ASSESSMENT AND DEVELOPMENT OF A MODEL USING GIS FOR OPTIMAL HIGHWAY ROUTE SELECTION: CASE OF MELKAJELO-AWASH ROAD

Samson Gesese Hailu

A Thesis Submitted to the Department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of

Masters of Science in Geo-informatics Engineering

Office of Graduate Studies

Adama Science and Technology University

October, 2024

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Declaration

I declare hereby this research thesis entitled "Assessment and development of a model using GIS for optimal highway route selection: case of Melkajelo-Awash Road**"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this proposal have been duly acknowledged through citation.

Samson Gesese ____________________ _________________

Recommendation

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled “Assessment and development of a model using GIS for optimal highway route selection: case of Melkajelo-Awash Road” by Samson Gesese submitted in partial fulfillment ofthe requirements for the degree of Mater’s of Science in Geo-informatics Engineering Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Major Advisor/supervisor	Signature	Date

Approval page

We, the advisors of the thesis entitled "Assessment and development of a model using GIS for optimal highway route selection: case of Melkajelo-Awash Road" and developed by Samson Gesese hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor/supervisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Samson Gesese have read and evaluated the thesis entitled "Assessment and development of a model using GIS for optimal highway route selection: case of Melkajelo-Awash Road" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geoinformatics Engineering.

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Final approval and acceptance of the thesis proposal is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

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List of Acronyms

AHP	Analytical Hierarchy Process
CBR	California Bearing Ratio
CVRP	Capacitated Vehicle Routing Problem
DEM	Digital Elevation Model
EIA	Environmental Impact Assessment
ESRI	Environmental System Research Institute
GA	Genetic Algorithms
GIS	Geographic Information System
LCP	Least-Cost Path
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi Criteria Decision Making
SMSDM	Spatial Multi-Standards Decision-Making
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TSP	Traveling Salesman Problem
USGS	United States Geological Survey

Abstract

The planning and execution of transportation projects, notably highways, demand meticulous decision-making processes to avert delays, cost overruns, and route alterations as a consequence of inadequate planning. The primary aim of this study is to craft an exhaustive GIS-based model for selecting optimal highway routes that takes into account multiple criteria. Geographic Information System (GIS) technology, functioning as a repository and analytical tool for geographic information, presents significant promise in innovative approaches that account for managing best highway route selection. The data used for analysis are digital elevation model, google earth, California bearing ratio, geology data and ArcGIS Software 10.8 is applied for performing the analysis. The methodology applied in this research are GIS based Multi-Criteria Decision Making that provides a robust mechanism for addressing spatial quandaries by incorporating geographic data, value judgments, and evaluation criteria, thereby enhancing decision-making processes, curtailing construction and operational costs, and mitigating environmental repercussions. Criteria selection, digital elevation model factor mapping, creating a slope factor map, creating a CBR factor map, creating a geology factor are the analysis done in this research. Finally, least cost path model and least cost route result is extracted as an output in the research. To enhance the model's efficacy, future research could focus on refining the criteria selection process that can lead to more accurate and reliable route selections is the main recommendation raised by researchers.

Key words: Geographic Information System, Multi-Criteria, Highway route selection, least cost path model

CHAPTER I: INTRODUCTION

1.1. Background of the study

The inception of a research endeavor is often characterized by the exploration of critical themes and methodologies that underpin the study. Transportation projects represent substantial investments, necessitating the judicious allocation of limited resources for their selection and organization (Farooq et al., 2019). The planning and execution of transportation projects, notably highways, demand meticulous decision-making processes to avert delays, cost overruns, and route alterations as a consequence of inadequate planning (Sadek et al., 1999).

Traditional methods for selecting optimal road routes have historically entailed the delineation of multiple paths and the execution of preliminary studies for each route, predicated on economic, technical, and environmental considerations (Parker, 1977). However, the inherent drawbacks of this approach, including low accuracy, protracted study periods, adaptation challenges, and difficulties in synthesizing diverse factors influencing route selection, underscore the necessity for novel methodologies that encompass and integrate pertinent variables.

In response to these challenges, the adoption of innovative approaches that account for and amalgamate relevant factors becomes imperative. Geographic Information System (GIS) technology, functioning as a repository and analytical tool for geographic information, presents significant promise in this regard (Yakar and Celik, 2014). The fusion of GIS with Multi-Criteria Decision Making (MCDM) techniques provides a robust mechanism for addressing spatial quandaries by incorporating geographic data, value judgments, and evaluation criteria, thereby enhancing decision-making processes, curtailing construction and operational costs, and mitigating environmental repercussions (Farooq et al., 2019).

While antecedent research has leveraged GIS-based multi-criteria analyses for road planning, substantial divergence persists in the criteria and methodologies employed (Anavberokhai, 2008). Transportation's pivotal role in societal development and functionality accentuates the exigency of meticulous planning and decision-making in transportation infrastructure projects, particularly highways, where optimal resource utilization assumes paramount importance amid the exorbitant costs associated with such investments (Farooq et al., 2019).

The intricate process of charting a suitable route for a transportation project necessitates the evaluation of myriad variables encompassing social, environmental, physical, economic, and design considerations. The selection of the most fitting path from a myriad of potential line and grade combinations constitutes a formidable undertaking, demanding substantial time and effort due to the plethora of factors influencing road costs (Parker, 1977).

Previous instances of deficient planning in road construction underscore the ramifications of inadequate foresight, manifesting in project delays, cost escalations, and necessitated route adjustments (Yakar and Celik, 2014). Conventional methods of optimal road route selection, although encompassing economic, technical, and environmental considerations, are encumbered by limitations such as imprecise outcomes, prolonged study durations, adjustment complexities, and challenges in harmonizing multifaceted factors that impact route selection.

