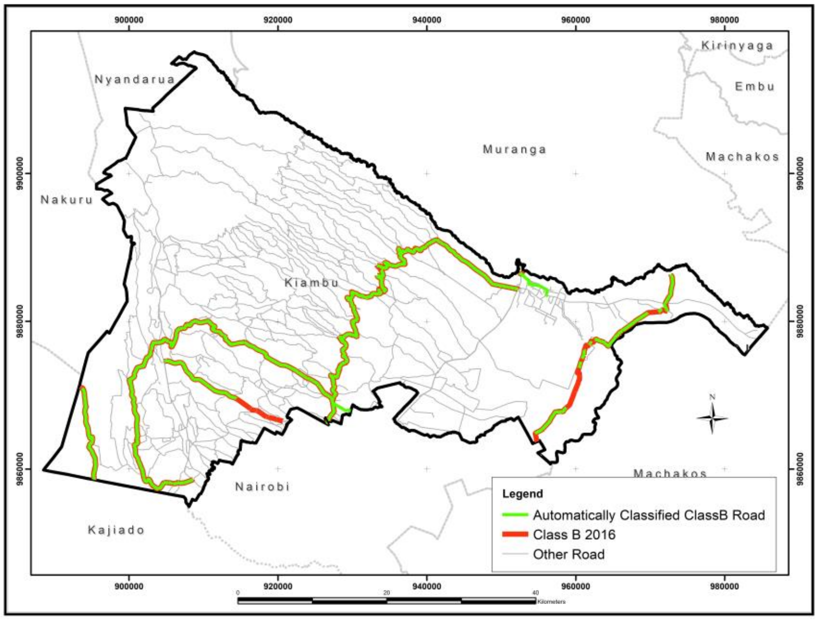

Figure 4.4: Map showing a comparison of Class B roads

4.1.6 Comparison of Class C roads

A composite map showing manually and automatically classified class C roads is shown in Figure 4.5

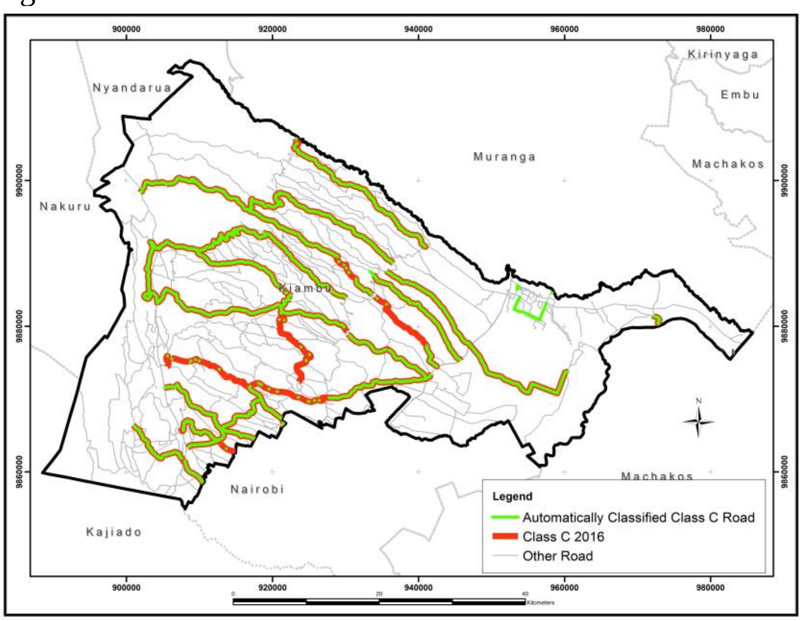

Figure 4.5: Map showing a comparison of Class C roads

4.1.7 Comparison of Class D roads

A composite map showing manually and automatically classified class D roads is shown in Figure 4.6.

