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DEPARTMENT OF SPATIAL AND SPACE TECHNOLOGY

Route Location by GIS Analysis: Case Study of the Proposed Lukenya-Kilimambogo Greater Eastern Bypass.

BY

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Declaration of originality

I **Edwin Wanyonyi Mabonga** 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.

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This Project report is submitted for examination with my approval as University supervisor.

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Turn it in report summary

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Abstract

Much traffic has been witnessed on city roads, thus prompting the authorities to come up with alternative route to ease the problem. In order to accrue benefits on cutting down on the lost manpower hours and movement of goods, there is a need for an optimal bypass to accommodate traffic from Mombasa on transit to Central, Eastern and North-Eastern counties without passing through Nairobi CBD. Routing is a very important aspect of highway planning and design, hence a distribution system that strikes a balance between environment, engineering, technological, as well as social factors is vital. This research uses GIS (Geographic Information System) analysis and geospatial modeling to develop an ideal Great Eastern by-pass route, using Lukenya junction and Kilimambogo on A3 as start and end nodes.

To find the best route, a model is created that takes into account highway lengths, topography, soils, populated regions, game parks, forests, rivers, swamps, roads, open water sources sites, and protected areas. For spatial modeling, analysis, and data overlay, GIS is used to assess their comparative preferences, the factors are weighted according to their importance.

Environmental elements have the highest level of preference in the weighting output, social and engineering considerations are next in line, and receive the lowest preference. The best path is determined by weighting, and the engineers' proposed route is evaluated for suitability. By minimizing high-cost environmental and congested areas, money is saved by taking the optimal route. As an early attempt for highway routing, the findings of this study will reveal the benefits of combining diverse data sources with GIS analysis. This can be used in Kenya to route other linear projects.

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Acronyms List and Definitions

GIS	Geographic Information System
DEM	Digital Elevation Model
GEB	Greater Eastern Bypass
WLC	Weighted Linear Combination
OWA	Ordered Weighted Averaging
MCDA	Multiple-Criteria Decision Analysis
MAUT	Multi-Attribute Utility Theory
AHP	Analytical Hierarchy Process
SAW	Simple Additive Weghting
LCP	Least Cost Path
ESRI	Enviromental Systems Research Institute
LiDAR	Light Detection And Ranging
WGS	World Geodetic System
SRTM	Shuttle Radar Topography Mission

CHAPTER 1: INTRODUCTION

1.1 Background

In Kenya, road transport is an important part of the country's transportation system, contributing to both employment and revenue production through the movement of products and people. Kenya's Vision 2030 strives to have good roads that make it easier to transport people and products. For the movement of goods and services, Kenya's economic system is largely reliant on road transport. Roads are an important mode of transportation for products, people, and several essential services.

Roads have long been an important part of a country's wealth, and they are important components of the social fabric in many countries because they make up a large percentage of the country's infrastructural capital, as a result, there may be a pressing need for certain roads to be optimized, lowering costs, during the development stage. At the same time, current routing tools such as GIS and remote sensing strategies will make it far easier to find appropriate routes that match the criteria.

There is also a need to avoid first-rate consequences and to provide long-term benefits, which are inherent in the concept underlying sustainable development. Geographic information systems, in accordance with (João, 1996), is capable of storing, combining, researching, and visualizing spatial features of environmental, social, and economic dimensions of evaluations. GIS can also provide a desirable characteristic of data generation, owing to its robust capacity for data processing, both geospatial and attribute. Geographic Information Systems are more widely used in developed countries because of their simple procedures, such as overlaying, interpolation, classification, and spatial data aggregation (Antunes, 2001). Evaluation of the final road is a difficult task because it may be necessary to balance several aspects in order to arrive at the most optimal path.

Network analysis is a term used to describe GIS-based route dedication methods that use vector or raster data models. Traditionally, assessment of network, pathfinding, and the path planning were greatest commonly utilized in graph theory and vector GIS, which contain a variety of algorithms. However, as this study illustrates, conforming those methods to a raster environment isn't always difficult. Raster programs are more likely to be based entirely on motion across a surface than motion alongside the side of a network, because the overall concept of locating the least expensive route is related to travel from one cell to another and no longer on a predetermined path. Many scholars have already attempted to address the drawbacks of the raster approach, resulting in a lot of solutions and recommendations.

Traditionally, road routing has relied on bulk office work and the use of baseline data that is no longer accurate or conclusive. As a result, such data records frequently lacked further detailed data on land cover, hydrogeology, drainage patterns, water, socioeconomics, and so on. They've now contributed to the fast as well as cost-effective generation of all correct and comprehensive temporal and spatial information on land use / cover, surface drainage, and aerosol for vast regions using advanced technologies such as GIS and remote Sensing. To give more precise land use/land cover demarcation, remote sensing data is obtained via passive or active sensors, as well as satellite imageries coupled with other data units. The use of remote sensing data combined with GIS has been utilized to detect land cover and land use (Weng, 2002). When it comes to the work of selecting a suitable site, decision-making is mostly dependent on a variety of data. This study describes a method for determining the best ideal path for the broader Greater eastern bypass that combines remote sensing data, GIS, and weighted overlay analysis.

Assuming that the broad decision to carry out a task has actually been reached, the emphasis now switches to the next phase:

Defining the transportation project in greater depth i.e. the technical element. Because of a large number of rules and regulations concerning the environment, public awareness, social responsibility, and budgetary restraints, these kinds of planning procedures for the construction of new transportation facilities are getting increasingly difficult. Furthermore, they are always linked to a variety of opposing interests. Taking all of these factors and competing interests into account, it is difficult to develop a solution that is agreeable to all stakeholders and parties. The secret to determining a path forward, is by finding the perfect balance of a system that enables the integration of the above aspects without pre-predicting the consequences, as well as public engagement in the decision-making process.

Land-use decisions that are appropriate are essential for maximizing land production and ensuring environmental sustainability. This necessitates effective land information management, on which such judgments should be made. Among the most beneficial techniques for this, is a land suitability assessment, Baja and colleagues (Baja, 2001). The qualitative and quantitative approaches to land suitability assessment are the two most common types.

1.2 Problem Statement

In third-world economies, traditional path planning has remained mostly reliant on topographical considerations, such as curvature gradient. Manually marking arcs of permitted slopes for road alignment on base maps at a large scale is standard procedure. When various aspects like geology, landslides, vegetation, soil type, landcover, and landuse are taken into account, such an approach is tedious, time demanding, and prone to errors. It may also be impractical. The most efficient path assessment is a multi-criteria issue with opposing goals which should be balanced. To discover the optimum path, this research utilises spatial modelling, GIS analyses, and a weighted overlay criterion and model with the resultant weights.

1.3 Objectives

1.3.1 Main Objective

To determine the optimal road alignment route for the proposed Great Eastern By-pass between Lukenya and Kilimambogo.

1.3.2 Specific Objectives

1. Identify the elements that impact road route location.
2. To determine the optimal route between Lukenya and Kilimambogo through GIS analysis.
3. To compare the optimal route with the Engineer's selected route.

1.4 Justification for the Study

The goal of route selection in public transportation is to choose the best path based entirely on predetermined criteria. As a result, selecting the best route usually comprises two stages:

i) Site investigation, which entails the identification of a number of potential parameters as well as a set of selection criteria.

ii) Site evaluation, which entails investigating each of the possible sites to determine the best option.

Spatial modeling, analysis, as well as weighted overlay are all performed in the GIS environment. Ecological, social, and engineering aspects are given as outputs for weighting levels of choice. The optimal path is determined by the weighted percentages.

1.5 Scope of work

The proposed GEB is approximately 60 kilometers long and runs through Machakos, Nairobi, and Kiambu counties. The study's optimum option will save money while also safeguarding our environment through sustainable development. The findings of this investigation will demonstrate benefits of combining numerous sources of data under one umbrella using GIS analysis in road routing.

1.6 The Report's Structure

This report consists of the chapters:

- The first chapter covers introduction, background information, an explanation of the problem, study objectives, scope and constraints, and report organization.
- The second chapter contains a survey of the literature on highway routing.
- The technique, which covers equipment, data sources, data preparation, and methodology execution, is covered in Chapter three.
- The fourth chapter presents the findings, analyzes them, and discusses them.
- Conclusions and suggestions are stated in Chapter Five.

These are followed by References.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

For third-world economies, traditional route planning had primarily on the basis of topographic considerations, such as curving and slope. On topographical maps at a vast size, the common procedure is to hand label portions of allowed gradients for route alignment. When a number of elements like, type of soil, geology, flora, land use, or land cover are included, such a method is complicated, prone to errors, and tedious, and it may not be viable (Saha, 2005). To reap long-term benefits, an appropriate road alignment must be devised that achieves a balance among environmental, engineering, technological, and social concerns. Lukenya and Kilimambogo are used as the starting and ending nodes, respectively. GIS capabilities are quite beneficial for combining several datasets, performing analysis, including modelling for the best route location. These features handle a variety of roadblocks, impediments, and issues in obtaining an ideal path based on a variety of parameters.

Over various sections, the proposed Greater Eastern Bypass road alignment passes primarily over flat to rolling terrain, with interchanging phases of undulating and somewhat steep terrain. The project road is located in the Athi River Basin, which is also known as Drainage Basin 3 and is one of Kenya's five major drainage basins. Along the road's route, there are various rivers. The rivers are the perennial Nairobi, Ndarugu, Thiririka, and Komu rivers, as well as the semi-perennial Athi River.

A highway routing approach usually takes into account a number of different variables, as a result, it's critical to prioritize each variable according to its significance. This makes determining an influence on for each variable posture just at routing technique much easier. A GIS-based approach to road routing optimization has been typically based entirely on weightages and scores applied suit project-specific conditions that influence the prospect path. This is really the most dependable outcome, as it shows the best financial path between the start and finish sites of the road. Technical, engineering requirements, environmental aspects, and population density all are factors that influence road course selection.

2.2 Study Review

Alternative routes should always be planned to suit construction practicality, cost, as well as current and future needs. In order to cut costs, a good route selection process is critical. Planners take into account elements such as the grades or slopes of an area, land-use as well as type of soil that are available, landmarks in the neighborhood or nationally, and interest of the state when building an appropriate road network. That's where GIS (Geographic Information System) as well as other technological advancements are beneficial. GIS is a type of system that enables efficiently archiving, retrieving, but also displaying both geospatial plus non-spatial data in a timely and structured manner. In the realm of transportation engineering, it is recognized as a crucial and essential tool, allowing transportation assessments to be performed. GIS aids in the design process by assisting in the right route selection, a key first stage in the design and construction process that has a substantial impact on the characteristics of the area's development and environment.

GIS is made up of three functions: handling spatial data, geography technology integration, remote sensing, GPS navigation, CAD, etc., and assisting in choice-making. The user/decision-maker can utilize GIS for geographical analysis, storage, data management, and visualization. GIS, according to (Carver, 1991), is a powerful toolset for processing and interpreting spatial data.

2.3 Evaluation based on multiple criteria

To examine the land suitability evaluation, the methodology of multi-criteria evaluations (MCE) is used. Multi-criteria analysis is a mathematical method for comparing a large number of possibilities or scenarios against a set of criteria in order to guide a decision maker to the best option. Land evaluation is used to determine whether or not a piece of land is suitable for a specific purpose.

Spatial multi-criteria forming an opinion relates to the use of multi-criteria evaluation in a space situation, when options, requirements, as well as aspects of the issue have distinct dimensionality of space. Multi-criteria analysis and Geographical information systems (GIS) has been utilized to enhance spatially multi-criteria decisions since late 1980s.

Making decisions based on multiple criteria (MCDM) combined with the help of GIS has significantly expanded traditional techniques for map overlay to land-use appropriateness evaluation (Carver, 1991); (Thill, 2000)). Spatial analysis Multicriteria can be described as a procedure for combining plus transforming spatial input (data) into an ultimate choice (outcome). Both input as well as output maps are connected using the MCDM procedures. The strategies include the use of geographical data, for the choice maker's preference, plus the modification of data choices based on established choice criteria. As a result, there are two key concerns in the instance of geospatial MCDA:

(i) Data acquisition, archiving, access, processing, and evaluation are all capabilities of the GIS as well as,

(ii) MCDM's ability to convert unidimensional values of decision alternatives from geographic data driven decision maker’s preferences.

For addressing land-use suitability issues, in the GIS context, a variety of multi-criteria decision rules have indeed been incorporated. Multi-objective and decision-making with several attributes approaches are two kinds of decision-making rules (Malczewski, GIS and multicriteria decision analysis. , 1999).

2.4 Methods with Multiple Attributes

WLC (Weighted Linear Combination) and its variations (Carver, 1991); (Eastman, Multi-criteria and multi-objective decision making for land allocation using GIS, 1998), methods for obtaining perfect points (Jankowski, 1995) analysis of concordance (Carver, 1991); (Joerin, 2001), as well as the analytic hierarchy method ((Carver, 1991); (Eastman, Multi-criteria and multi-objective decision making for land allocation using GIS, 1998) are just a few of the multiple-attribute methods of evaluation that were used in the research, (Banai, 1993).

2.5 WLC Methods

The WLC as well as Boolean overlaying functions, such like intersections and unions, are the simplest and widely used. SAW (simple additive weighting) is an average weighted concept. For every feature map layer, the choice maker gives relative relevance weights. Following that, there is a score generated for every choice by increasing the important weight given to every attribute is determined by scaled weights given to the substitute on that feature, then adding results throughout all entire characteristics. After determining the total score for entire options, option with the overall highest score is picked. The technique can be implemented utilizing whatever GIS system that supports overlays. Combine approaches enable map layers as a criterion for evaluation (input maps) to be integrated as a result to generate the composites map layer (map of the output). These methods can be used GIS platforms, either vector or raster.

The WLC technique has built-in functions in some GIS systems. However, there are some significant drawbacks to employing these techniques in the course of making a decision (Jiang, 2000)present a thorough examination of these drawbacks, suggesting that the (OWA) Ordered Averaging by Weighted Means technique is an oversimplification and extensions of classic GIS map combining techniques. OWA is a multi-criteria operator class (Malczewski, 2006). There are two types of weights in this system; criterion importance weights as well as weights in order. An important weight is given to a certain criteria (attribute) aimed at all places in a research area to reflect their relevance (as determined by the choice-preferences) in the process of putting together a list of factors to consider. The ordered weights are paired with the criteria values assigned to each location (object by object). They're allocated to the attribute values of a place in order of decreasing, regardless of whatever the source of the value. The ordered weights are significantly used in OWA pairing processes. The OWA operations allow the creation of a diverse variety of land use plans. As a result, OWA can be considered as a generalization and extension of typical GIS combination methods, (Jiang, 2000).

GIS-based MCDA was investigated by (Wang, 1990)for determining land suitability for agriculture. They looked at over 600 distinct places, as well as various land conditions, over 11 different attributes, and two different crop varieties. And according to value of agricultural locations, they compared Boolean and fuzzy techniques.

(Kiker, 2005) discussed the difficulties of analysing many factors in terms of price in decisions analyses with environmental concerns. Furthermore, by assessing existing literature on MCDA, the shortcomings and strengths of multiple-attribute value theory, such as Outranking, MAUT, and AHP techniques, had been fully highlighted. As a result, the AHP methodology for pairwise comparison has been found to be more efficient compared to MAUT, it's also essential to evaluate the criteria using outclassing methods instead of pairwise comparison techniques.

The PROMETHEE technique was employed as a pragmatic decision-making process for domestic dwelling development site location, and GIS was used as a spatial evaluation, presentation, and data visualisation, (Marinoni, A discussion on the computational limitations of outranking methods for land-use suitability assessment, 2006). PROMETHEE was found to be a useful method in land use analysis in this research. Combining homogeneous raster pixels instead of assessing them was offered as a way to overcome the PROMETHEE method's computing limitations (Marinoni, 2005). Fundamental GIS and decision-making tools were employed for automated distribution smooth lines and best route sitting. Nevertheless, the GIS application is restricted because the difficulty with routing is often treated as a geographical issue, this led to development of an artificial intelligence-based decision tool is built, (Sumic, 1993). The The Automatic Principal Router was created with the help of optimization algorithm to select the optimal transmission line path, and it was then combined with a Geographic Information System (GIS) to manage geographical data. (Yeh, 1999).

(Dedemen, 2013) used satellite pictures to study an overhead transmission line layout. They took environmental and economic constraints into account when planning the best transmission route. They clearly established the environmental restrictions before digitizing satellite pictures to create layers such as land use and hydrology. The layers then were weighted based on their importance in line routing decision-making. The option with the least amount of environmental effect as well as the shortest distance was chosen.