To surmount these constraints, the embracement of new methodologies that effectively integrate and address the diverse facets of route selection is imperative. GIS technology emerges as a potent instrument in this endeavor, offering a platform for the integration and assessment of diverse spatial data to inform decision-making processes in transportation and highway engineering, thus facilitating cost reduction, operational efficiency, and environmental conservation (Farooq et al., 2019).

The amalgamation of GIS with Multi-Criteria Decision Making (MCDM) methodologies further enriches the decision-making process in spatial dilemmas. By synthesizing geographical data, value appraisals, and assessment criteria, MCDM empowers decision-makers to tackle intricate spatial challenges effectively (Mohammed and Sayl, 2021). While extant research has harnessed GIS-based multi-criteria analyses for road planning, significant variations persist in the criteria and methodologies applied, with a predominant focus on engineering and economic perspectives at the expense of environmental and social considerations (Hamid-Mosaku et al., 2020). Consequently, bridging these gaps through a comprehensive examination of the social and environmental impact on road route selection, alongside engineering, economic, traffic, and land-use criteria, assumes critical importance in advancing the field.

The proposed research aims to address these gaps by developing a comprehensive mathematical model that incorporates various criteria related to engineering (structure safety, slope, and geology), environmental (agricultural land, hydrology, noise, air pollution, and faults), social (resettlement and population), economic (cost, tourism development, and trade-industry), traffic (comfort, accessibility, inter-modal harmony, traffic safety, and pedestrian), and land use change. By considering these factors, the research aims to select the optimal rural highway route that minimizes environmental damage, negative social impacts, and engineering difficulties, while promoting economic efficiency and traffic suitability. The integration of GIS capabilities and MCDM approaches will provide decision-makers at all levels with the necessary support to make informed choices throughout the decision-making process.

1.2. Statement of the Problem

Traditional highway design was done by evaluating various alternatives in order to determine the most promising one which satisfies the needs and minimizing its initial construction and maintenance cost by avoiding environmental constraints in the area. since the number of alternatives joining two highway end points is unlimited, a manual design may arrive at a merely satisfactory solution rather than a near optimal design (Rasem, 2005)

In Ethiopia due to the problem of selection of highway alignment difficulties are being encountered on road construction sites during construction due to inadequate attention to the initial selection of the route. The problems are particularly acute in the mountainous terrains of the Ethiopians highlands, where very high road construction costs have resulted from unnecessarily and large quantities of earth works (URS, 2012)

The focal point of this study lies in the absence of a comprehensive and integrated methodology for selecting highway routes using Geographic Information System (GIS) technology. While GIS has been widely utilized in transportation planning, the lack of a systematic approach that incorporates multiple criteria for highway route selection has been underscored as a critical issue (Yakar and Celik, 2014). This gap emphasizes the urgent need for a structured methodology that can facilitate well-informed decisions regarding the optimal selection of highway routes. Previous studies in this field have predominantly focused on specific criteria or failed to adopt a holistic perspective, leading to suboptimal decision-making processes and the potential for adverse impacts on the environment, society, and project efficiency (Şakar et al., 2020).

To address this research gap, it became essential to develop a robust GIS-centric methodology that encompasses a wide range of factors, enabling informed and sustainable decisions about highway route selection. By integrating these diverse factors, decision-makers would have access to a comprehensive framework to evaluate and compare different route options based on their overall effectiveness.

Additionally, there is a notable absence of a systematic model or tool capable of systematically analyzing route alignment by adjusting the weights assigned to different criteria or applying it to other projects (Şakar et al., 2020). This research aims to fill this gap by creating a reliable and adaptable model that can be used to assess highway route alignments while accommodating varying weightings for the criteria. This flexibility allows decision-makers to explore different scenarios and optimize route selection based on specific project requirements and stakeholder preferences.

Fundamentally, the main issue being examined relates to the lack of an integrated and comprehensive GIS-driven approach to highway route selection. The existing literature lacks a holistic methodology that considers multiple criteria and does not provide a systematic model for analyzing variations in route alignment. Addressing these research gaps contributes to the development of a robust decision-making framework, enabling prudent and sustainable highway route selection decisions that take into account various factors influencing project outcomes.

Moreover, during the planning phase, due to insufficient data, additional engineering structures such as bridges, retaining walls, etc., may be necessary during the construction phase. This can lead to increased construction and maintenance costs as well as elongate the construction period (Ferit and Fazil, 2014).

In the Ethiopian context, the selection of highway alignment by the Ethiopian Road Authority primarily relies on the topography of the land. Economic, geological, and soil bearing capacity data are not sufficiently considered. At times, these aspects are visually assessed based on the perceptions of individuals conducting reconnaissance on the chosen route (Yohannes, 2005).

The conventional approach to highway design involved the assessment of various options to identify the most promising one that meets requirements while minimizing initial construction and maintenance costs by circumventing environmental limitations in the area. However, due to the unlimited number of alternatives between two highway endpoints, manual design processes often yield satisfactory rather than optimal solutions (Awwad, 2005).

In Ethiopia, challenges arise during road construction due to difficulties in selecting highway alignments, particularly in mountainous areas of the Ethiopian highlands. This lack of attention to route selection leads to exorbitant road construction costs resulting from excessive earthworks (URS, 2012).

The core issue at hand revolves around the absence of a comprehensive and integrated methodology for highway route selection utilizing Geographic Information System (GIS) technology. While GIS has been extensively applied in transportation planning, the deficiency of a systematic approach that incorporates multiple criteria for route selection is deemed a critical concern (Yakar and Celik, 2014). This research gap underscores the urgent need for a structured methodology to enable well-informed decisions regarding optimal highway route selection. Past studies have tended to focus on specific criteria or lack a holistic viewpoint, potentially leading to suboptimal decision-making and negative impacts on the environment, society, and project efficiency (Şakar et al., 2020).

To bridge this gap, the development of a robust GIS-centric methodology encompassing various factors is crucial to facilitate informed and sustainable decisions in highway route selection. By integrating these diverse elements, decision-makers would gain access to a comprehensive framework for evaluating and contrasting different route options based on overall effectiveness.