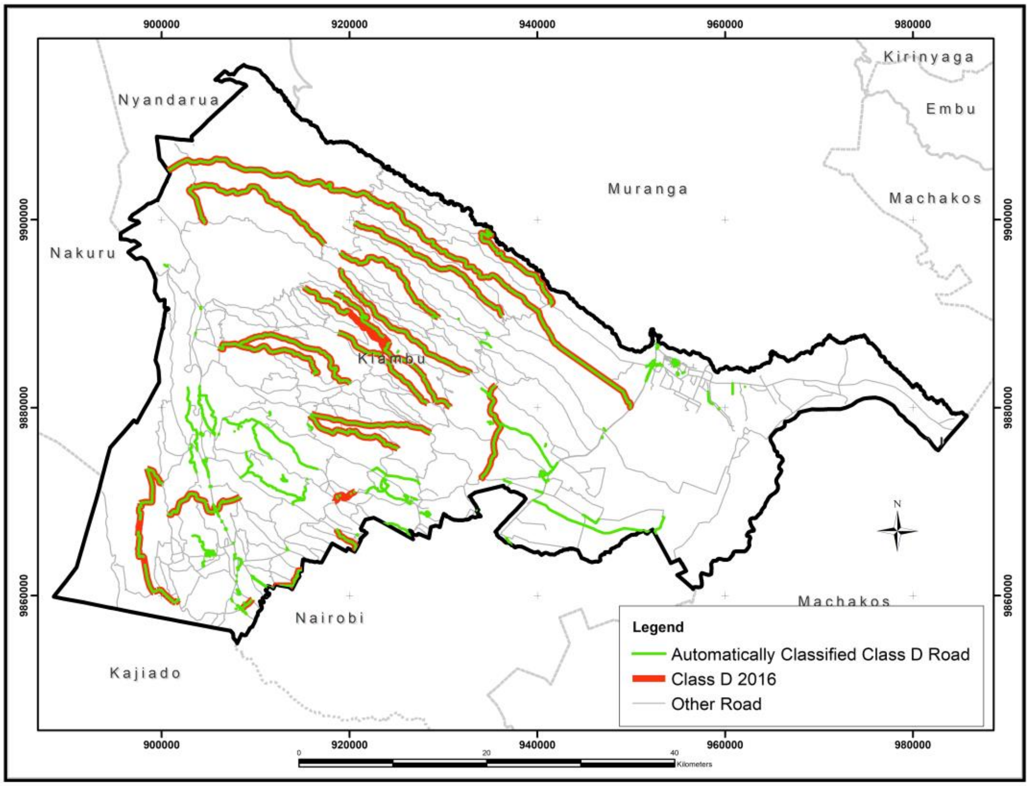

Figure 4.6: Map showing a comparison of Class D roads

4.1.8 Comparison of Class E roads

A composite map showing manually and automatically classified class E roads is shown in Figure 4.7.

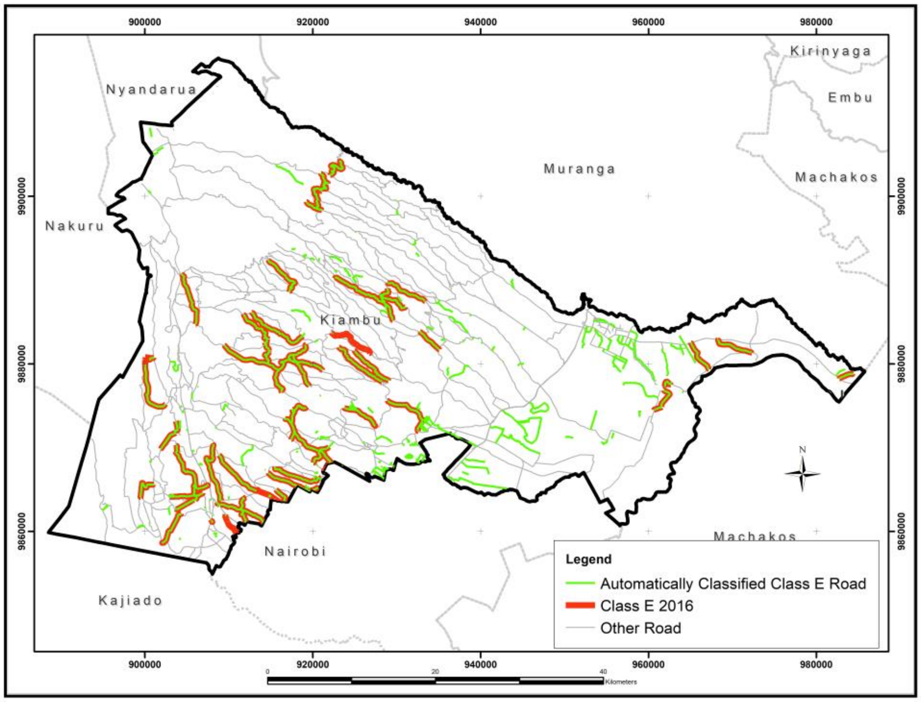

Figure 4.7: Map showing a comparison of Class E roads

4.1.9 Comparison of Class F roads

A composite map showing manually and automatically classified class F roads is shown in Figure 4.8.