Using Euclidean and spatial distance between the beginning and destination places, (Öztürk, 2007)calculated the PTL route. The SAW technique was used in this study to investigate different layers in order to determine the optimum route. When the resulting route options were examined, it was revealed that the spatial distance routing approach was preferred to the Euclidian distance routing method.

(Cheng, 2001) created an objective function, the impedance index (II), which was retrieved from road segment, as well as the weight result of the AHP technique for determining the best path. The study's purpose was to develop an automatic routing system that would discover the most efficient route in terms of physical barriers and cost.

In 2002, the Georgian Transmission Company (GTC) as well as Electric Power Research Institute EPRI began collaboration on a fresh approach to power transmission routing. GTC-EPRI assembled a team of experts to bring together power distribution understanding, Geospatial methods, including choice-making procedure to address difficulties in routing, (Brown, 2017). The electricity route's macro corridor was established and the remainder within the same corridor by using some simple layers. To find the best route, different corridors were created. GIS (geographic information system) technology was employed as the major body for picking corridors and alternative routes, while Delphi and AHP technique were applied for weighing critical reviews obtained from numerous stakeholders (Demircan, 2011).

Furthermore, (Monteiro, 2005) introduced new method for automatic route choice for high voltage transmission lines utilizing GIS technology. Dynamic programming is employed in this study to determine the best routing and route choice. The installation and operation costs of the new transmission line were also a factor, which included environmental and engineering constraints. The research had two goals: one was to find a new path, another was to determine the most cost-effective route for the transmission line. This strategy can be simply applied to various linear line routing difficulties in a variety of industries.

According to input circumstances, GIS has also been utilized in a number of geographic decision-making aids with several criteria to address different modes of transportation challenges as an example, acceptable path creation, rapid routing of traffic, choice of a proper driving route, and so on, ((Effat, 2013) ; (Stefanakis, 1995, September). LCP (Least Cost Path) is one of the GIS-based methodologies that is particularly beneficial for this purpose. Many researchers have been using LCP analytics to determine the "least expensive" route between 2 points on a costing surface which may be approximated through integrating multiple- criteria as well as accounting for various obstacles (ecological effect, monetary investment, etc) (Douglas, 1994); (Collischonn, 2000). In multiple-criteria route selection, geotechnical, geometric, sociological, and financial variables are frequently considered, (Farkas, 2009, JUNE).

2.6 Least Cost Path

The process for developing these low-cost models for a variety of criterion evaluations as well as integrating several variables into a single least-cost models was established by the review of several papers, including, (Feldman, 1995)and (Atkinson, 2005). The types of criteria that were considered have been restricted due to the least cost model's complications. Because of the more straightforward way of weighting the changes of a certain element, the majority of the criteria investigated were physical characteristics of the provided geographic area (Atkinson, 2005); (Collischonn, 2000); (Saha, 2005); (Aissi, 2012).

Scholars have been examining various ways to design a procedure to discover the quickest and least expensive routes since a long time. Among the first educators to offer appropriate solutions to the challenge was Edsger Dijkstra, who came up with it a computer code for determining the optimal route between two networked sites. Most least-cost routing models incorporate this algorithm as one of the major components. With the help of a cost accumulated surface, the algorithm can find the least expensive path through a particular area. This method of analysis starts with the cells in the immediate vicinity of the proposed beginning place and expands outward from there to cover the full study region.

The algorithm can generate the cost accumulated surface in a variety of ways, each presenting a unique method to solving the problem. The Dijkstra Algorithm is one of the most widely used and simplest methods for determining the least cost route through a surface. This is because when all of criteria have been put together into cost accumulating surface, the algorithm just needs to examine the nodes throughout the surface. However, using this method has the disadvantage of being computationally costly and generating large amounts of data that must be saved, (Saha, 2005).

Recently, the ESRI Institute has created an increasingly complicated extensions to the cost path tool and incorporated features into their primary ArcGIS solutions. Among these adjustments which has proven to be really valuable is the Cost Path Calculator. This program enables you to you to create a Cost Direction and a Surface of Backlinks, which are after that combined with the surface of primary cost to calculate a more exact and accurate Cost for the route taken from one point to another, as well as the cost that the path incurs throughout the surface, (Collischonn, 2000); (Rees, 2004).

Roads and canals, like gas pipelines, are linear infrastructures that employ least-cost routing strategies to generate more precise economic routes. Because of these qualities, topography has a considerable impact on the cost accumulated surface, particularly in canals, by rendering the weighted values orientation dependent. As a result of this limitation, the mechanism for processing the cost accumulated surface must be changed to suit it, (Collischonn, 2000). This type of constraint appears to be more common in places where the topography is relatively stable, because the algorithm should add a feature expressing the incline into its computations.

This study demonstrates the broad range of applications in planning, using GIS-based optimal routing of large projects that are linear. By updating computer codes and integrating extra diversified standards into the cost collected raster, route extensions with the lowest cost in many GIS software platforms may rapidly evaluate the criterion and provide the most cost-effective and least expensive risky path to take in a particular geographic zone.

2.7 Integration: general-purpose GIS

The most crucial aspects impacting the progress and efficiency of GIS applications mostly in 1980s were major advances in computer technology, which resulted in a large decline in the price of processing power. Among the advancements are large and extremely huge embedded processors, memory-equipped microprocessors, and controlling circuitry, i.e. a complete microchip-based centralized processing unit. These advancements in technology breakthroughs opened the way for the development of household computers like the IBM PC and Apple, as well as the Microsoft Disk Operating System. As a result of these advancements in computing technology, a significant change in GIS sector happened towards the end of 1980s. The profession is moving away from workstations and toward a PC environment. There has been a change in computer systems from from command-line interfaces to software created for GUIs (Graphical User Interfaces) on desktop of the computer.

Even though some big private or companies that sell GIS software were started in the late 1960s. It is really worth noting that some commercial GIS systems didn't emerge until the 1980s. Two of the better examples are the Intergraph Corporation and the Environmental Systems Research Institute (ESRI), both established in 1969. The very first GIS to make use of the new hardware for super-mini computers was ESRI's ARC/INFO, which was released in the early 1980s. One of the system's most notable aspects or features was the successful implementation of unique attributes and positional information notions using a combination of a conventional relational database management system to maintain attribute tables, with software that is specialized to deal with data stored in the form of arcs. ARC/INFO was a vector-based application-oriented system with a modular (toolset), function, and user interface with a product focus that allowed intricate programs to be built on top of toolkit. Several other GIS companies, notably MapInfo and Caliper, have followed suit, with the former offering an inexpensive desktop GIS MapInfo and ultimate specializing on GIS for transportation (TransCAD GIS).

As computational power rose while hardware costs decreased during the 1980s, for states GIS technology became an essential tool, departments of urban planning, as well as educational institution units. It was crucial in this scenario to construct minimal-cost GIS based on rasters. Research on map algebra influenced this study as well at Yale School of Forestry and Environmental Studies, which as a result of which the Map Analysis Package was created , GRASS ((Warwick, 1994), (Eastman, 1998), SPANS GIS, and MAP II are only a few of the raster GIS that have since been released (Pazner, 1995). It's also important worth noting that GIS applications evolved rapidly mostly in 1980s was aided through a wide variety of available commercial information technologies and products, including computer-assisted design process, database systems (DBMS), satellite imagery, LiDAR, a global navigation satellite system (GPS), and a rise in data in digital format available to individuals plus institutions, such as open street maps, (Maguire, 1991).

In previous years, stakeholders were more concerned with finding the shortest and most direct route. This is primarily to reduce building and other capital expenditure costs. Aside from that, there are various more variables for route selection that must be considered in addition to cost. The route selection process is influenced by geophysical, social, environmental, economic, cultural, and regulatory variables. Although finding the parameters to consider when choosing an ideal route may not be difficult, the geospatial community faces a significant issue in ranking these routing criteria in order by significance Most researchers consider the views and opinions of policymakers, engineers, contractors, and environmentalists when ranking and ordering the routing criteria, but very little attention is paid to the views and opinions of local community members who typically live in areas where the roads are to be located. Women, teenagers, and other groups who will be directly impacted by the roads must be contacted extensively, and their ideas and opinions must be taken into account while determining weights for the routing criteria procedure.

The purpose of this research is to take a comprehensive approach to the issue of highway route selection. GIS technologies will be used to analyse spatial data, and the routing criteria will be thoroughly and precisely weighted. This will increase the accuracy of the data acquired and, in turn, result in an optimal highway route that is acceptable to all stakeholders. In addition to being a cost-effective project, such a road path will be kind to people and the environment.

2.8 Road Route Selection Using GIS

2.8.1 Route selection

Few attempts have been made in the preceding decade to automate the route design using GIS, and the methodology is still in its early phases. In this respect, a study by Saha found that using a computer-assisted route design methodology is faster than using a manual one. The least-cost strategy developed from a study in the Caspian Sea was 21% greater in length than a straight path between the nodes of destination, although it saved 14 percent on construction expenses. In highway route selection, the use of GIS and multi-criteria decision making was proved in study to create an optimal highway route for example in Malaysia using GIS. In Iran, a prototype of the least-cost highway routing was tested, with the resulting highway being longer but 29 percent cheaper than the present highway line.

2.8.2 Key routing factors

For public transit convenience, the highway route should be developed near populous regions. Topography, geology, river, soils, and road crossings were all engineering considerations. Different classes and subclasses frequently bring with them different difficulties during processing.The use of existing linear disturbances decreases environmental concerns while also lowering building costs, which are always connected with vegetation clearing. A catalogue of landowners will also be required to estimate the number of land parcels for compensation of their property. The route's environmental implications must be considered, then justified and accepted by authorities, and ultimately by the general public through public consultation. To supplement the studies, environmental impact assessment study should be conducted. It's imperative. to evaluate land cover and land use.

2.8.3 Weighting

Because the many factors under this study are not equally weighted, it is frequently necessary to order each variable in order of significance. The three most typical approaches for creating evaluation criteria for any given project are a review of available literature, an analytical analysis, and expert opinions. To build a proper average adverse score grid, the weight allocation technique involves a mix of several different elements. Commercial GIS packages do not permit the incorporation of alternative weighting situations and diverse points of view in routing, whereas free GIS packages do.

GIS technology is increasingly being used in the road projects, particularly in industrialized countries, as a useful tool for aiding decision-makers in selecting the best route while building new highways. This helps to reduce construction and operational expenses while also reducing negative environmental impacts during the construction process. Similarly, GIS integration aids in the protection of the environment during construction. Several diverse components, such as topic matters and variables, are commonly used as input in the geographical process in such initiatives. The following are some of the most regularly used variables:

- The lowest possible grade (removal of trees etc.)
- The cost of acquiring the road's right of way

- Topographic gradient
- The number of streams and railroad crossings are both significant.
- Material (rock and soils)
- Laws and regulations currently in effect (wetlands)
- Population Centres' Proximity
- Existing utility routes and easements will be used.
- Other engineering considerations
- Stay away from aquaculture areas.

It's also worth noting that any set for evaluation criteria are problem-specific, and there's no one-size-fits-all approach to developing a set of requirements.

Significant changes in legislative requirements, and also growing public awareness of the social as well as environmental repercussions of transportation infrastructural development, have resulted in new needs for transportation project assessment methodology over the last two decades, (Tischler, 2017). In most nations, three key forces have pushed for a critical examination of old approaches:

- Project development takes longer: Detailed project documentation, complicated approval procedures, prolonged discussions with landowners, and other issues all contribute to extended time intervals amid the initial task concept as well as the start of construction. Route selection systems' outputs typically become out of date over time, and new needs from authorities must be considered. Traditional approaches, on the other hand, aren't adaptable sufficient for them to be included in their workflows.
- Longevity: Conventional cost-benefit analysis methods are largely concerned with financial and technological issues. The increasing demand for sociological, environmental, and financial considerations to be considered while building new transportation infrastructure projects involves including these factors into the process.
- Participation of the public: Traditional methods are more scientific than democratic. In an increasing number of countries around the world, the people affected are no longer accepting of such activities. The public has expressed a strong desire to be kept informed about the development process and even to participate in it.

2.9 Decision making methods

People make decisions in everyday life based on the circumstance they want to be in. When making a personal decision, such as purchasing a new car, vehicles are typically classified based on the price, fuel economy, color, impact on the environment, and deluxe; another instance of decision-making is a person's choosing between a male and a female partner based on his sexual identity and the other's personal traits, brilliance, and visual appeal, among other factors, (Bagherzadeh, 2016).

The choice process is similar to a complex spatial decision problem encountered in everyday life, and can be described as an assessment of various options based on the decision- maker's goals as well as preferences. When renting a new property, for example, certain requirements must be met, such as closeness to recreation areas and markets, rental rate, and comfort. The rental home problem can be solved with a computer since it may be considered as a spatial decision problem. The spatial AHP approach, as in the preceding examples, can be used to address spatial problems (Malczewski, 1999a). The aim in decision issues is a declaration of the intended outcome in terms of the criteria (Chen, 2011) (Malczewski, GIS and multicriteria decision analysis. , 1999) defines the decision-making process as a collection of tiny significant pieces, their separate study, and acceptable integration of little solutions to produce a whole solution to problems.

Because of the price, social and environmental implications of linear elements such as electricity transmission lines, railways, pipelines, and highways, route selection is also a critical decision-making concern. For linear structure routing, there are several constraints, varying levels of preferences, and varied criteria. As a result, optimum highway route selection (Great Eastern Bypass) can be conceived of as a GIS tool for problem-solving decision-making. In practice, however, the decision-maker may not consistently compare several aspects. However, with the use of GIS strong analysis tools, numerous characteristics, such as landuse, buildings, rivers, wetlands, restricted areas, slopes, and other road networks in the area, may be compared.

2.10 Case Study

RURAL ROAD SELECTION MANIFESTATION OF BEST ROUTE ALIGNMENT, ENVIRONMENTAL AND ENGINEERING SUITABILITY IN MIND, USING GIS AND THE MODEL OF THE LOWEST COST PATH (LCP): A NEPAL CASE STUDY

Problem statement

Designing a road alignment in underdeveloped countries like Nepal was discovered to be done manually and with firmness decisions, this necessitated to a significant amount of time and effort and was not effective or optimal. Several important aspects in aligning the route choices, including as socioeconomic situations, geographical features, terrain, as well as the environment, were not taken into account holistically.

Methodology

The Least Cost Path (LCP) model was combined with a Geographical Information System to find the most cost-effective route for long-term road construction. Dupcheswor Rural Municipality, Nuwakot, Nepal, and a portion of Langtang National Park was chosen as a research area; To construct a cost layer, environmental and engineering characteristics were chosen. In the GIS, fifteen routes were created using the (LCP) model. The price of all fifteen created routes was compared, and the ideal route was chosen based on the lowest cost. In this study, the best path was determined using a hybrid engineering and the environment theme approaches. Other elements have to be included in preliminary for comprehensive design collaboration and road alignment planning, according to this study. ESRI ArcGIS 10 was used to create five cost criteria maps with issues related to engineering and the environment. The following were the descriptions of the criterion maps:

a) Slope: The study area's slope map was created using a Digital Elevation Model obtained from the USGS. The slope sub-classes, as well as the area of coverage and rating values, were provided.

b) The order of the stream: The drainage map given by the Nepalese government's Department of Survey was used to create the order of the streams in the research region. The Strahler method was used to create the stream order. The stream order sub-classes, as well as the area of coverage and rating values, were provided.

c) Landslide: Aerial photographs and maps of land cover from the Nepalese government's Department of Survey, and Google earth images obtained at various times were used to create the landslide in the research region.

d) Landuse: The land usage in the research region was created using the Survey Department, Government of Nepal's map of land cover and use, which was updated using Google Earth pictures. The landuse sub-classes, as well as the area of coverage and the rating values, were provided.

e) Areas that are protected: The study region's protected area was created using a land cover map given by the Nepalese government's Department of Survey. The protected area's sub-classes, as well as the covering area and rating values, were determined.

Results

This research uses a Geographic Information System and a Least Cost Path (LCP) model to find multiple route alignment options for various scenarios. As a result, by avoiding the use of steep to extremely steep slopes and maintaining a moderate to high stream order, landslides, sand mining, and other instability, cliffs, bodies of water, and a slope orientating in the north and National Parks and other protected areas, the proposed path must be both technically and environmentally sound. Using various scenarios, fifteen possible routes are generated in this study. In terms of distance and relative cost, fourteen of the fifteen routes are equivalent. Only one route is based on an environmental theme, stream order, on the other hand, simply presents the most expensive route due to its length. The present road in this research region is around 11 kilometers long, but the ideal path recommended by the LCP model is approximately 9.2 kilometers long. As a result, the LCP model was highly successful in dealing with the concerns described earlier in these routes. Because this model is straightforward and adaptable, it may be applied to various portions of Nepal's rural areas to determine the most effective route alignment for connecting rural communities via road.