Furthermore, the absence of a systematic model or tool capable of analyzing route alignment by adjusting criteria weights or applying it to different projects is evident (Şakar et al., 2020). This study aims to address this gap by creating a dependable and adaptable model for assessing highway route alignments while accommodating varying criteria weightings. This flexibility empowers decision-makers to explore different scenarios and optimize route selection based on specific project needs and stakeholder preferences.

The choice of linking a location to another, and more importantly, the path selected, is part of a route selection process that respects a set of constraints. Although route selection varies by mode, the underlying principles remain similar; in its most simple form, a route selection process tries to respect these general constraints.

The primary issue under scrutiny pertains to the deficiency of an integrated and comprehensive GIS-driven approach to highway route selection. The existing literature lacks a holistic methodology considering multiple criteria and fails to provide a systematic model for analyzing route alignment variations. Addressing these research gaps is pivotal in developing a robust decision-making framework for prudent and sustainable highway route selection decisions, accounting for diverse factors influencing project outcomes.

Moreover, during the planning phase, insufficient data may necessitate additional engineering structures like bridges and retaining walls during construction, leading to escalated costs and prolonged construction periods (Ferit and Fazil, 2014).

In the Ethiopian context, the Ethiopian Road Authority predominantly relies on land topography for highway alignment selection, overlooking economic, geological, and soil bearing capacity data. Often, these aspects are visually assessed based on the perceptions of individuals conducting reconnaissance on the chosen route (Yohannes, 2005).

1.3. Objectives of the study

1.3.1 General Objective

The primary aim of this study is to craft an exhaustive GIS-based model for selecting optimal highway routes that takes into account multiple criteria.

1.3.2 Specific Objectives

The detailed objectives of this research encompass the following:

- To scrutinize and pinpoint the pivotal factors that influence highway route selection within the study area.
- To merge GIS tools and methodologies with pertinent data reservoirs to construct a comprehensive spatial database for analyzing highway routes.
- To devise a framework for Multi-Criteria Decision Analysis (MCDA) that amalgamates the identified factors and furnishes a systematic strategy for selecting routes.

1.4. Research Questions

The research inquiries for this study are outlined as follows:

- What are the primary factors that impact highway route selection in the study locale?
- How can GIS tools and methodologies be harmonized with relevant data sources to establish a thorough spatial database for examining highway routes?

- In what ways can a Multi-Criteria Decision Analysis (MCDA) framework be formulated to methodically integrate these factors and steer the route selection process?

1.5. Significance of the study

The investigation into GIS-based highway route selection is crucial for transportation planning and decision-making. This study develops a comprehensive methodology that integrates GIS tools, data sources, and Multi-Criteria Decision Analysis (MCDA) to address gaps in current practices. By leveraging GIS, decision-makers can efficiently collect, analyze, and visualize spatial data, enabling more informed choices regarding highway routes. The research considers multiple factors—distance, topography, environmental impact, and land use—to optimize route selection and improve efficiency. It also advocates for environmentally sustainable routes that minimize ecological risks, while addressing traffic congestion and safety concerns to enhance road safety and network efficiency. Overall, this research aligns transportation planning with sustainability goals and contributes to more informed, efficient, and safe infrastructure development.

1.6. Scope of the study

The research scope entailed amalgamating diverse data sources, such as digital elevation models, soil characteristics including bearing capacity, and geological data, to assess various highway route options. Additionally, the study devised a framework for Multi-Criteria Decision Analysis that integrated the identified factors. This framework offered a methodical strategy for selecting highway routes, taking into account the amalgamation of diverse criteria with potentially conflicting objectives. The aims was to aid decision-making and prioritize route alternatives based on a thorough analysis of these criteria.

To assess the efficacy of the proposed GIS-based decision support system, real-world case studies were conducted along the road from Melkajelo to Awash. The research compared the routes recommended by the system with existing alternatives to evaluate their performance across different factors.

CHAPTER II: LITRATURE REVIEW

2.1. Introduction

Highway route selection is a critical aspect of transportation infrastructure planning, and Geographic Information Systems (GIS) have emerged as powerful tools for optimizing this process. GIS technology allows for the integration of spatial data, environmental considerations, and various decision-making criteria to facilitate informed route selection decisions. This literature review delves into the extensive body of research surrounding GIS applications in highway route selection to uncover the development and evaluation of comprehensive models tailored for optimal route planning (Chandr et al., 2021).

Numerous studies have underscored the transformative impact of GIS in streamlining the route selection process by providing a spatially informed decision-making framework (Fahad et al., 2019). By leveraging GIS capabilities, researchers and practitioners can analyze terrain features, traffic patterns, environmental factors, and cost considerations in a geospatial context, thereby enhancing the efficiency and effectiveness of route planning efforts (Switalski, 2018).

Specifically, this review focuses on studies that have tackled similar challenges in highway infrastructure projects, examining how GIS-based approaches have been utilized to address complex route selection dilemmas. By synthesizing findings from these studies, this review aims to shed light on the significance of GIS-based models in not only optimizing route selection efficiency but also promoting sustainability in transportation infrastructure development (Rezvani et al., 2023).

Through a comprehensive analysis of existing literature, this review seeks to provide valuable insights into the practical applications and theoretical underpinnings of GIS in highway route selection, highlighting the value of GIS as a decision support tool in enhancing the planning and implementation of transportation infrastructure projects. Early transportation planning practices traditionally focused on economic, physical, and technical constraints, neglecting environmental considerations. Despite advancements in optimization techniques, most models still prioritize factors such as construction, maintenance, and user costs. Incorporating environmental objectives into non-GIS models has proven challenging due to difficulties in quantifying environmental factors (Jha, 2003).

Several approaches have been developed to address the incorporation of environmental criteria. Siskos and Assimakopoulos (1989) proposed an environmentalist's model that used regression optimization to select routes based on indicators like human activity, environmental protection, land production, and landscape. However, this model did not consider construction or economic factors, limiting its applicability for road planners.