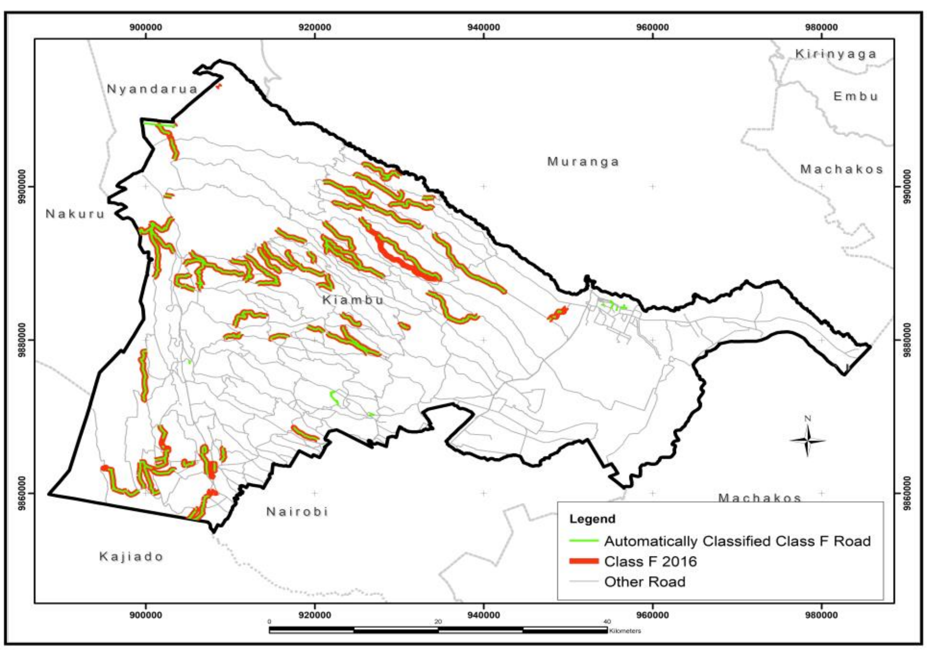

Figure 4.8: Map showing a comparison of Class F roads

4.1.10 Comparing all the roads

Map showing an overlay of all manually and automatically classified roads from Class A to F is shown in figure 4.9.