Conclusions and Recommendations

The research's findings could help the relevant authorities, engineers and planners choose the route alignment that is acceptable in the study region. For any kind of road development activity, this study gives essential information so that attention may be made to steep to incredibly steep slopes, landslides, high-order streams, a variety of land uses, a slope aspect, as well as protected places. The LCP model was used in this analysis, which took into account the road's engineering and environmental characteristics. If social, economic and political factors were taken into account, the results would have been different. This study suggests that, depending on data and information availability in the study area, more research be done to determine the effects of socioeconomic and political aspects. Other strategies for improvisation in this study include uneven weighted overlays, Analytic Hierarchy Process, techniques such as fuzzy logic and genetic algorithms, and so on.

CHAPTER 3: MATERIALS AND METHODS

3.1 Area of Study

One of the most important milestones in the government's 2030 vision is the projected Greater Eastern Bypass (GEB). The proposed road connects two major highways: The Nairobi-Mombasa highway, the Kangundo-Nairobi highway, and the Garissa-Thika highway.

The proposed GEB is approximately 60 kilometers long and runs through Machakos, Nairobi, and Kiambu counties. The proposed route begins around 1.7 kilometers southeast of the A104/109 intersection, close to Athi River town, at Lukenya Junction (A109/D519). The proposed route then heads east, intersecting C98 at Ngundu/Kamulu, before heading north to the Nairobi river turn-off, where it splits with the westbound limb linking the current Eastern Bypass at Nairobi River Turnoff. The proposed bypass road continues in a northern direction to the Munyu region, then turns and travels in a north-eastern direction before joining the A3 road near Kilimambogo.

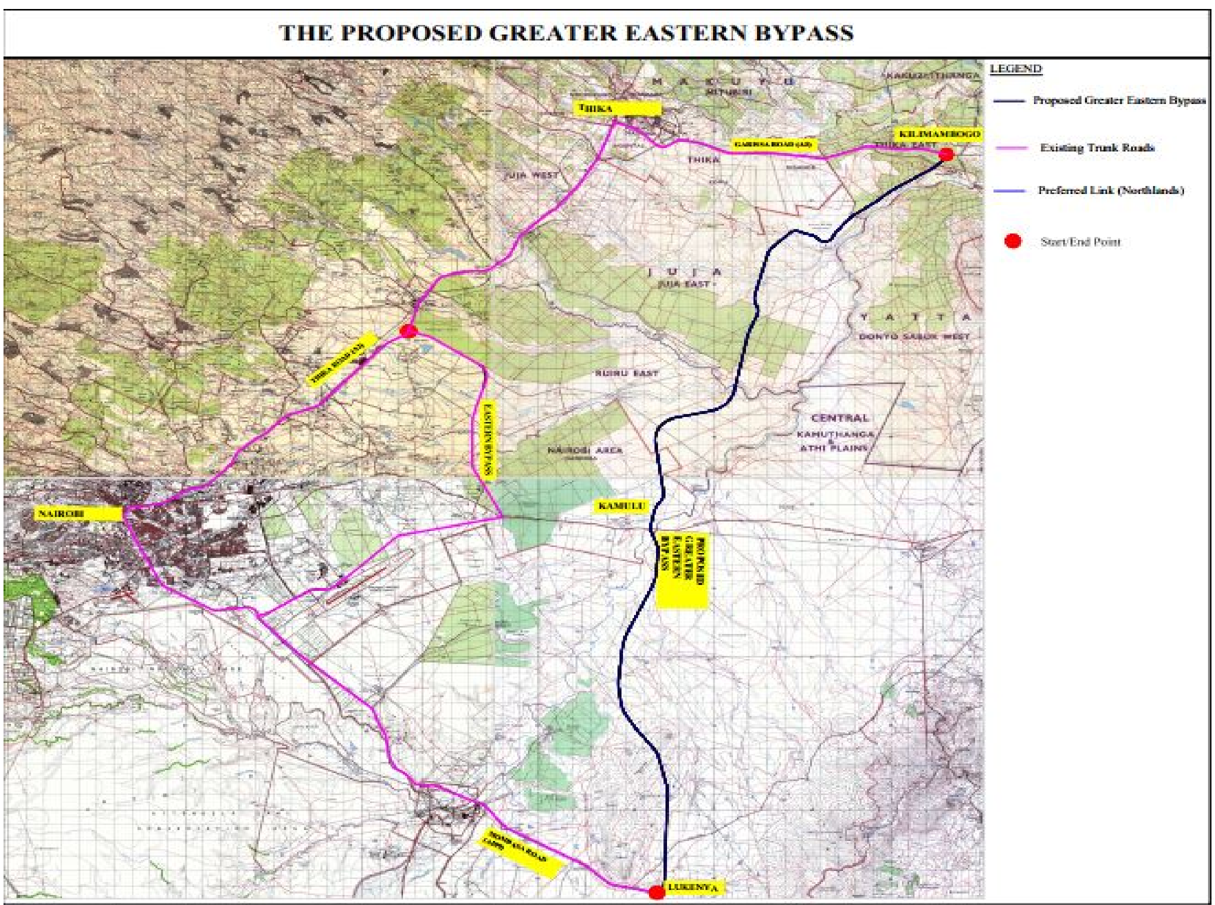

Figure 3.1 Map of Greater Eastern Bypass

3.2 Methods

The purpose of this study was to create a model that demonstrates how to choose the ideal route for a road between Lukenya and Kilimambogo. The stages below outline the approach for selecting the optimum path:

1: Establish criteria and gather information.

2: Weighting the criteria.

3: Making a route suitability map.

4: Creating route options and deciding on the best path.

The operations were performed utilizing ArcGIS 10.5 from ESRI Spatial Analyst, as depicted in the figure 3.2.

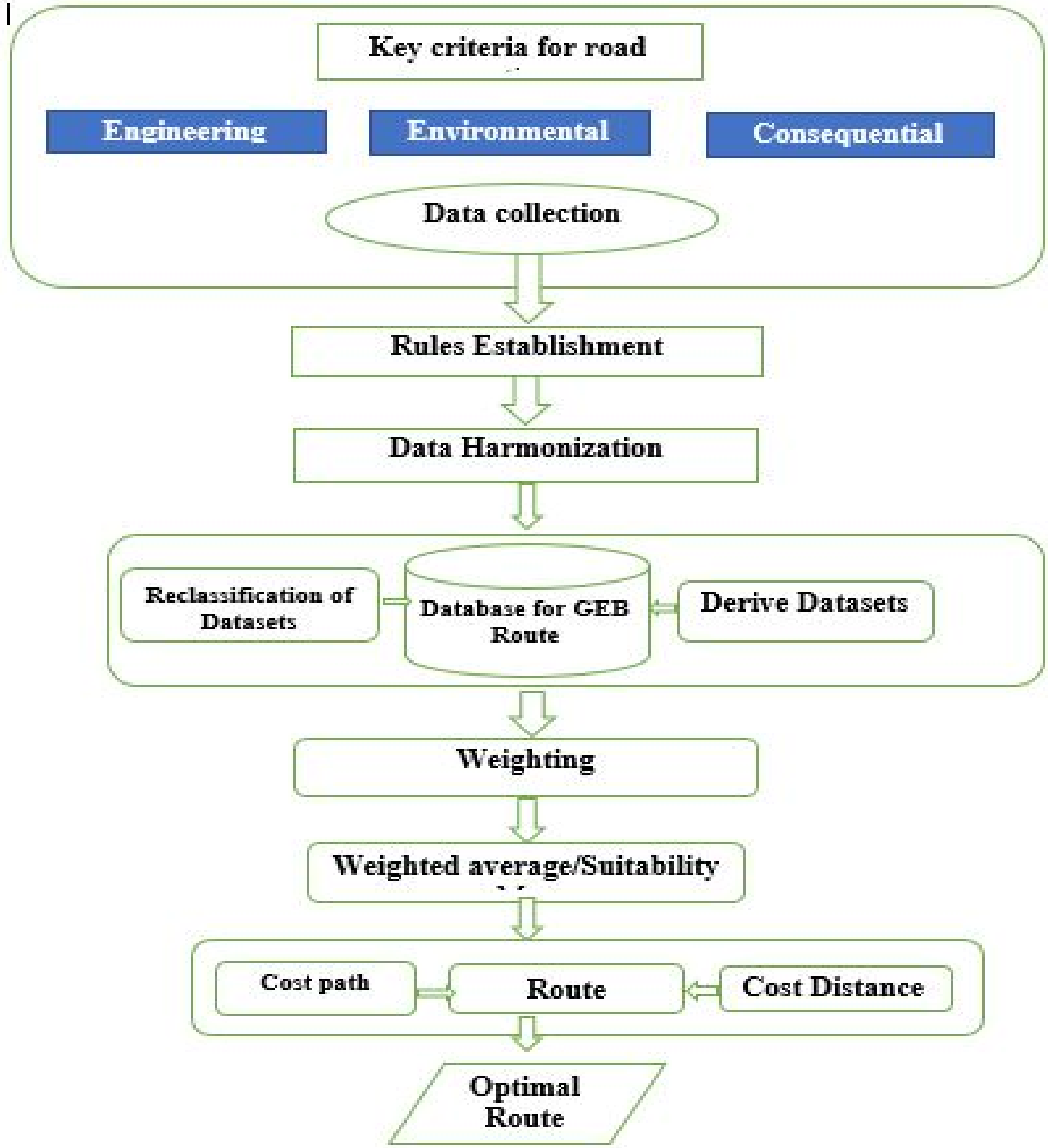

Figure 3.2 Flowchart for determining the best route between Lukenya Junction and Kilimambogo.

3.3 Datasets

The research area is mapped and analyzed using a variety of data type

Table 3.1 Data Sources and Applications

DATA TYPE	DATA SOURCE/FORMAT	USE
KENSOTER-Soils	RCMRD - Raster	For soil characteristics rating and ranking.
Kenya roads	KeNHA - Vector	For connectivity rating and ranking.
Kenya_SRTM30m	Shuttle Radar Topography Mission (RCMRD)-Raster	For developing slopes factor map.
Kenya_Sentinel2_LULC2020	RCMRD - Raster	For land use rating and ranking.
kenya_major_rivers	RCMRD - Vector	For drainage rating and ranking.
kenya_minor_rivers	RCMRD - Vector	For drainage rating and ranking.
GEP_Alignment	KeNHA - Vector	Defines the area of interest.

Confirming and assuring that the datasets were in the same projection and datum was part of this process. Prior to further examination, the mapping scale was also unified. Because the majority of the data was in the GSC WGS 1984 projection, it was transformed to Arc 1960, which was used for all data and outcomes. Any other data in a different format was re-projected and transformed.

3.4 Design of the System

The components of the system begin with files geodatabase containing input, tool kit, and a final product. The information is combined to form a surface cost using layers for the start as well as end points. To produce the best path for the highway in the field of research, the best highway tool is adapted utilizing tools from the ArcGIS toolkit. The Least-Cost Path tool generates a line feature type as an outcome that reflects an optimal route between Lukenya and Kilimambogo, given the starting and ending points respectively.

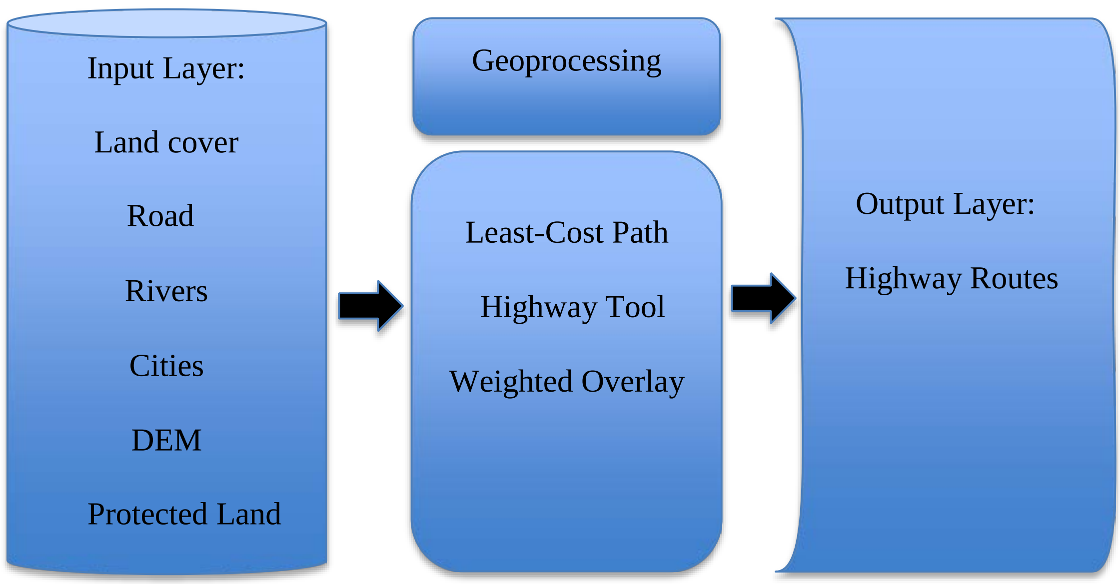

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Figure 3.3: The System Design

3.5 Criteria Selection

The criteria that should be considered when choosing the ideal country road route are briefly discussed below. The following variables were ranked in order of priority after consulting with KeNHA Highway Engineers experts:

i) Gradient: The DEM for the research region is used to create the slope map. As illustrated in below, the slope is separated into five groups (3.4). The amount of earthwork required increases as the slope percentage increases. As a result, low-slope fields receive the highest appropriateness rating, while high-slope fields receive the lowest. Reduce cut and fill expenses by maximizing route length on level and mild slopes.

ii) Soil type: The qualities of the soil have a crucial role in route selecting. Examining soil qualities along the roadway and identifying dirt appropriate for filling and subsoiling are all part of soil surveys for highway construction. A careful examination for the area of land at the road's terminus is always performed since soil properties have a significant effect on the positioning of highways. A soil map depicts the research region, see Fig. 3.5, which is classified into four categories; Namely Loamy, Sandy, Clayey and Very Clayey. Soils that are stable, for example, loams, are preferred over soils that are unstable, such like sand or clay, in order to save both building and maintenance expenses (Karrow 1983).

iii) Distance to ridges: Ridges are the highest points on a hill where construction is less suited and requires more work in transferring dug material and transporting building materials. In the future, the danger of harm from highway automobiles falling from high peaks could be substantial.

iv) Length: The overall construction time is determined on the route's length. The shorter the length, the less time the construction will take and the less disturbance it will cause to the public and nearby businesses. Finally, each candidate route's length in kilometers was calculated using GIS. The path that has the greatest length was the least suited.

v) Hydrology: To prevent the costly construction of highway, bridges, and other infrastructure, route lengths intersecting river networks should be kept to a minimum.

vi) LULC: The use of Land Cover Land Use is critical for demonstrating of socioeconomic as well as the effects of a construction project on the environment. Due to compensation costs paid during demolition and the environmental negative consequences that may come from deforestation, higher costs were ascribed to built-up areas and forest reserves. To avoid or reduce land acquisition, reduce route length in farmland and urban areas. See fig.3.6.