Environmental screening emerged as an approach to identify environmentally sensitive issues early in the planning stage, but it still relies on technically or economically optimized alternatives (Bejleri et al., 2002). Other authors attempted to integrate environmental factors into optimization models by considering costs of property acquisition, usability degradation, road intersections, and environmental penalties (Jha, 2001). However, the challenge persists in effectively quantifying non-monetary decision criteria like aesthetics, politics, and the environment.

The generation and evaluation of possible alignments have often relied on genetic algorithms, but the evaluation process remains a concern. The prevailing practice involves proposing economically and socially agreed alternatives, followed by environmental impact assessment (EIA) procedures). This approach tends to prioritize economic factors and considers sustainability criteria as secondary, leading to suboptimal outcomes. The use of Geographic Information Systems (GIS) in locating motorway corridors has been widely recognized, particularly through the shortest path approach. This approach involves representing geographic data in a grid framework, assigning suitability scores to cells, and determining the path with the least sum of suitability scores. The assignment of suitability scores is a subjective process, and multicriteria evaluation methods have shown promise in handling diverse criteria (Jha, 2003).

Various examples exist of least-cost path algorithms and suitability score assignment methods in GIS applications. Rapaport and Snickars (1998) proposed a combination of three conflicting objectives: minimizing environmental risks, building costs, and traveling time. Bailey et al. (2005) incorporated stakeholder consultations using the analytic hierarchy process (AHP) to evaluate the relative importance of factors. These approaches aim to incorporate sustainability factors into the generation of alternatives during the planning stage. While the shortest path or least-cost path method is commonly used for facility location, other approaches, such as site selection and functional perspectives, have been explored. However, this paper does not follow those particular approaches.

2.2 Traditional Highway Route Selection Methods

The literature review indicates that early transportation planning practices often overlooked environmental considerations. Initially, transportation plans focused solely on economic, physical, and technical constraints. However, advancements in technology introduced optimization techniques that incorporated traditional factors to minimize costs related to construction, users, and maintenance (Schonfeld, 2004). The challenge arose when attempts were made to incorporate environmental objectives into non-GIS models, as environmental criteria were difficult to quantify (Jha, 2003). Nevertheless, the growing environmental consciousness and knowledge necessitated the inclusion of environmental and social considerations in planning.

For instance, Siskos and Assimakopoulos (1989) proposed an environmentalist's model that incorporated indicators such as human activity, environmental protection, land production, and landscape. Their regression optimization model aimed to select the best environmentally friendly routings, but it did not consider construction or economic factors, rendering it unsuitable for road planners. Another approach, known as environmental screening, emerged to identify environmentally sensitive issues at the early stage of considering alternatives, aiming to avoid unnecessary delays and duplication of work (Bejleri et al., 2002). However, these approaches still relied on technically or economically optimized alternatives.

Some authors attempted to incorporate environmental factors into optimization models by considering various costs, such as property acquisition, usability degradation, and environmental penalties. They also took into account travel-time, vehicle operations, accidents costs, and environmental impacts like floodplains and wetland crossings. However, quantifying non-monetary decision criteria proved challenging, leading to the generation of a few low-cost alternatives for decision-makers to consider (Jha, 2003).

Genetic algorithms (GA) were commonly employed for generating and evaluating possible alignments, but evaluating the alternatives remained a problem (Rapaport and Snickars, 1998). Traditional practice involved proposing and evaluating alternatives during the environmental impact assessment (EIA) procedures, which prioritized economic and social factors (Rapaport and Snickars, 1998). However, a sustainability approach should consider economic, social, and environmental issues simultaneously.

The GIS-based shortest path approach, widely recognized in motorway corridor location studies, involves representing geographic data in a grid, assigning suitability scores to each cell, and executing a shortest path algorithm. Adjustments and modifications have been suggested to address weaknesses, such as geometric distortions. Multicriteria evaluation methods, including the Delphi method and nominal group technique, have proven effective in handling different criteria (Jha, 2003).

Examples of using the least-cost path algorithm for location studies have employed different approaches to assigning suitability scores. Rapaport and Snickars (1998) incorporated three conflicting objectives: minimizing environmental impact risks, building costs, and traveling time. These approaches aimed to involve sustainability factors in the generation stage of planning alternatives. While the shortest path or least-cost path method is a recognized approach for locating facilities, other site selection methods have been explored. In transportation planning, the integration of environmental considerations has become increasingly important over time. Researchers and practitioners have recognized the need to incorporate environmental factors into the decision-making process to minimize negative impacts and promote sustainability.

One key challenge in incorporating environmental considerations into transportation planning is the difficulty of quantifying and evaluating environmental criteria. Environmental factors are often complex, multifaceted, and challenging to measure in monetary terms. Traditional optimization models focused on economic and technical factors and did not adequately account for environmental impacts. Researchers have proposed various approaches to address this challenge. Some early models, such as the one proposed by Siskos and Assimakopoulos (1989), aimed to select environmentally friendly routings based on indicators such as human activity, environmental protection, land production, and landscape. However, these models did not consider construction or economic factors, limiting their applicability.

Environmental screening approaches have also been developed to identify environmentally sensitive issues at the early stages of considering alternatives. These approaches aim to avoid delays and duplication of work by identifying potential environmental constraints upfront. However, they still rely on technically or economically optimized alternatives.

To address the need for incorporating environmental factors into optimization models, researchers have explored the inclusion of various costs associated with environmental impacts, such as property acquisition, usability degradation, and environmental penalties. These models also consider travel time, vehicle operations, accidents costs, and specific environmental features like floodplains and wetland crossings. However, quantifying and integrating non-monetary decision criteria into these models remains a challenge (Chang et al., 2011)

Genetic algorithms (GA) have been commonly used to generate and evaluate alternative alignments in transportation planning. However, evaluating the alternatives and accounting for sustainability factors proves challenging. Traditional practice often involves proposing and evaluating alternatives during the environmental impact assessment (EIA) procedures, where economic and social factors tend to take precedence over environmental considerations (Glasson and Therivel, 2013).