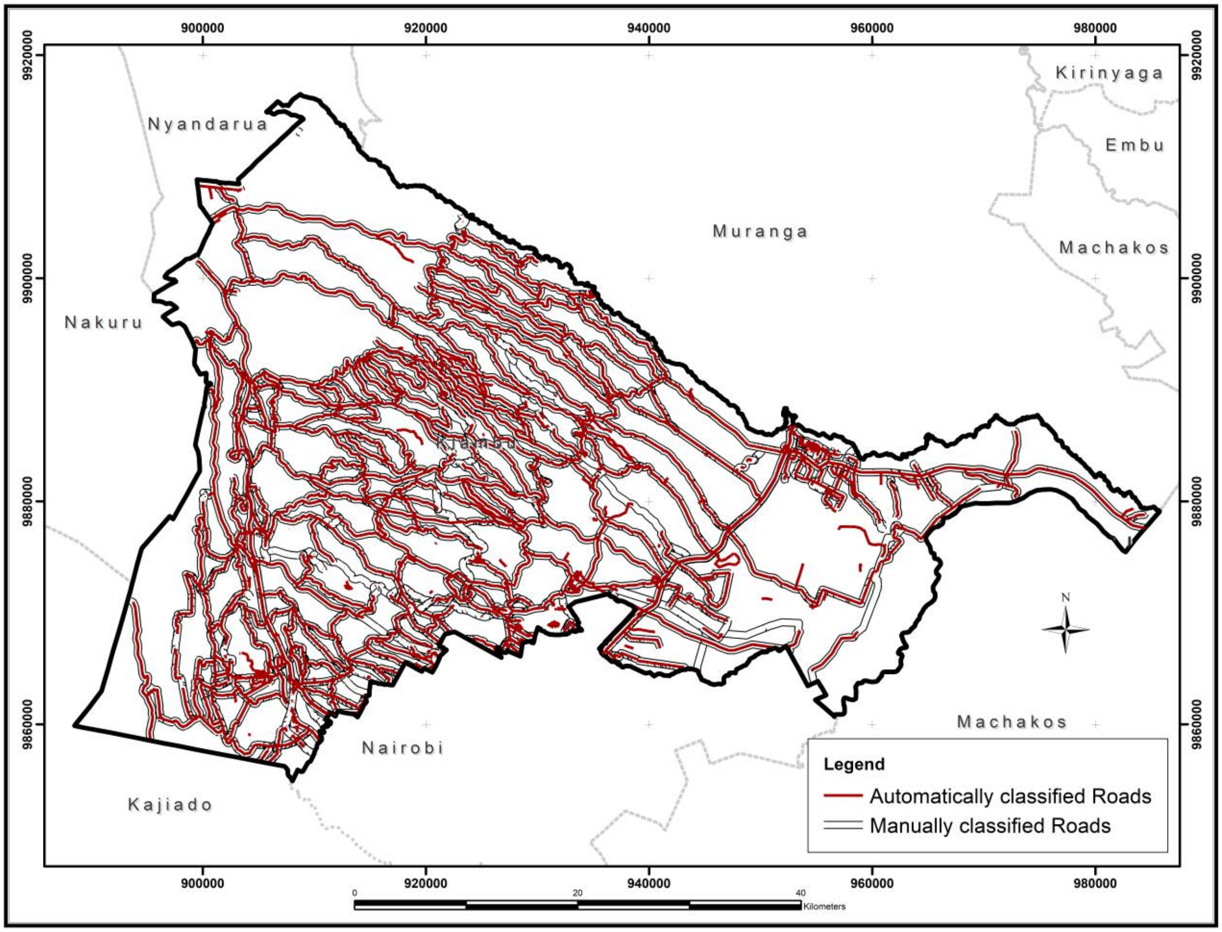

Figure 4.9: Map showing a comparison of all classified roads

Table 4.2 shows a comparison between manually and automatically classified roads in kilometres.

Table 4.2: Summary Comparison Table

Class	Manually classified (Km)	Automatically Classified (Km)	Difference (km)	Comparison
A	124.15	125.13	0.98	More
B	197.46	185.49	12	Less
C	407.38	350.323	57	Less
D	312.76	472.115	160	More
E	243.76	440.90	197	More
F	293.98	283.16	10	Less
Total	**1579.49**	**1857.118**		

4.2 Discussions

Kiambu County has a total of 5380 kilometres of gazetted roads as per the data obtained from Kenya Rural Roads Authority (KeRRA) in February 2020. From 2016 manual classification, a total of 1580 kilometres of roads were classified in classes A, B, C, D, E and F. In this study using Kiambu county gazetted roads, a total of 1858 km were automatically classified in Classes A, B, C, D, E and F which accounts for 34.5% of the total gazetted roads.

Using the road classification model, results shows that 125 kilometres of roads were automatically classified as Class A whereas 124 km were manually classified in 2016 in the same category. The difference is 1km which means that both classifications largely agree and only 1km more has been automatically classified as class A.

Using the road classification model, results shows that 186 km were automatically classified as Class B compared to 198 km of manually classified roads in 2016 in the same category. The difference indicates that some 10 km of roads had been manually classified in this category but did not meet the criteria.

The results also show that 350.32 km were automatically classified in Class C category compared to 407.38km that were manually classified. This shows automatically classified roads for this category were less indicating that 57 km of the manually classified roads in class C did not meet the criteria required.

In Class D category, the results show that 472.16 km were automatically classified as compared to 312.76 km manually classified in 2016, 160 km had been left out yet they met the criteria.

In Class E, the results show that 440.90km were automatically classified compared to 243.76 km manually classified. This means that 197km of manually classified roads had been elevated yet they did not meet the criteria.

Finally, 283.16km were automatically classified in Class F category whereas 293.98 km were manually classified in 2016 indicating that 10km had been left out yet they met the criteria.

Generally, roads automatically classified in Classes A, D and E had been omitted yet they met the criteria. Classes D and E were the most adversely affected. The roads that were automatically classified in Classes B, C and F had been elevated yet they did not meet the criteria, Class C being the most affected. The results reveal that during manual classification there is either inclusion of roads that do not meet the criteria or omission of roads that meet the criteria. This can be understood to mean that there is bias in the manual system since the judgement of classification is not scientific.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objectives of this study were achieved as follows:

1. Criteria for road classification was identified from the road classification manual and guidelines. This was adopted into the study considering the data sets that were available.
2. A GIS model for automatic road classification was created in ArcGIS Model Builder.
3. Automatically classified roads were assessed against manually classified roads and differences noted and discussed.

Further, this specific study has clearly demonstrated the application of GIS in road classification, therefore GIS can be sufficiently used to classify rural roads. Geospatial data is very significant in the road classification process since it supports making informed decisions that helps achieve sustainable development.

The GIS spatial modeling techniques can be used to help avoid bias in the road classification process. GIS spatial modelling techniques are able to consider and integrate various criteria resulting into informed decisions. By using GIS, the process can be implemented fairly and the transport planners can certainly detect possible challenges and address them more competently and economically than with prevailing methods.

5.2 Recommendations

To achieve efficient road network planning and also improve safety on the roads, the results obtained from this study can be used to layout road classification policies done by both transport planners and other policy makers. A good road classification system will assist in infrastructure management, prioritizing road maintenance and rational funding allocation.

To achieve sustainable development in the roads sector, the road geodatabase should be updated and well maintained by relevant authorities since it is key in informed decision making. Also, the classification guidelines should be updated to be in line with the Kenya Constitution 2010. Traffic studies should be carried out continuously to provide traffic data which can be incorporated in the criteria.

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