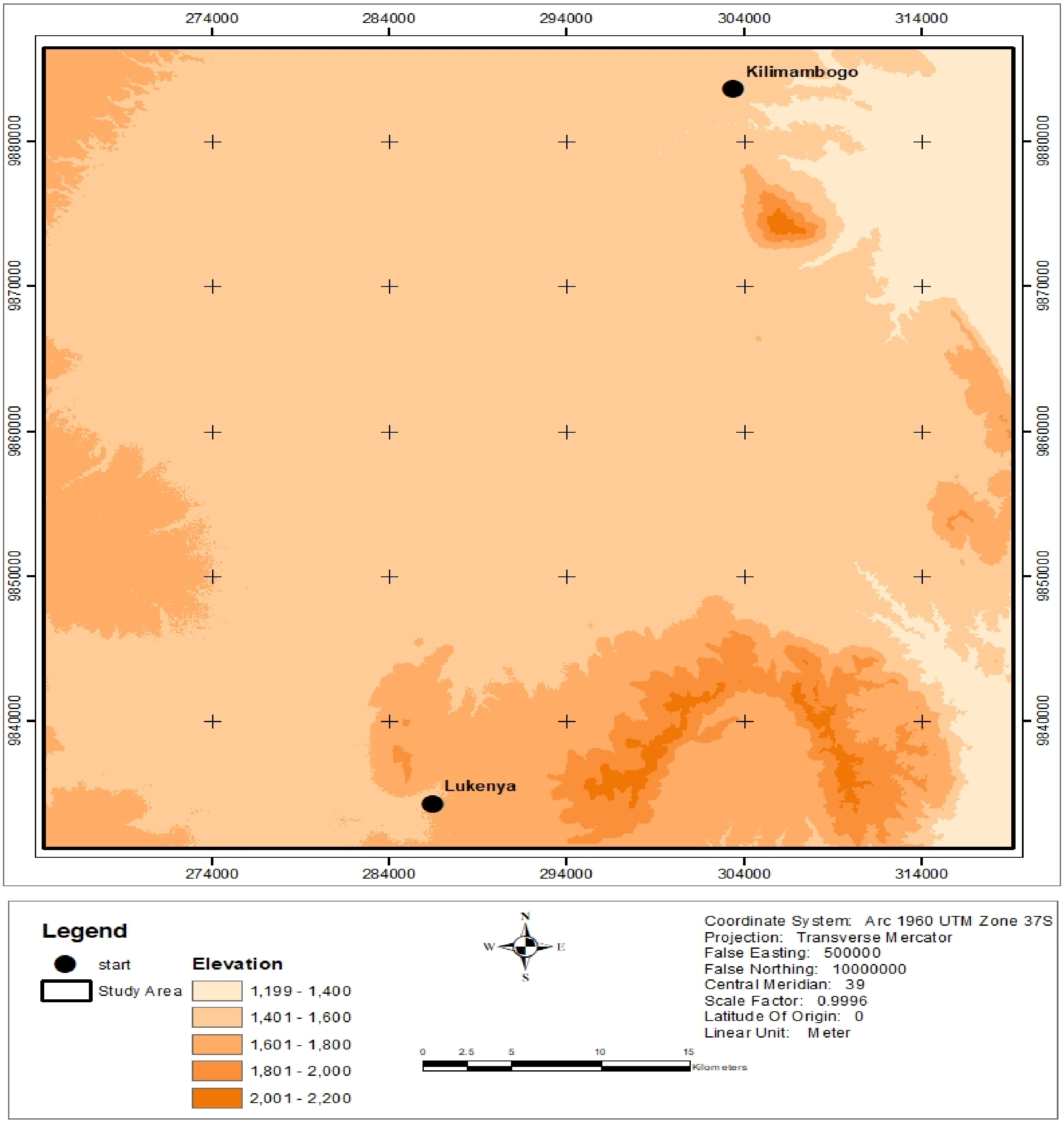

Figure 1.4 STRM 30 Showing Slopes in the Study Area.

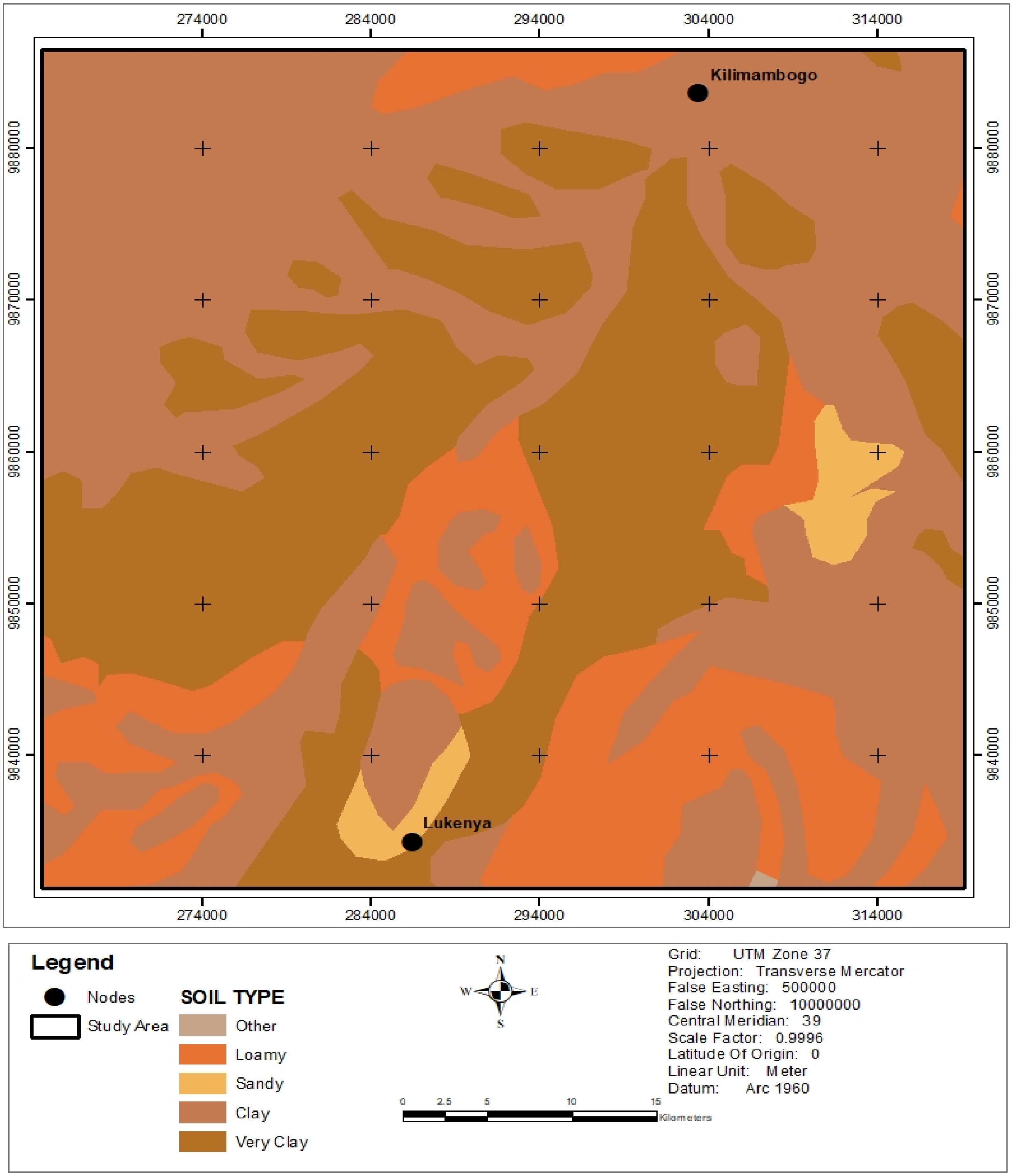

Figure 3.5 Soil Types in the Study Area

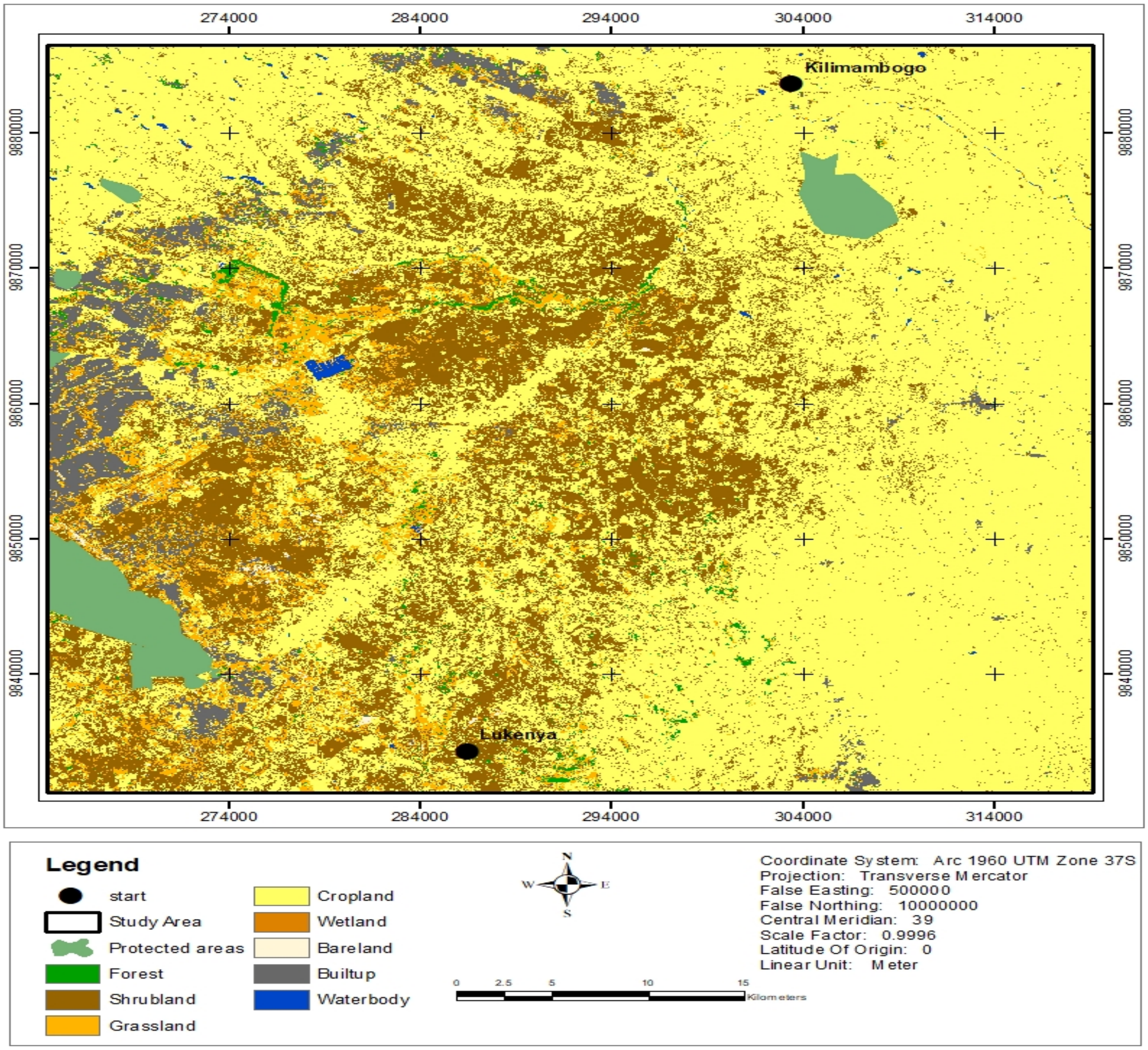

Figure 3.6 Land Use in the Study Area

3.6 Criteria standardization

The initial phase is to choose the geographical and non-spatial aspects that affect the highway route, such as engineering, environmental, and social considerations. Minimize crossings of rivers, wetlands, highways, agricultural land, forest, game parks/reserves, ground water sites, and lakes are among the rules set. Avoid hard rocks and clay soils, and focus on low-lying areas and bare ground, routing through town centers while avoiding settlements.

Cleaning data for inaccuracies and transforming coordinate systems is all part of the harmonization process. Except for the raster DEM, all datasets are rasterized. Slope is calculated from the DEM. A suitability map is created by combining the derived data sets. This was accomplished by converting all of the data sets to a single measurement scale ranging from 1 to 5, which assessed how acceptable a cell is for highway route location. Lower numbers indicated regions that are more appropriate. Reclassification was used to assign a new value to each pixel in the generated dataset that corresponded to its contribution to the routing. After the feature layers have been ranked, they are integrated into a single layer based on weights that are used in GIS analysis. The least-cost path from Lukenya Junction on A109 to A3 near Kilimambogo is determined using the Cost Path tool.