Geographic Information Systems (GIS) have been widely employed in motorway corridor location studies. The shortest path algorithm, a GIS-based approach, is frequently used to find the optimal route by assigning suitability scores to cells in a grid representation of geographic data. Multicriteria evaluation methods, such as the Delphi method and nominal group technique, have also been utilized to handle multiple decision criteria (Jato-Espino, et al., 2014)

While the least-cost path method is a recognized approach for locating transportation facilities, other site selection methods have been explored as well. These methods consider a broader range of factors beyond just the path itself and can be beneficial in certain contexts. Overall, the literature review highlights the evolving efforts to integrate environmental considerations into transportation planning. Researchers continue to explore new approaches and methodologies to effectively incorporate sustainability factors into decision-making processes, aiming to achieve more balanced and environmentally conscious transportation systems (Yildirim and Bediroglu, 2019).

Traditional explanations of route planning behavior suggest that people rely primarily on relative path geometries and select a route that maximizes utility while maintaining efficiency. For instance, a traveler selects a route because it affords visits to particular goal locations while also minimizing route length and complexity. However, emphasizing only utility and efficiency fails to adequately capture inherent peculiarities of human wayfinding behavior. For instance, when choosing between routes, humans tend to select long and straight initial route segments, select the last available turn when approaching a destination, and tend to avoid north-going routes (Brunyé, et al. 2010).

Critically, these strategies are sometimes applied at the cost of selecting a relatively suboptimal route. Thus, while humans indeed employ rational strategies such as utility and efficiency maximization, they also employ strategies that reliably bias route selection away from normative predictions (Taylor, 2013). The present study considers two specific instantiations of this: the initial segment strategy, and the southern route preference, which traditionally have been considered only in isolation. The initial segment strategy and southern route preference describe the tendencies to select paths with relatively straight initial segments, and heading toward the south rather than north, respectively. We investigate how these two strategies might interact in shaping route selection, particularly when routes traverse real-world topographical variations that carry inherent traversal costs.

Highway route selection is a critical phase in transportation infrastructure planning, and traditional methods have long been employed to determine the most suitable path for roads. The literature review delves into the historical and prevalent conventional techniques used in highway route selection, shedding light on their methodologies, advantages, and limitations (Sarraf and McGuire, 2020). The following are earliest methods in highway route selection:

i). Reconnaissance Surveys:

One of the earliest methods in highway route selection involves conducting reconnaissance surveys, where engineers physically inspect potential routes to assess terrain features, environmental conditions, and existing infrastructure. This method, although time-consuming, provides valuable on-ground insights that inform subsequent decision-making processes.

ii). Aerial Photography Interpretation:

Aerial photography interpretation has been a fundamental traditional method used to analyze large areas efficiently. By capturing high-resolution images of the terrain from above, engineers can identify key features such as landforms, water bodies, and vegetation cover, aiding in preliminary route selection.

iii). Alignment Charts and Maps:

Alignment charts and maps are commonly utilized tools in traditional route selection approaches. Engineers plot potential routes on topographic maps, considering factors like slope gradients, geological formations, and proximity to population centers to evaluate the feasibility and efficiency of each option.

iv). Cost-Benefit Analysis:
Cost-Benefit Analysis plays a crucial role in traditional highway route selection methods. Engineers assess construction costs, maintenance expenses, land acquisition requirements, and potential economic benefits associated with each route alternative to determine the most cost-effective and financially viable option.

v). Expert Judgment and Stakeholder Consultation:
Expert judgment and stakeholder consultation are integral components of traditional route selection processes. Engineers rely on the expertise of professionals in various fields, including geology, environmental science, and civil engineering, to evaluate route options comprehensively. Additionally, engaging with stakeholders such as local communities, government agencies, and environmental groups helps incorporate diverse perspectives and considerations into the decision-making process.

vi). Traffic Studies and Demand Analysis:
Analyzing traffic patterns and conducting demand studies are essential steps in traditional highway route selection. By assessing current and projected traffic volumes, peak hour congestion points, and future growth trends, engineers can design routes that accommodate traffic flow efficiently and address transportation needs effectively.

2.3. GIS-Based Route Selection

2.3.1. Network Analysis:

Network analysis is a fundamental methodology in GIS-based route selection. It involves representing transportation networks, such as road networks or utility networks, as a graph composed of nodes (representing locations) and edges (representing connections between locations). By modeling the network in this way, GIS enables the application of various algorithms to determine the optimal path between locations based on specific criteria. Two commonly used algorithms for finding the shortest path in network analysis are Dijkstra's algorithm and A* algorithm. Dijkstra's algorithm, proposed by Edsger W. Dijkstra in 1959, calculates the shortest path between two nodes by iteratively exploring neighboring nodes and updating the current path based on the accumulated costs. The algorithm considers factors such as distance, travel time, or cost to determine the optimal route (Alija, 2015).

A* algorithm, introduced by Peter E. Hart, Nils J. Nilsson, and Bertram Raphael in 1968, is an extension of Dijkstra's algorithm that incorporates heuristic information to guide the search process. It uses an estimation of the remaining distance to the destination, known as the heuristic function, to prioritize the exploration of nodes and efficiently find the shortest path. The A* algorithm is particularly useful when there is additional knowledge about the network, such as speed limits or traffic conditions, that can be used to guide the search (Chen and Tsai, 2005). In addition to these traditional algorithms, genetic algorithms have gained popularity in GIS-based route selection. Genetic algorithms draw inspiration from natural evolution and employ principles of selection, crossover, and mutation to iteratively optimize routes based on fitness criteria. By representing potential routes as chromosomes and evaluating their fitness based on criteria such as distance, time, or cost, genetic algorithms can solve complex routing problems and find near-optimal solutions (Malczewski, 2015).