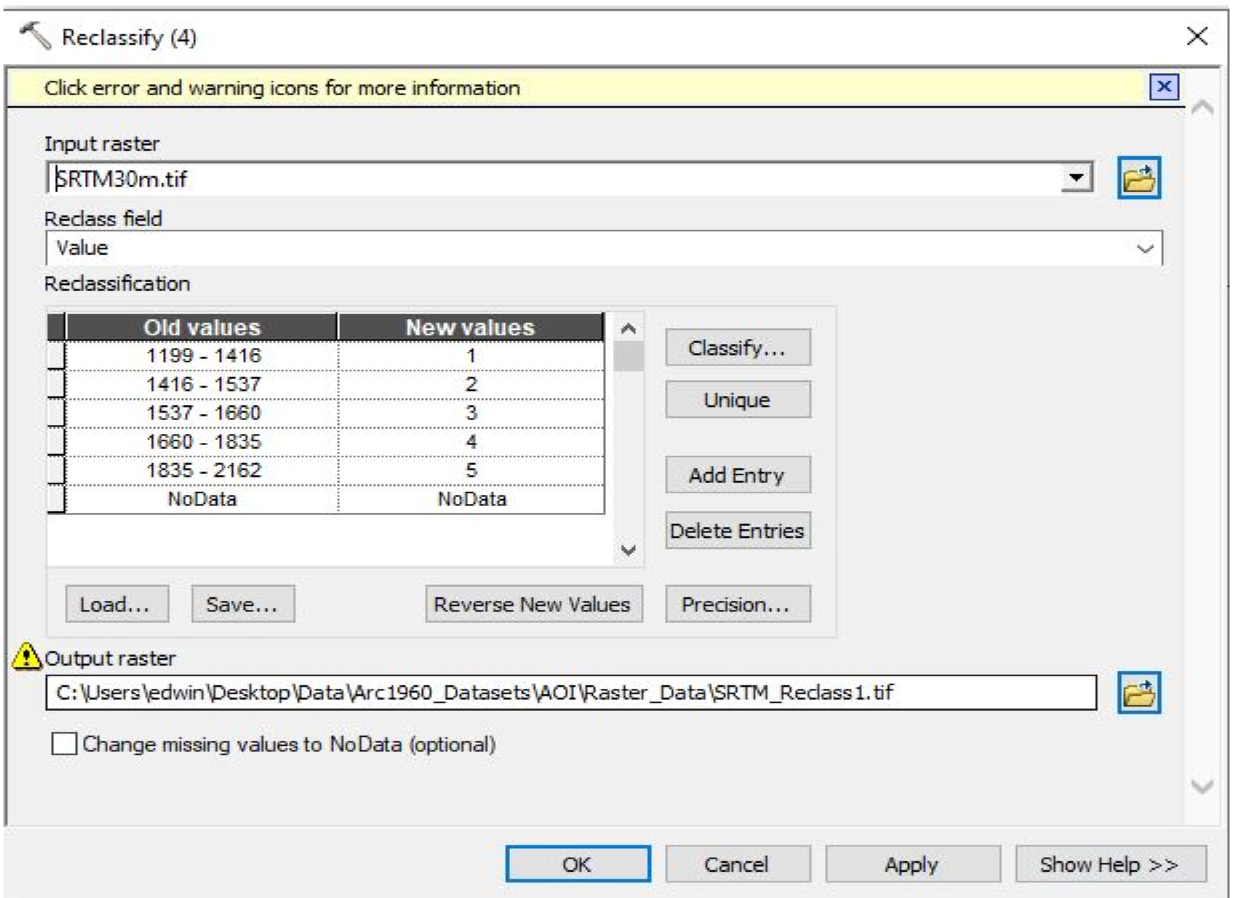

Figure 3.7 Reclassify process for the Slope

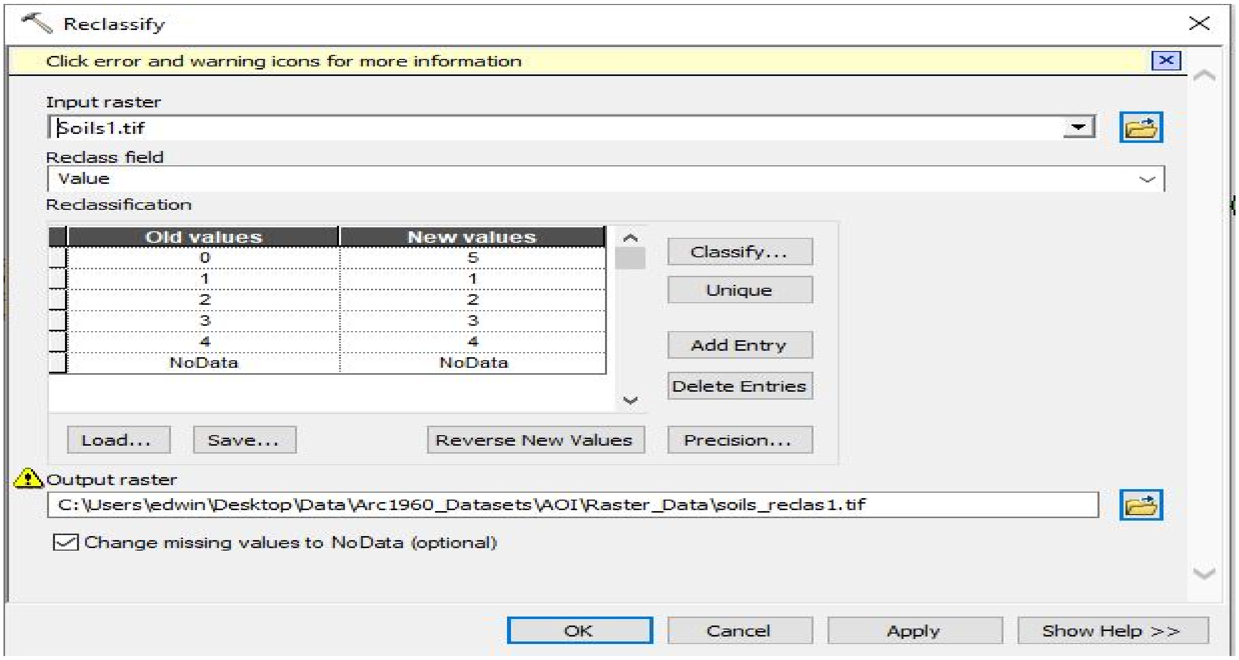

Figure 3.8 Reclassify process for Soil

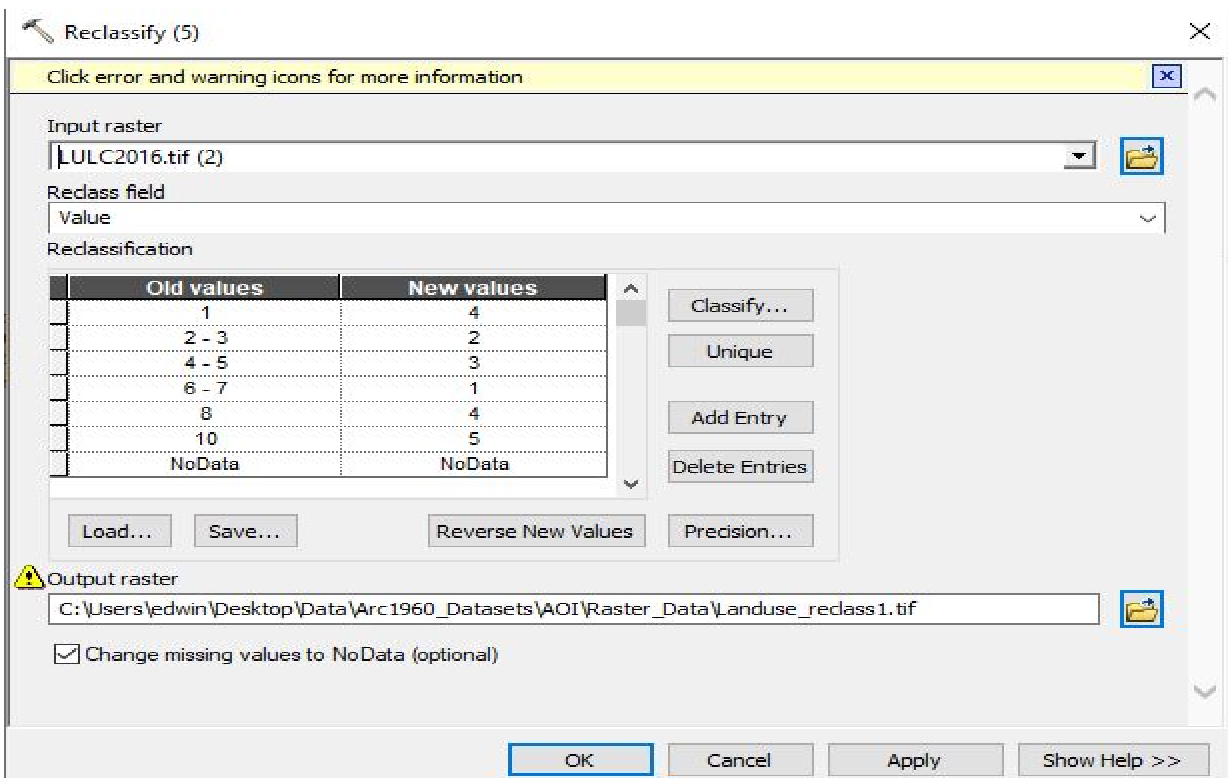

Figure 3.9 Reclassify process for LULC

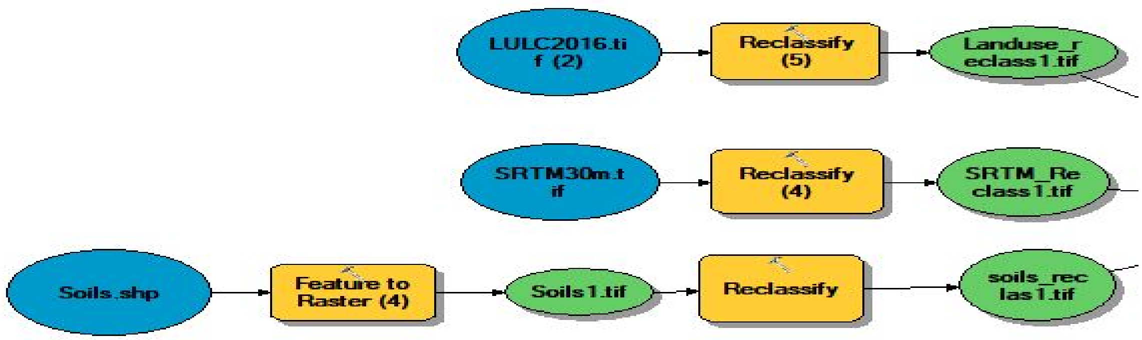

Figure 3.10 Reclass Model

3.7 Criteria weights

Because the priority of the criterion variables for each choice vary based on the objectives and goals, each must be given a certain weight. The AHP methodology is a powerful weight-computing method of comparing every variable in relation to its corresponding aspect, which is better than providing absolute weight in the absence of a comparison. In Analytic hierarchy process analysis was performed in 3 steps:

The initial step is by creating a comparison matric for matrices. The Saaty grading scale is utilized to establish the relative importance of the chosen factors. The enhanced matching matrices derived from prior comparison in the 2nd phase, the data is normalized. The last phase is to compute the weight of each factor, which will be accustomed to determine the eigenvectors of the comparison matrix.

Table 3.2 AHP Saaty scale

Definition	Preference
Equal important	1
Moderately important	3
Strongly important	5
Very strongly important	7
Extremely important	9
Intermediate values	2,4,6,8

The following formula can be used to compute the weighting method:

The factors are first compared to one another, and then each attribute factor's weight is determined. This component indicates the matrices' principal Eigenvectors as a result of multiplication the pairwise matrices. The row summation will then be computed for each attribute but also standardized according to total of entire rows, resulting in actual weighted factor.

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \qquad (1)$$

$C_{ij} = \sum^{n}{}_{i=1} C_{ij}$

The column sum is then divided by each cell:

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \quad X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \qquad (2)$$

To create a weighted matrix, dividing the total of normalized columns of matrix by quantity of parameters (n).

$$\begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} \quad W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} \qquad (3)$$

The views of the decision maker must be validated for uniformity prior to utilizing the weights. Increasing the number of every layer scores based on the preceding evaluation criteria, summing the findings across the rows, then dividing every row's sum by the weight of the related layer, the evaluation matrix's eigenvector is generated.

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} C_{v_{11}} \\ C_{v_{21}} \\ C_{v_{31}} \end{bmatrix} \qquad \text{Step-I} \qquad (4)$$

By removing the quantity of criteria (n) from a matrix then dividing the outcome by number of criteria (n), the CI (consistency index) is computed (n-1). Divide the Index of Consistency (CI) by Randomized Index (RI) to get the Consistency Ratio (CR). The coefficient of variation (CR) is less than 0.10.

$$C_{v_{11}} = \frac{1}{W_{11}}[C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}]$$

$$C_{v_{21}} = \frac{1}{W_{21}}[C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}] \qquad \text{Step-II} \qquad (5)$$

$$C_{v_{31}} = \frac{1}{W_{31}}[C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}]$$

$$\text{CI} = \frac{\lambda - n}{n - 1} \qquad (6)$$

where n = number of criteria used.

Random inconsistency indices (RI) for N = 10

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Source: Saaty (2000).

$$C_r = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{7}$$

Three key criteria are accepted as part of the goal (choice of the best motorway path) in the hierarchy constructed for this study. For each of these three categories, pair comparison matrices were created. As can be seen in Table (3.3), which illustrates the matrix of pairwise comparisons that was constructed. The Analytical hierarchy approach is then used to establish the weights of every single variable.

Table 3.3 Matrix of Pairwise Comparisons

criteria	Soil type	LU/C	Hydrology	Slope	weights
Soil type	1	1/6	1	1/2	11.5%
LU/C	6	1	8	1	48.3%
Slope	3	1/3	6	1	40.2%
Sum	10	1.49	15	2.5	100%

3.8 Weighted Overlay Tool

A cost surface was created after all three rasters were classed . The sole geoprocessing tool required to build such surface was the Weighted Overlay tool. This utility integrates many rasters into a single analysis, different varriables are given percentages as derived in the above paragraph. This tool is quite similar to the Weighted Sum tool, but instead of floating-point numbers, it only accepts integers.

Table 3.4 Weighting Overlay Table

Weighted overlay table

Raster	% Influence	Field	Scale Value
Landuse_reclass1	48	Value	
		1	1
		2	2
		3	3
		4	4
		5	5
		NODATA	NODATA
SRTM_Reclass1.tif	40	Value	
		1	1
		2	2
		3	3
		4	4
		5	5
		NODATA	NODATA
soils_reclas1.tif	12	VALUE	
		1	1
		2	2
		3	3
		4	4

Sum of influence 100 Set Equal Influence

The cost friction maps for each scenario are constructed using the Weighted Overlay function, as illustrated in Fig. 3.11, after the maps of criteria (restrictions and factors) have been created and their corresponding weights have been designated to every other input layer.

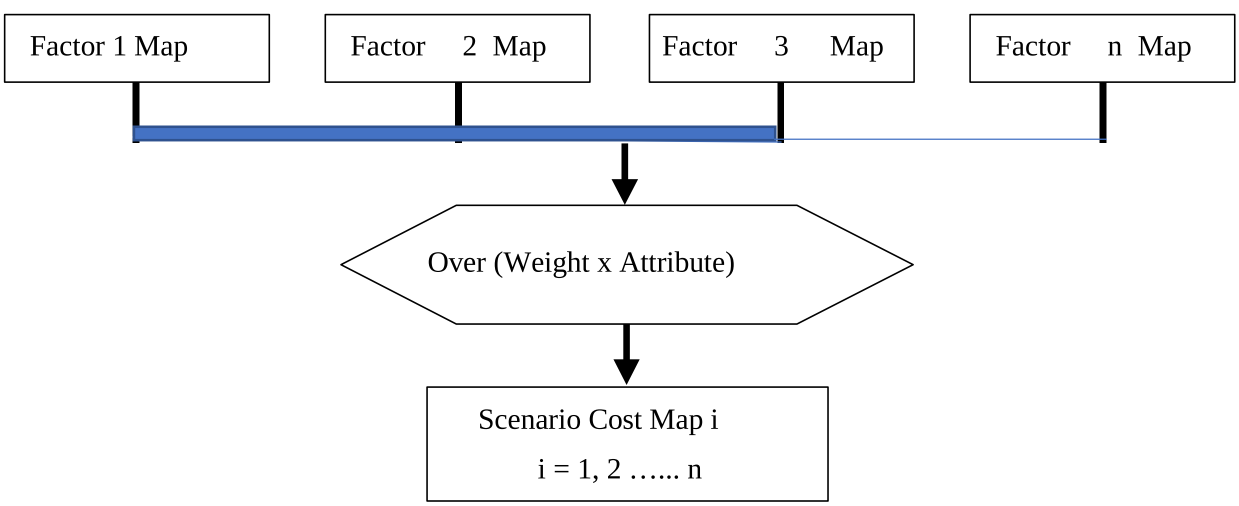

Figure 3.11 Diagram for producing cost maps based on various circumstances

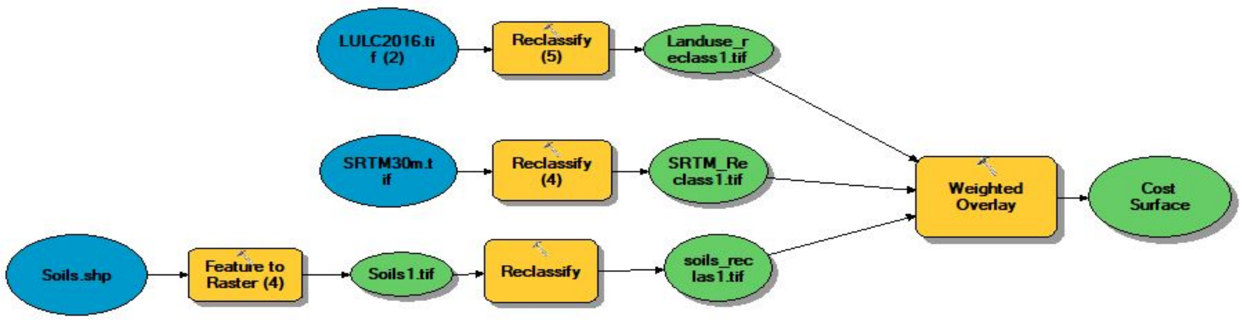

Figure 3.12 Weighted Overlay Model

3.9 Analysis of the Lowest-Cost Route

To accomplish this function properly, the least-cost path tool requires three inputs. The surface cost in raster format, the data source for the feature, then the details on the destination are major three elements. The cost surface was calculated according to criteria mentioned in the preceding section. Weighted Overlay tool was used to combine the cost surfaces of each factor to create a single cost surface (Figure 3.13).

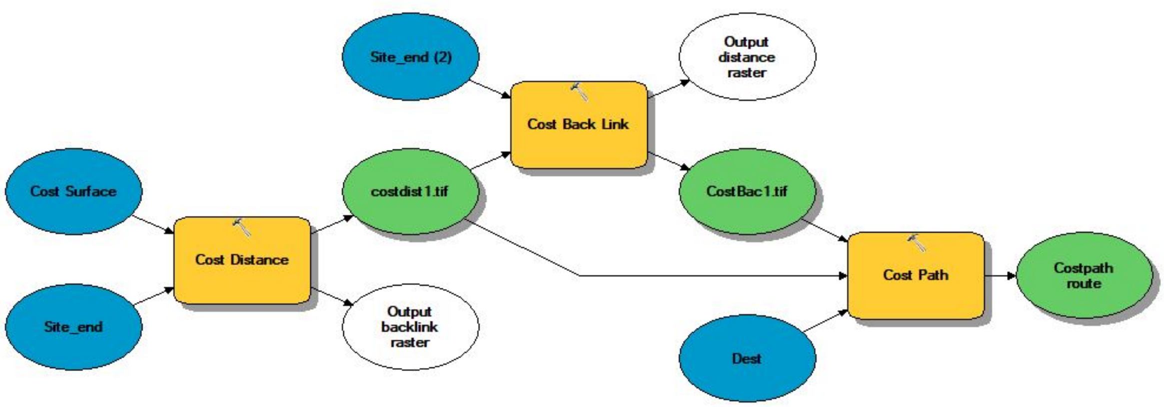

Figure 3.13 The Main Cost Surface Model's Workflow

The least-cost path analysis involves two steps: calculating the distance cost plus determining the path of least cost (as illustrated in Figure 3.13). Data source information, output distance raster and cost raster are the three inputs for the costs distance. The cost route, on the other hand, calls for four different inputs: destination input, the raster of cost distance, a raster cost of backlink, as well as a raster-output are all included. The cost distance was initially estimated with the inputs of the cost surface and start point datasets. The cost path used the cost distance output as an input. The cost of a backlink was received from the distance cost procedure as a additional the cost path's input. The end destination dataset was the 3rd input, while the fourth one was indeed the raster file created as a result. A raster image of the last suitable path was the final output. The Raster - Polyline converter was employed to transform a raster data into a dataset of features. In the end, to create a spline feature class, the raster acceptable route was utilized.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results

4.1.1 Creating a suitability map for GIS route selection

Following the collection and preparation of data, the data was reclassified on a scale that is proportionate from 1 - 5, with 1 representing ideally suited locations while 5 representing less suitable places. The categorized map makes it easier to differentiate between good and bad locations while deciding which highway route to take. Very high indicates more favorable places, whereas very low indicates areas that are unsuitable.

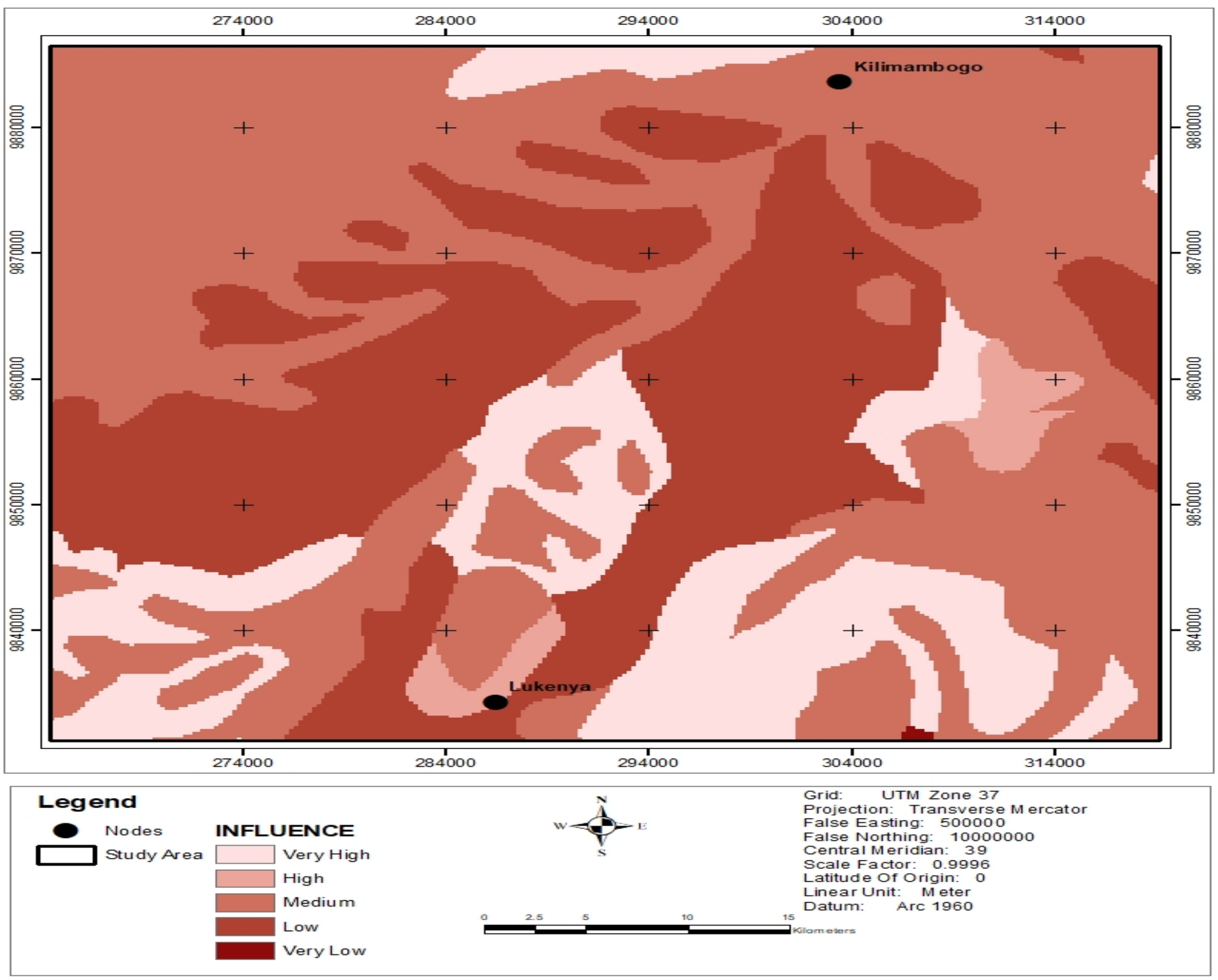

Figure 4.1 Soil Reclass

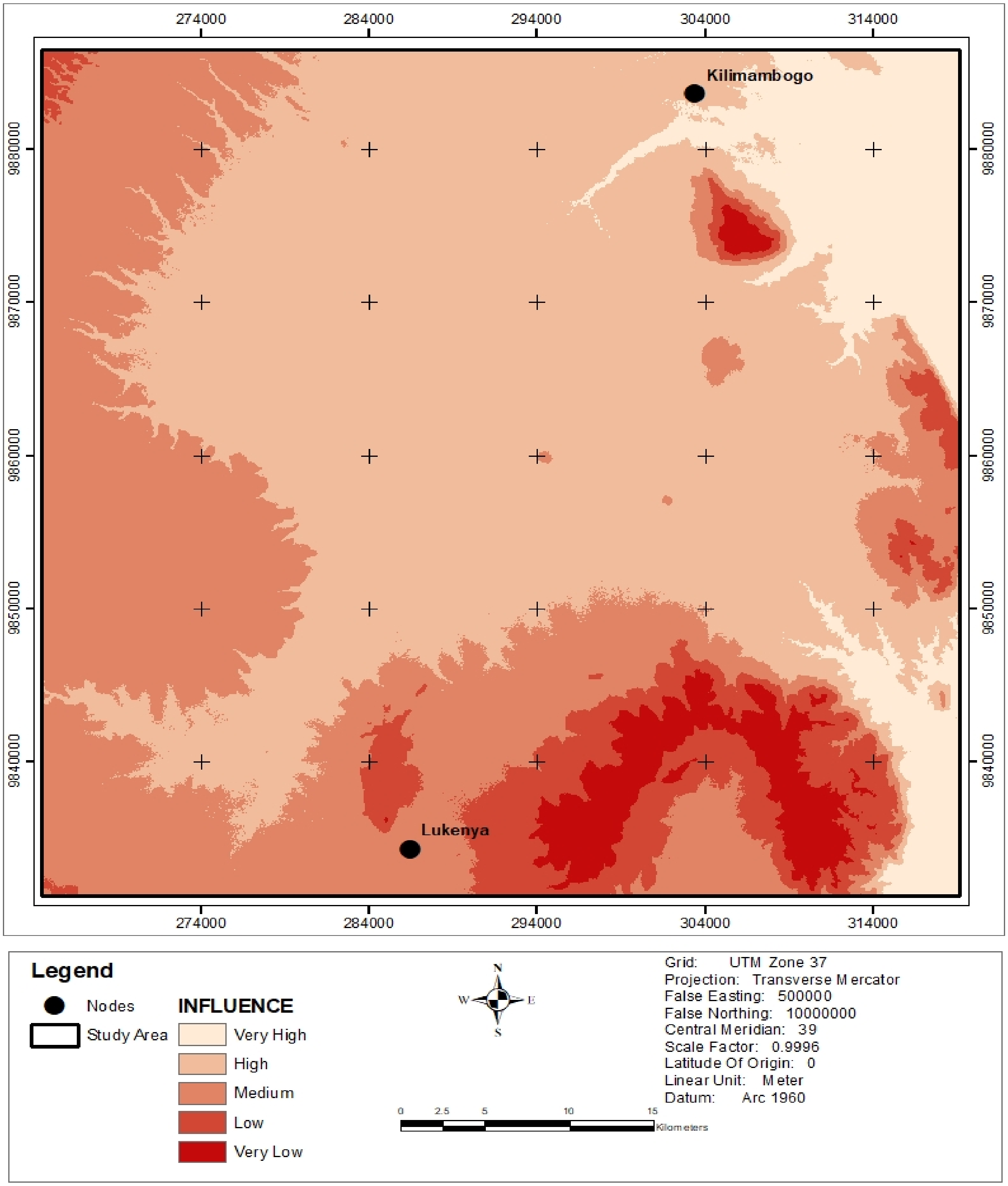

Figure 4.2 STRM 30 Reclass

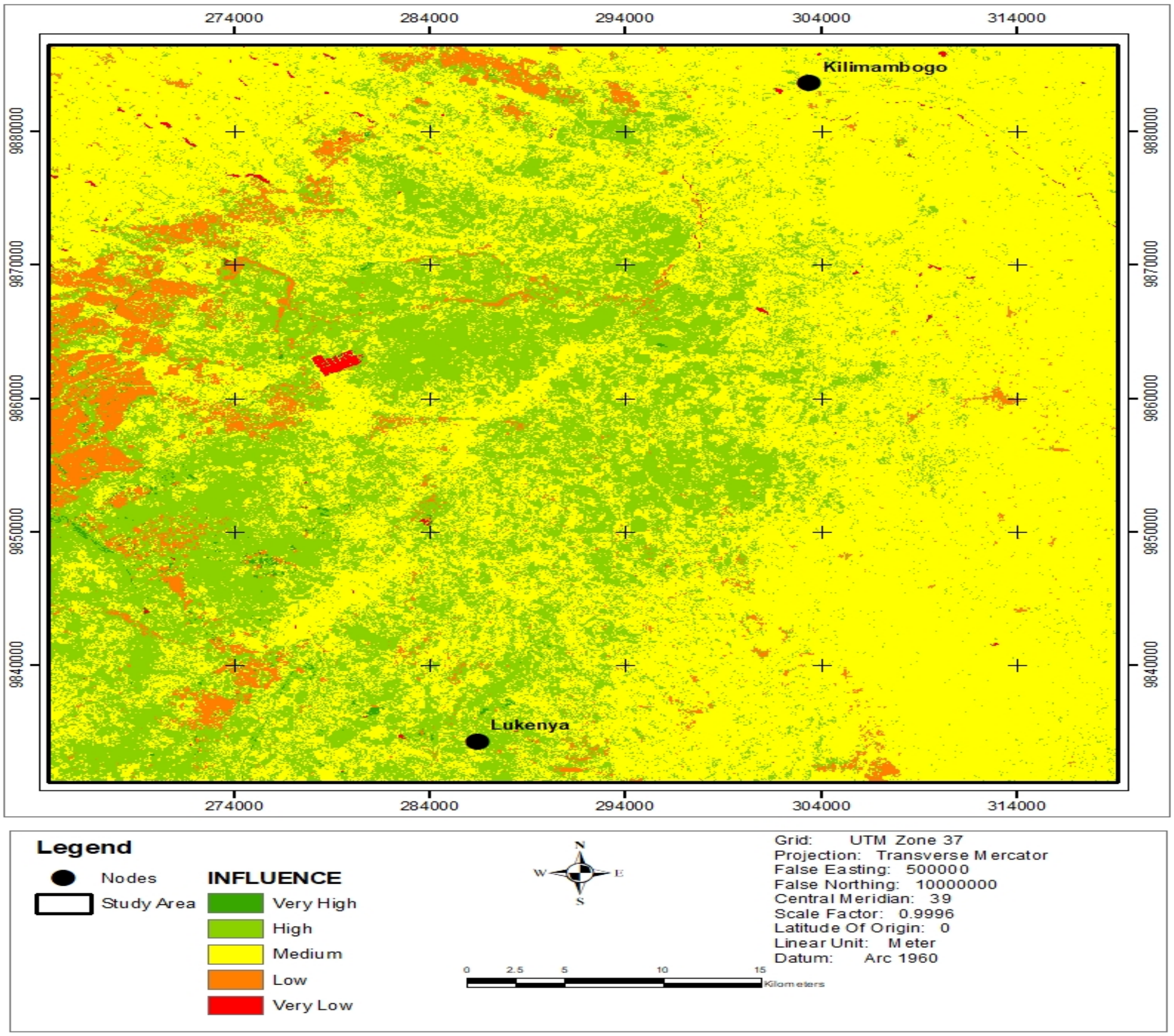

Figure 4.3 Land use Reclass

Following the weighing of the factors and formation of suitability surface based on the perceived significance of every set of criteria and the suitability index, the set of criteria maps were combined utilizing weight outcome from AHP, and a the last Spatial suitability map has been created employing a weighted overlays to acquire the a similar surface costs according to all norms. This technique can be developed with a Geographic Information System (GIS) that has capacities of overlaying, enabling the assessment for layers of criterion map to be mixed to generate the combined layered map.

The results in the investigation are displayed as maps with varied colored areas varying from high to extremely low when it comes to appropriateness for picking a route course Fig. 4.4. The red sections were labeled as excellent places, while orange portions was defined as good regions, brown portions was recognized as moderate areas, pale green sections were labeled as terrible locations, as well as dark green regions were marked as really problematic places in the generated weighted overlay maps. The initial cost surface for bypass routing took into account all three criteria (slope, soil, and LULC), with each criterion accounting for 33.3 percent of the overall cost value per cell. Figure 4.4 depicts a consistent cost surface over the research area as a result of the three elements mentioned in the previous sections.

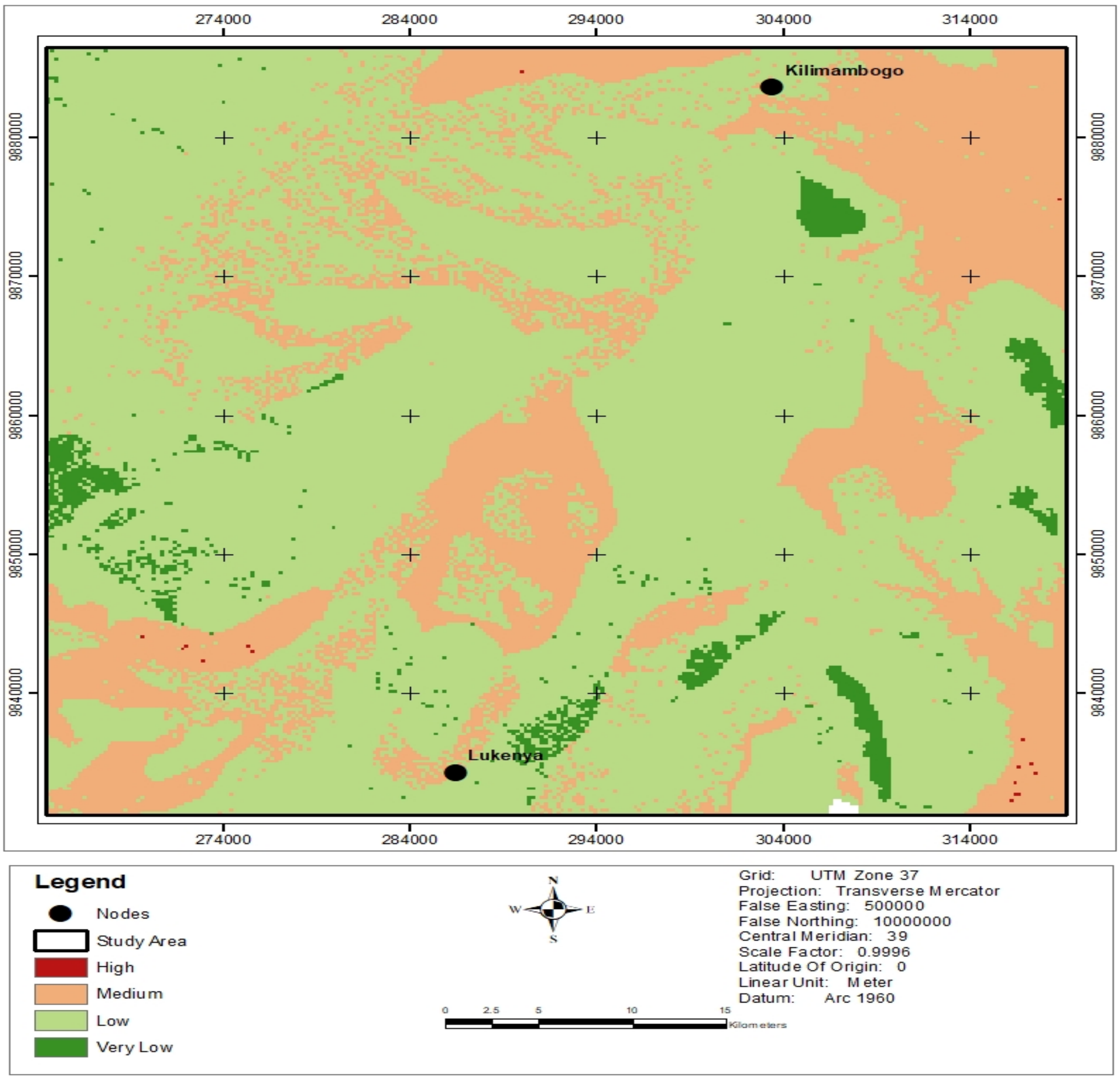

Figure 4.4 Suitability Map With Equal Weights

Figure 4.5 shows the path with the lowest cost determined from such a cost surface, with its length and relative cost value summarized in Table 4.2.