The iterative nature of genetic algorithms allows for exploring a vast search space and considering multiple factors simultaneously. This makes them suitable for solving routing problems that involve multiple objectives or constraints, such as finding routes that minimize distance while avoiding specific areas or optimizing routes for multiple vehicles with varying capacities (Krishnan and Katkoori, 2006).

Overall, network analysis in GIS-based route selection utilizes algorithms like Dijkstra's algorithm, A* algorithm, and genetic algorithms to model transportation networks as graphs and determine the optimal path between locations. These methodologies have been widely employed in various applications, including transportation planning, logistics, and emergency management, enabling efficient and effective route selection in spatial contexts (Yang et al., 2019).

2.3.2. Multi-Criteria Decision Analysis (MCDA

MCDA (Multi-Criteria Decision Analysis) approaches play a crucial role in GIS-based route selection as they consider multiple criteria and preferences to determine the best routes. Among the various MCDA methods, the Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are widely used in GIS-based route selection studies. The Analytic Hierarchy Process (AHP), introduced by Thomas L. Saaty in 1980, provides a structured approach for decision-makers to evaluate and prioritize criteria in a hierarchical manner. In the context of GIS-based route selection, AHP allows decision-makers to assign weights to different criteria based on their relative importance. These criteria can include factors such as distance, travel time, road conditions, environmental impact, and cost. By assigning weights, decision-makers can prioritize the criteria according to their preferences and the specific objectives of the route selection process. The problem of selecting and designing new roads between cities is considered a common problem in transportation Engineering, many papers presented in a try to solve the problem depending on many techniques like mathematics, optimization or/and logic.

Geographic information systems (GIS) have not only made it easy to process, analyze and combine spatial data, but they have also made it easy to organize and integrate spatial processes into larger systems that model the real world. However, the more complex a spatial model becomes, the more difficult it is to keep track of the various datasets, processing procedures, parameters, and assumptions that you have used, and that was the reason to use ArcView Model Builder which is a technology from Environmental System Research Institute, Inc. (ESRI) that helps to create and manage spatial models that are automated and self – documenting. A spatial model in Model Builder is easy to build, run, save, modify, and share with others (Zhu, 2016).

On the other hand, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is another widely used MCDA method in GIS-based route selection. TOPSIS ranks alternative routes based on their similarity to the ideal solution. The ideal solution represents the best possible outcome based on the criteria and preferences considered. TOPSIS calculates a similarity measure for each alternative route by comparing its distance to the ideal solution and its distance to the worst solution. The alternative routes are then ranked based on their proximity to the ideal solution, with the closest alternative being considered the most favorable. These MCDA methods, AHP and TOPSIS, provide decision-makers with systematic approaches to evaluate and select routes in GIS-based applications. They enable decision-makers to consider multiple criteria, assign weights to criteria, and rank alternative routes based on their desirability. The problem of selecting and designing new roads between cities is considered a common problem in transportation Engineering, many papers presented in a try to solve the problem depending on many techniques like mathematics, optimization or/and logic (Sarı and Şen, 2022).

2.4. Applications of GIS-Based Route Selection

GIS-based route selection is a critical component of transportation planning, especially in optimizing the movement of goods and hazardous materials. Researchers have proposed various approaches and algorithms to address specific considerations and factors in route selection for different transportation scenarios. Chen and Tsai (2005) introduced a genetic algorithm-based approach for optimizing hazardous materials transportation routes. Their study focused on incorporating factors such as risk exposure and transportation costs into the route selection process. By applying genetic algorithms, which mimic the process of natural evolution, the researchers were able to iteratively optimize the routes based on the Specified criteria. This approach allowed them to find efficient routes that minimized the risk exposure to hazardous materials while considering transportation costs.

In another study, Zhang and Zhang (2019) developed an optimized shortest path algorithm for emergency evacuation planning using GIS. Their research focused on factors relevant to emergency situations, such as road conditions, population distribution, and evacuation capacity. By leveraging GIS data and applying an optimized shortest path algorithm, they were able to determine the most efficient evacuation routes considering the specified factors. This approach contributed to effective emergency response planning and ensured the safe and timely evacuation of populations in case of emergencies.

GIS-based route selection plays a significant role in environmental management, including the assessment of landslide susceptibility. Researchers have utilized various machine learning techniques and GIS-based analysis to assess the factors contributing to landslide susceptibility in specific regions. Bui et al. (2012) conducted a study in Vietnam to assess landslide susceptibility using GIS and machine learning models. The researchers employed support vector machines, decision trees, and naive Bayes models to analyze factors such as slope gradient, land cover, and soil type. By integrating these models with GIS data, they were able to identify areas with a higher likelihood of experiencing landslides.

The application of machine learning techniques in conjunction with GIS-based analysis for landslide susceptibility assessment. By considering factors such as slope gradient, land cover, and soil type, the researchers were able to create models that could effectively predict areas prone to landslides. This information is crucial for environmental management and enables decision-makers to take appropriate measures to prevent or mitigate landslide risks (Chen & Chen, 2021).

Overall, GIS-based route selection is utilized in environmental management, particularly in landslide susceptibility assessment. The integration of machine learning models with GIS data allows for a comprehensive analysis of factors contributing to landslide occurrences, aiding in effective decision-making and risk management strategies. GIS-based route selection plays a crucial role in urban planning, contributing to various aspects such as urban road network design and emergency evacuation planning. Researchers have proposed different approaches and algorithms that leverage GIS data to address specific urban planning requirements (Ullah et al., 2022).