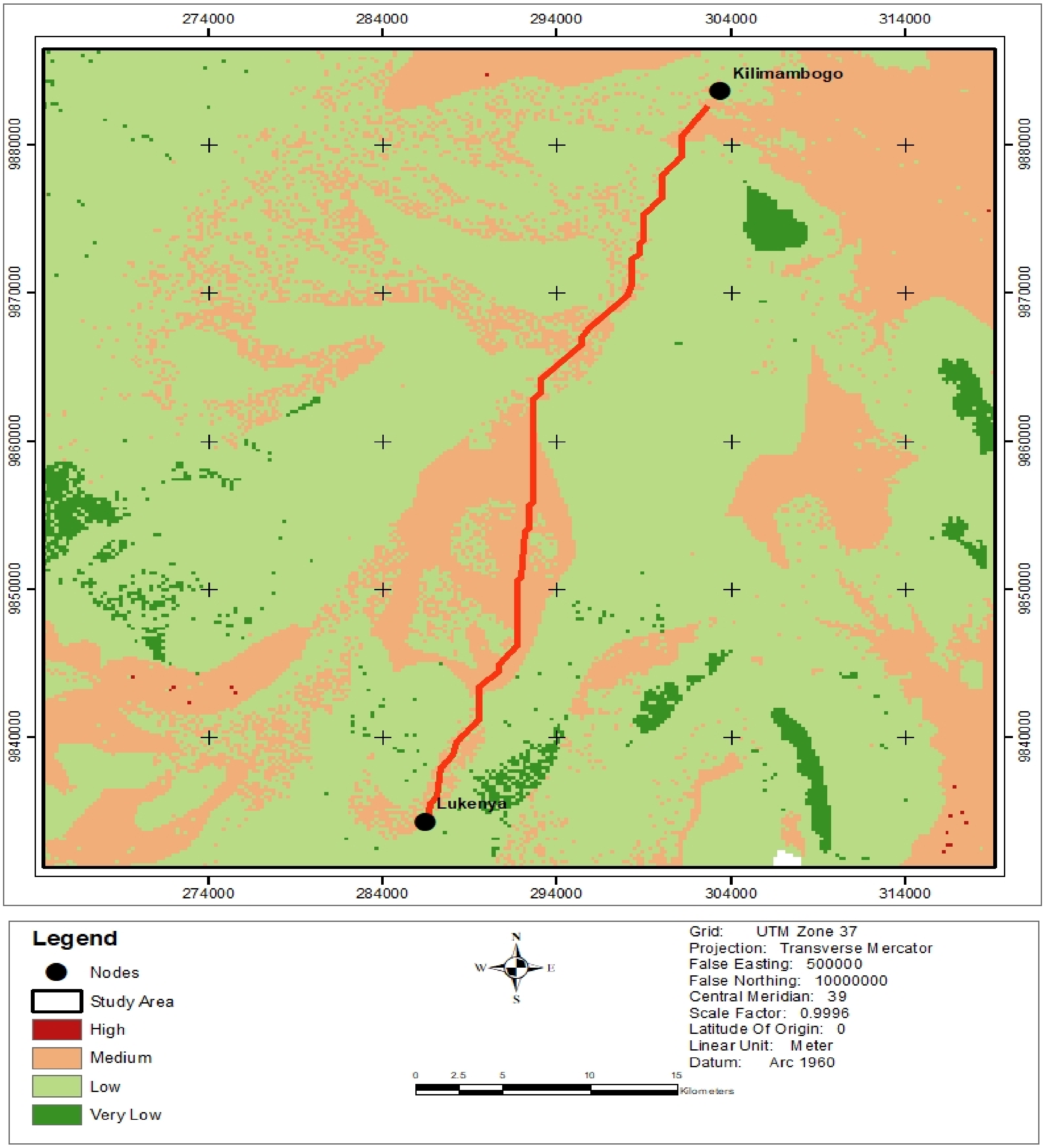

Figure 4.5 Route Generated By Equal Weighting.

The most important element is still finding the best route; to do so, all the constraints are considered in order to come up with various highways options, one among these is the most optimal road path. The optimum highway route might be identified by meticulously laying out a path that passes through colored zones denoted by a high level of suitability while minimizing the less suited, as shown by the weighted overlay map that produced.

4.1.2 Weighted Overlay output

With ArcMap software, you could use Weighted Overlay feature, multiple cost surfaces were built with particular weights assigned to each criterion. Table 4.1 shows the weight percentages for every weighting cost surface which was generated. Every Overlay with Weight surfaces generated highlighted one or even more criteria more than most to demonstrate how they impacted the least-cost approach.

Table 1.1 Weight Percentages for each Criterion

Cost Surface	**Criterion**	**Weight Percentage**
Weighted Overlay 2	The Slope	40%
	Soil type	12%
	Landuse/Landcover	48%
Weighted Overlay 3	The Slope	60%
	Soil type	12%
	Landuse/Landcover	28%

.

In scenario2 Weighting is different, preference given to Environmental and Social factors, Soil 12%, Landuse/Landcover 48% and Slope 40%.

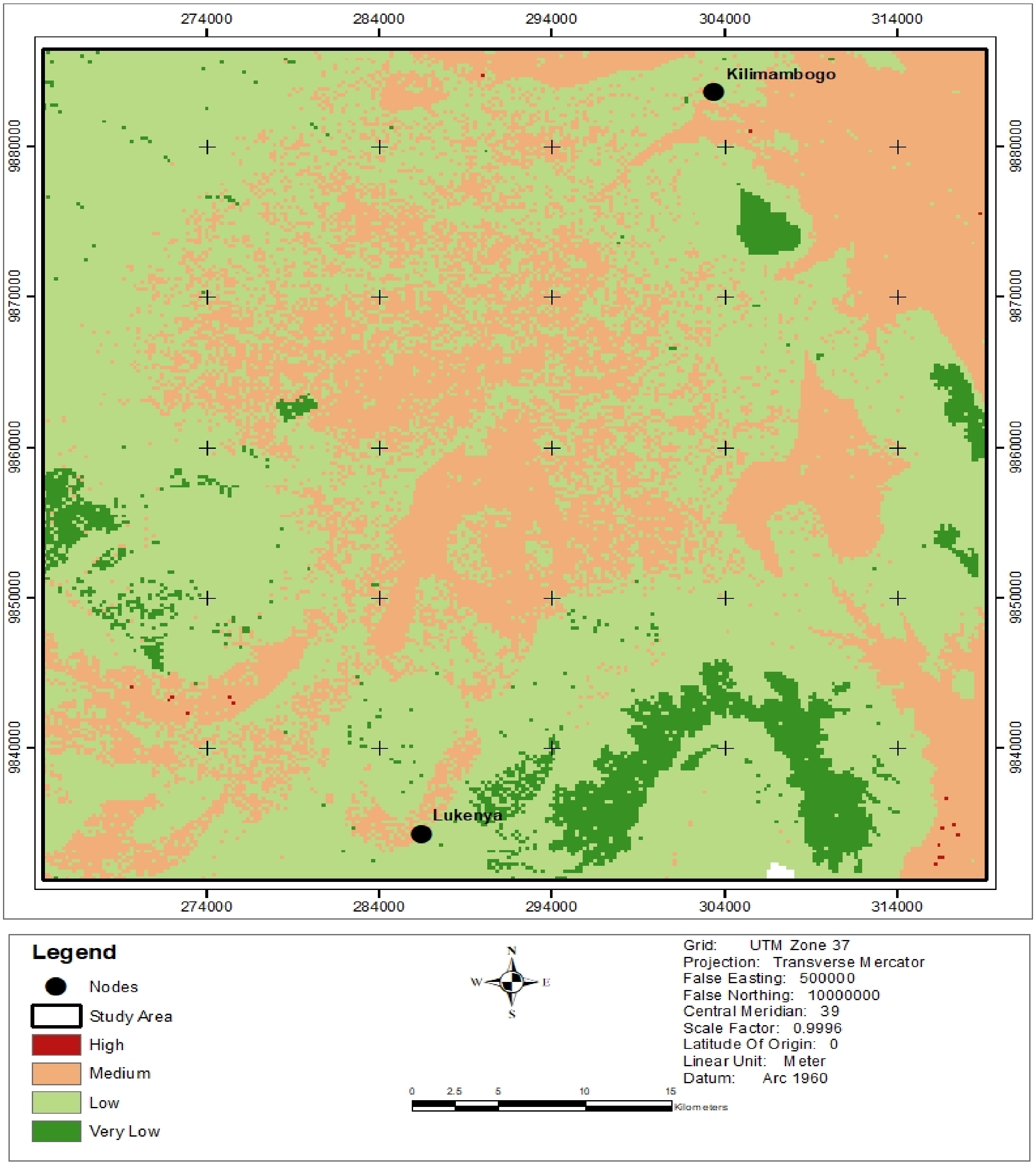

Figure 4.6 Suitability Map Based on Sustainable Development.

While in scenario3 Weighting is based on the engineering concept, whereby preference given to varriables as follows; Soil 12%, Landuse/Landcover 28% and Slope 60%. See the figure below.

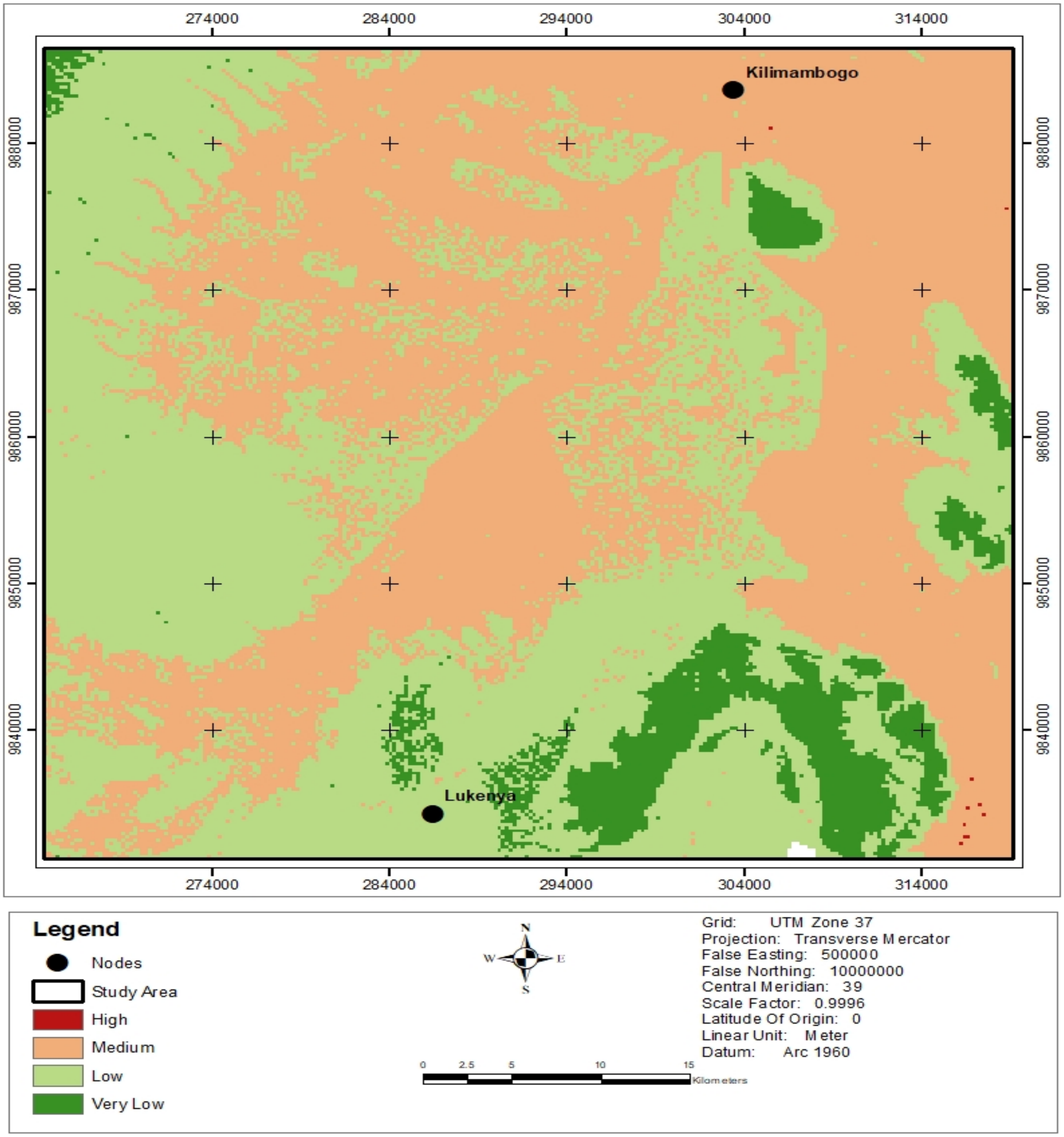

Figure 4.7 Suitability Map Based on Engineering Theme.

Figures 4.8 and 4.9 show the routes that were chosen for each of cost surfaces with a weighted overlay.Table 4.2 lists dimensions of each path as well as the related relative cost.

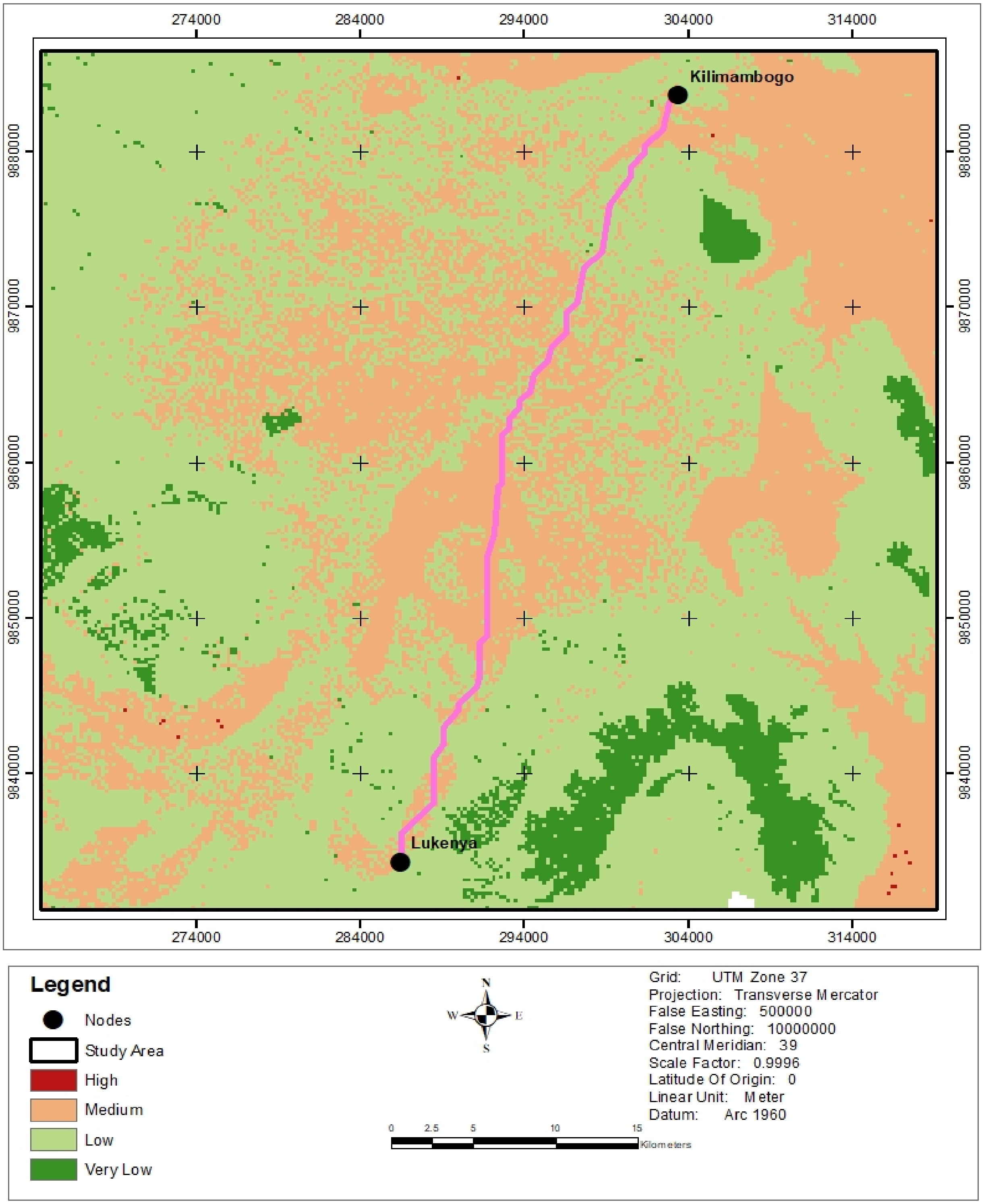

Figure 4.8 Map Showing Optimal Route.

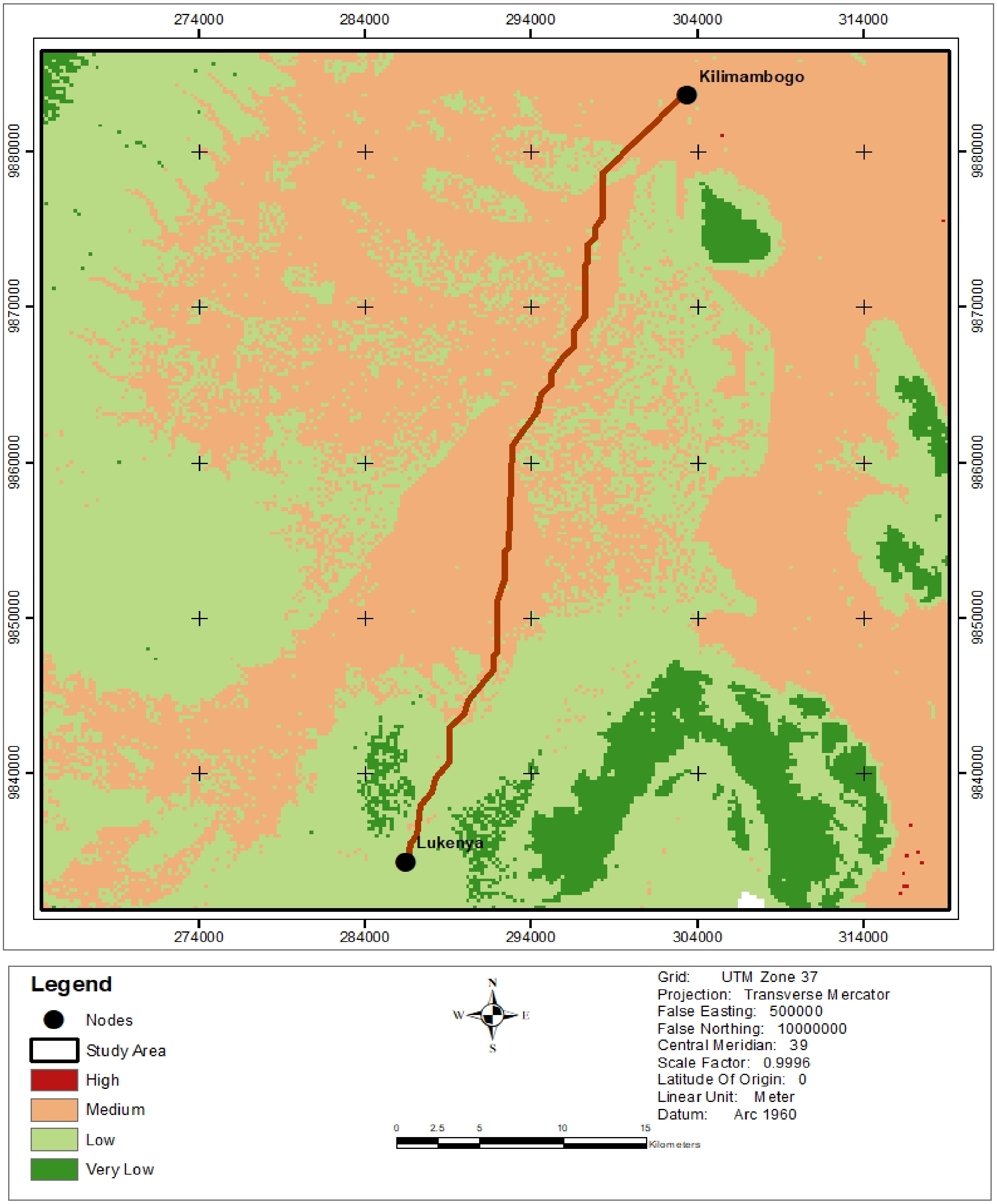

Figure 4.9 Map of Route Generated from Engineering Theme.

See the figure 4.10 for the final map of the suitable routes and optimal route.

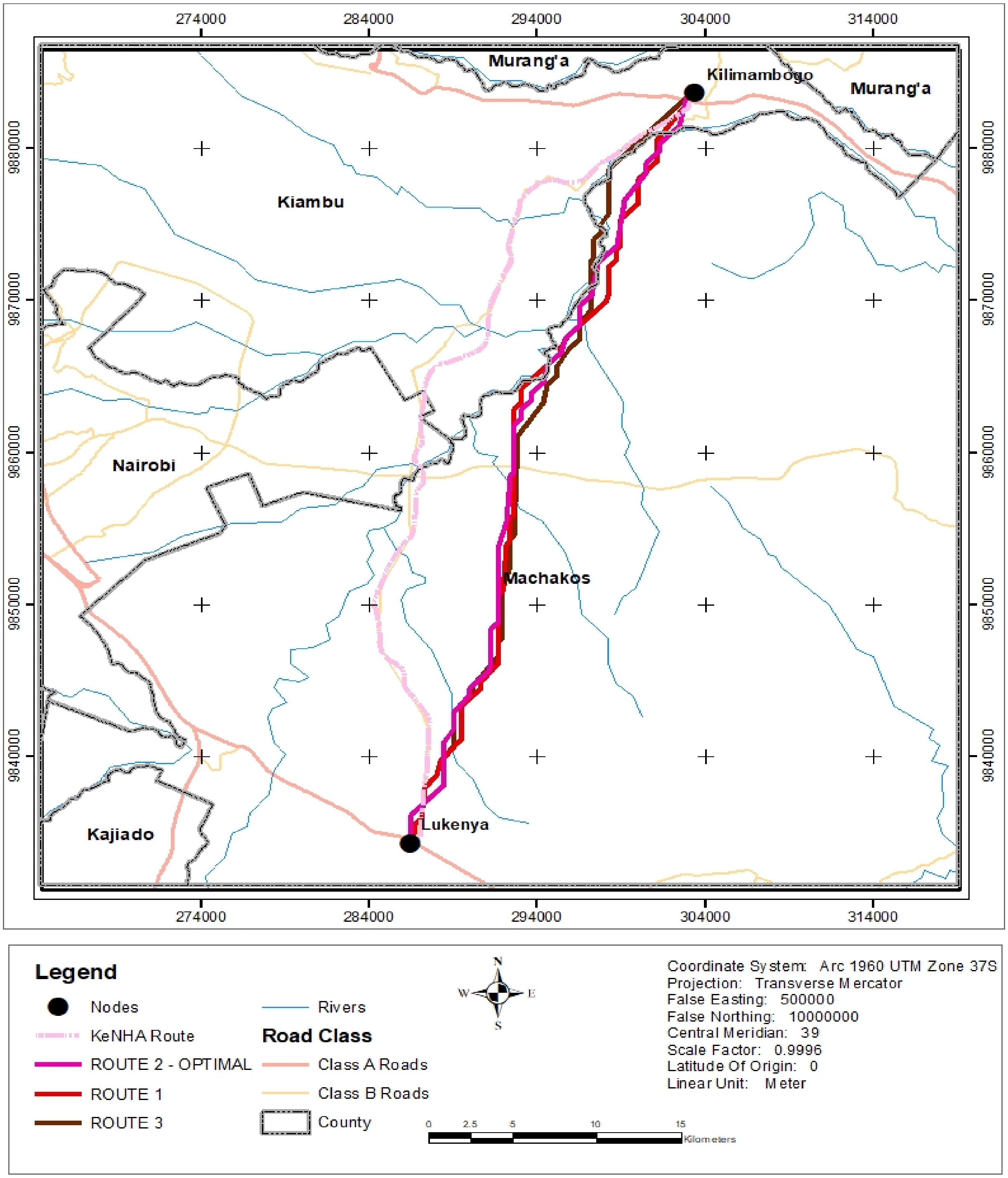

Figure 4.10 Final Map of all routes

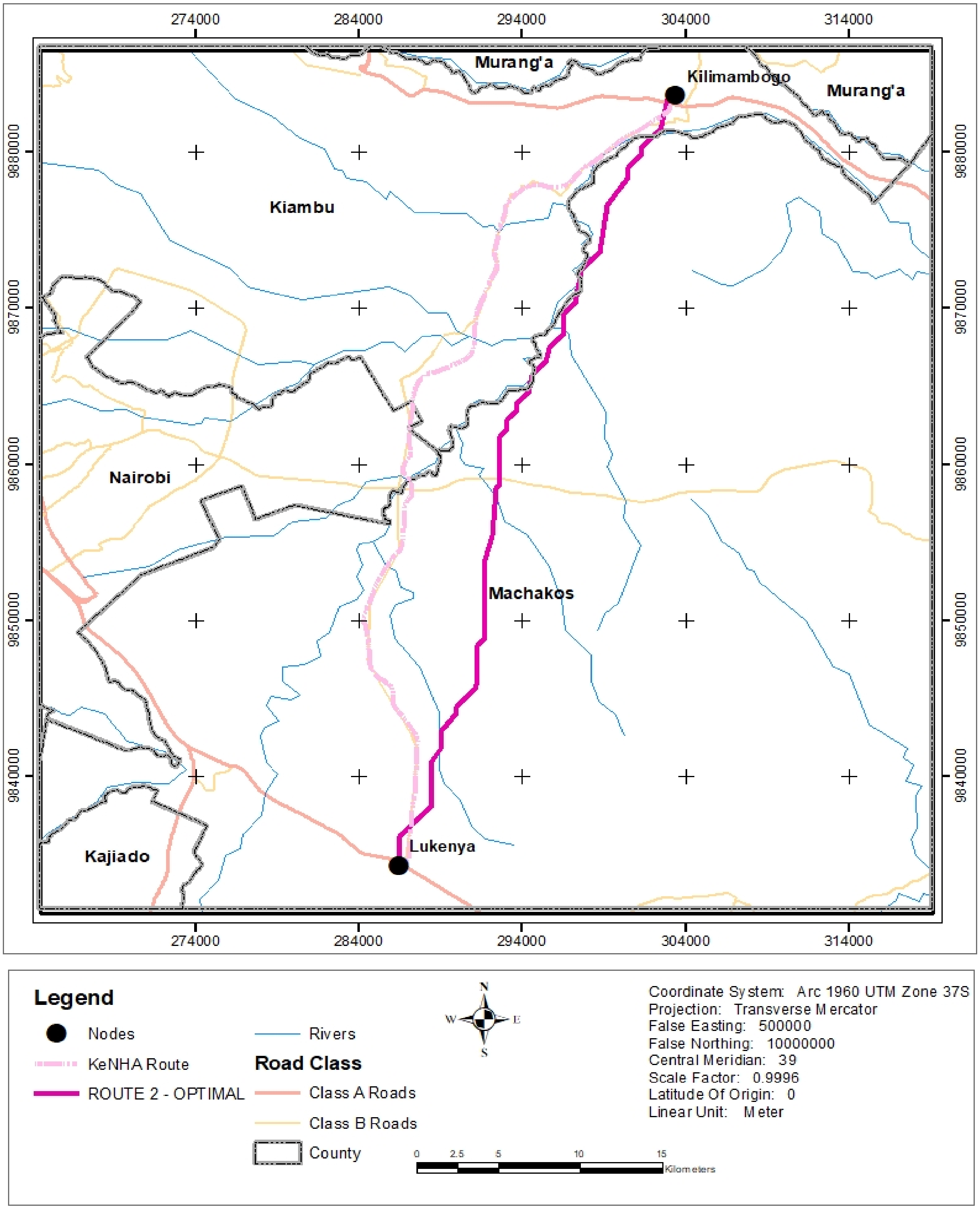

Figure 4.11 Optimal Route

Table 4.2 Comparison of the routes.

Route	Cost Surface	Length (km)	Number of bridges	Number of Junctions
Least-Cost Path	Weighted Over-lay 1	54.259	4	4
Proposed Path(KeNHA)		59.755	5	6
Difference		- 5.496	-1	-2
Least-Cost Path	Weighted Over-lay 2	54.695	6	4
Proposed Path (KeNHA)		59.755	5	6
Difference		-5.06	+1	-2
Least-Cost Path	Weighted Over-lay 3	54.859	5	4
Proposed Path (KeNHA)		59.755	5	6
Difference		-4.896	0	-2

4.2 Discussion

This study has employed GIS, appropriateness, and Least Cost Path (LCP) models to identify multiple route alignment options for a variety of circumstances. As a result, the suggested path must be technically, socially, and environmentally sound by avoiding steep to extremely steep slopes and keeping a moderate to significant rivers crossings, road crossings, farmland, cliffs, bodies of water, and National Parks and other protected regions. In this study, three potential paths were constructed using distinct scenarios. Route 1 is the least cost path in terms of distance, few bridges required, and junctions, with a length of 54.259 km. While route 3 is based on an engineering theme; rivers crossings and number of junctions required, is simply the most expensive route due to its length, which is 54.859 kilometers. Route 2 is the route that considers the environmental, social, and engineering themes with AHP weighting, has a distance of 54.695 km. This should be the best option because it considers the aspect of sustainable development hence the most optimal route. The current route in this research area is approximately 59.755 kilometers long, however the LCP model recommends a path that is 54.695 kilometers long. As an outcome, using suitability and LCP models proved quite effective in addressing the issues raised earlier for each of these paths.

The results of the weights showed that highway routing is important for environmental conservation and human life protection, while engineering aspects can be overcome utilizing technology. According to the suitability layer, the study region was a good routing zone. The developed model could indeed be utilized in a wide range of linear construction projects in Kenya. The dynamics of road routing were discussed in this research, as well as the interrelationships between engineering, ecological, and social elements in road routing.

The discovery that massive build-up bias of Overlay with Weight did not lead to maximum effectiveness came as a shockin view of the assertions made at the outset of the project. Because of the power that individuals might wield over construction sites that cross their private property, one might believe that the most densely populated zones would have been a main deciding aspect for where major projects like GEP are routed. While this component is undoubtedly important procedure of routing, it seems to be secondary in comparison to other factors. primarily soil type as well as topography, because it is not as firmly established as the other criteria. A mountainous or steep cliff valley cannot be repaired as readily as land could be purchased and buildings relocated to make it possible for the road to traverse a more acceptable terrain gradient. In this way, the construction company can alter this criterion to fit their goals when building the highway, while the natural environment and terrain impose a far stricter set of standards.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The objectives of this study were to identify the elements that impact road route location, to determine the optimal route between Lukenya and Kilimambogo through GIS analysis and finally to compare the optimal route with the Engineer's selected route. These have been achieved and it is concluded that:

- The weights assigned to diverse criteria culminated in a unique Eigen vectors that were normalized.
- The weights then were utilized to build a model, in deciding the right path.
- Slope, existing roads, rivers, type of soil, Landuse/Landcover, protected areas, and settlements were all taken into account.
- The Analytic Hierarchy Process was utilized to determine each factor's relative preferences in this research.
- The findings on topographic and physical elements led to the conclusion that there is a great need to maintain the environment by minimizing river divergence, vegetation removal, and extensive land excavation.
- Domain of soils, in this study revealed that the majority of the land was unsuitable for this route, with only a small fraction providing the best location.
- Settlements were given higher priority, meaning that people can pave the way for the road in order to attain the best route alignment.
- The significance of preserving vegetation, rivers, and choosing a route with a good slope is demonstrated by these findings.
- This study is limited in that it does not consider the economic and political implications.

5.2 RECOMMENDATIONS

From the study, it is recommended that:

- Additional aspects which were not included may be factored in to produce more precise outcomes.
- GIS, remote sensing, and AHP approaches should be utilized for determining the best paths in Kenya for the linear constructions.

- Policymakers and decision-makers must embrace the GIS's function as a decision-making device.
- To optimize the outcomes of this research, it is suggested that more research be conducted, with more datasets being added into the final model to provide the ultimate criteria.
- This project could benefit from the use of a web GIS application e.g ArcGIS Online or Esri Story Maps programs could be used to publish this project on the web for wider audience.
- A complete economic, social, environmental, and political evaluation of existing and to-be-built infrastructure projects is required in order to pick the best option.
- Obtaining high resolution STRM 10 was extra challenging, to address these issue, the government must prioritize the developments as well as updating geographical data with high resolution and infrastructural data available in the nation.

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