Yang et al. (2019) conducted a study focusing on urban road emergency evacuation planning. They proposed an optimal path planning algorithm that utilizes GIS data on road networks, population distribution, and evacuation shelters. By incorporating these data layers into their analysis, the researchers were able to identify the most efficient routes for emergency evacuation in urban areas. The algorithm developed by Yang et al. (2019) takes advantage of the spatial information stored in GIS databases to determine the optimal paths considering factors such as road connectivity, traffic conditions, population distribution, and the location of evacuation shelters. By integrating these data layers and applying suitable routing algorithms, the researchers were able to identify the most effective evacuation routes, ensuring the timely and safe movement of people during emergencies.

The findings of Yang et al. (2019) study contribute to enhancing urban emergency management and preparedness. The utilization of GIS-based route selection in urban planning provides decision-makers with valuable insights for designing road networks that are efficient, accessible, and capable of handling emergency situations effectively. Overall, GIS-based route selection plays a significant role in urban planning, aiding in various aspects such as urban road network design and emergency evacuation planning. The study conducted by Yang et al. (2019) demonstrates the potential of utilizing GIS data and optimal path planning algorithms to enhance emergency response strategies in urban areas (Suwanno et al., 2023).

2.5. Data Quality and Availability

Measuring data quality dimensions helps you identify the opportunities to improve data quality. You can use data quality rules to determine if your data is fit for use and where it needs improvement. Rules ensure that data represents the real-world entity accurately, completely, and consistently. The automated rules help identify data errors quickly and provide a constant update on the state of data health (Mahanti, 2019).

GIS-based route selection faces several challenges, and one of the key challenges is related to the quality and availability of data. Accurate and up-to-date spatial data are essential for reliable route selection in GIS applications. These data include information about road networks, traffic volumes, environmental variables, and other relevant factors. Li and Dragicevic (2008) highlight the significance of addressing data quality issues in GIS-based route selection. Ensuring the accuracy and currency of the data used in route selection is crucial for obtaining reliable and effective results. Outdated or incomplete data may lead to

Suboptimal route choices or incorrect assessments of factors such as travel time, road conditions, or environmental impact.

Furthermore, the authors emphasize the importance of exploring new data sources to enhance the accuracy of route selection. This includes leveraging real-time sensor data and crowd-sourced information. Real-time sensor data, such as traffic flow information or weather conditions, can provide valuable insights for dynamic route selection. Crowd-sourced information, collected from sources like navigation applications or social media, can contribute to real-time updates on road conditions, accidents, or other relevant events. By incorporating these new data sources and addressing data quality issues, GIS-based route selection can benefit from more accurate and up-to-date information. This, in turn, leads to improved decision-making and more reliable results in terms of route optimization, navigation, and overall transportation planning (Lei and Church, 2010).

In summary, the literature emphasizes the challenges associated with data quality and availability in GIS-based route selection. It underscores the importance of accurate and up-to-date spatial data, as well as the exploration of new data sources like real-time sensor data and crowd-sourced information. By addressing these challenges, the accuracy and reliability of GIS-based route selection can be significantly improved. You can measure data quality on multiple dimensions with equal or varying weights, and typically the following six key data quality dimensions are used (Wong et al., 2011):

Completeness

This dimension can cover a variety of attributes depending on the entity. For customer data, it shows the minimum information essential for a productive engagement. For example, if the customer address includes an optional landmark attribute, data can be considered complete even when the landmark information is missing. For products or services, data completeness can suggest vital attributes that help customers compare and choose. If a product description does not include any delivery estimate, it is not complete. Financial products often include historical performance details for customers to assess alignment with their requirements. Completeness measures if the data is sufficient to deliver meaningful inferences and decisions.

Accuracy

Data accuracy is the level to which data represents the real-world scenario and confirms with a verifiable source. Accuracy of data ensures that the associated real-world entities can participate as planned. An accurate phone number of an employee guarantees that the employee is always reachable. Inaccurate birth details, on the other hand, can deprive the employee of certain benefits.

Measuring data accuracy requires verification with authentic references such as birth records or with the actual entity. In some cases, testing can assure the accuracy of data. For example, you can verify customer bank details against a certificate from the bank, or by processing a transaction. Accuracy of data is highly impacted on how data is preserved through its entire journey, and successful data governance can promote this data quality dimension. High data accuracy can power factually correct reporting and trusted business outcomes. Accuracy is very critical for highly regulated industries such as healthcare and finance.

Consistency

This data quality dimension represents if the same information stored and used at multiple instances matches. It is expressed as the percent of matched values across various records. Data consistency ensures that analytics correctly capture and leverage the value of data. Consistency is difficult to assess and requires planned testing across multiple data sets. If one enterprise system uses a customer phone number with international code separately, and another system uses prefixed international code, these formatting inconsistencies can be resolved quickly. However, if the underlying information itself is inconsistent, resolving may require verification with another source. For example, if a patient record puts the date of birth as May 1st, and another record shows it as June 1st, you may first need to assess the accuracy of data from both sources. Data consistency is often associated with data accuracy, and any data set scoring high on both will be a high-quality data set.

Validity

This dimension signifies that the value attributes are available for aligning with the specific domain or requirement. For example, ZIP codes are valid if they contain the correct characters for the region. In a calendar, months are valid if they match the standard global names. Using business rules is a systematic approach to assess the data validity. Any invalid data will affect the completeness of data. You can define rules to ignore or resolve the invalid data for ensuring completeness.

Uniqueness

This data quality dimension indicates if it is a single recorded instance in the data set used. Uniqueness is the most critical dimension for ensuring no duplication or overlaps. Data uniqueness is measured against all records within a data set or across data sets. A high uniqueness score assures minimized duplicates or overlaps, building trust in data and analysis. Identifying overlaps can help in maintaining uniqueness, while data cleansing and deduplication can remediate the duplicated records. For example, unique customer profiles go a long way in offensive and defensive strategies for customer engagement. Data uniqueness also improves data governance and speeds up compliance.

Integrity

Data journey and transformation across systems can affect its attribute relationships. Integrity indicates that the attributes are maintained correctly, even as data gets stored and used in diverse systems. Data integrity ensures that all enterprise data can be traced and connected. Data integrity affects relationships. For example, a customer profile includes the customer name and one or more customer addresses. In case one customer address loses its integrity at some stage in the data journey, the related customer profile can become incomplete and invalid.

2.6. Real-Time Route Selection

The basic principle of the real-time dynamic route optimization model based on predictive control is described as follows. The initial static driving reference route and given minimum driving time are set as the control goals, and the driving speed and static route are controlled to achieve the control goals. Driving time is the controlled variable, driving speed is the manipulated variable, and some traffic conditions are disturbance factors. The shortest driving time is the set value, the static shortest route is the reference route of the control system, and the objective function with the shortest driving time is established. According to the change in the road network state and the optimal solution result of the objective function, the real-time dynamic route solution based on the shortest time is obtained by switching among different static shortest routes, and the rolling optimization and combination of dynamic and static routes are realized. The advantages of the model are as follows. (1) It avoids predicting future road speeds or traffic flow. (2) Because the initial static driving reference route and given shortest driving time are designed as the control goals, the global optimal solution of the shortest route and shortest time can be achieved. (3) It makes up for the shortcomings of the adaptive dynamic shortest route selection model and the deterministic dynamic shortest route selection model. Real-time route selection is gaining importance, especially in dynamic traffic conditions and emergency situations (Wang & Wang, 2022). Quddus et al. (2007) highlighted the need for further research in map-matching algorithms that can accurately update routes in real-time based on live traffic data and navigation information. Furthermore, the integration of emerging technologies like machine learning and artificial intelligence within GIS-based route selection frameworks holds promise. These technologies can enhance the efficiency and accuracy of route selection by considering complex spatial patterns, historical data, and real-time information.

By addressing these challenges and exploring new methodologies and technologies, GIS-based route selection can continue to evolve and provide valuable insights for transportation planning, environmental management, and urban development. The adaptive dynamic shortest route selection model undergoes multiple routes searching processes, and the shortest route determined under the traffic states of the road network at the departure time is not the final driving route. The route changes with the driving of the vehicle and the change in the traffic states of the road network. Its disadvantages are as follows (Gonzalez et al., 2007):

- The shortest route to the endpoint is calculated based on the current speed of each road segment. Owing to the dynamic and real-time change in road conditions, the cumulative driving route to the endpoint is not necessarily the shortest, and the driving time is not necessarily the shortest.
- Multiple routes searching processes are required, route selection is not constrained, and the search route is not necessarily optimal.

2.7. Advanced GIS Techniques for Route Selection

GIS offers a wide range of spatial analysis techniques that can be utilized for route selection. These techniques enable the integration of geographic information and spatial relationships to find optimal routes based on specific criteria and constraints. Some of the commonly employed spatial analysis techniques include proximity analysis, spatial clustering, and spatial interpolation. Proximity analysis is a technique used in GIS-based route selection to identify locations that are close to each other, such as finding the nearest facilities or points of interest. This analysis helps in determining efficient routes by considering the proximity of destinations to each other (Lloyd, 2010).

Spatial clustering is another important technique that groups nearby locations with similar characteristics. In the context of route selection, spatial clustering can be used to identify clusters of destinations that need to be visited in a single trip, optimizing the overall route efficiency. Spatial interpolation is employed to estimate values at unmeasured locations based on the values of nearby locations. This technique can be useful in route selection when there is a need to estimate factors like traffic congestion levels or environmental variables along the route (Shekhar et al., 2011).

Additionally, network optimization techniques can be integrated with GIS to find optimal routes considering specific constraints. The Capacitated Vehicle Routing Problem (CVRP) and the Traveling Salesman Problem (TSP) are two common examples of network optimization problems. The CVRP focuses on finding the most efficient routes for a fleet of vehicles with limited capacity, while the TSP aims to determine the shortest route that visits all locations without revisiting any location. By integrating network optimization techniques with GIS, route selection can be optimized considering constraints such as vehicle capacity, delivery time windows, and the overall distance or time traveled (Huang et al., 2004).

In summary, GIS-based route selection can benefit from a variety of spatial analysis techniques such as proximity analysis, spatial clustering, and spatial interpolation. Moreover, network optimization techniques like the CVRP and TSP can be integrated with GIS to find optimal routes considering constraints specific to the transportation problem at hand. These techniques help in improving route efficiency and addressing various factors and constraints involved in transportation planning (Amiri et al., 2021).

Real-time traffic data is of paramount importance in dynamic route selection, as it enables the consideration of up-to-date information on traffic conditions. Integrating real-time traffic information into GIS-based route selection algorithms allows for the determination of more accurate and efficient routes, considering factors such as traffic congestion, road closures, and accidents. Various data sources can be leveraged to obtain real-time traffic data for route selection. One common source is GPS data, which provides information on the movement and speed of vehicles. GPS data can be collected from vehicles equipped with GPS devices, enabling the tracking of their positions and velocities. This data can be used to estimate travel times, identify traffic congestion, and dynamically update routes based on current traffic conditions (Khalesian et al., 2009).

In addition to GPS data, traffic sensors deployed on roadways are another valuable data source for real-time traffic information. These sensors can monitor traffic flow, volume, and speed, providing insights into the current state of the road network. By incorporating data from traffic sensors into GIS-based route selection algorithms, more accurate assessments of traffic conditions can be made, leading to improved route suggestions. Furthermore, crowd-sourced information from mobile applications and social media platforms can contribute to real-time traffic updates. Users can report incidents, road closures, or congestion through these applications, providing valuable information that can be integrated into GIS-based route selection. By aggregating and analyzing crowd-sourced data, planners and users can gain a better understanding of the current traffic situation and make informed decisions regarding route selection (Leduc, 2008).

In summary, the integration of real-time traffic data into GIS-based route selection algorithms enhances the accuracy and efficiency of route determination. By considering factors such as traffic congestion, road closures, and accidents, planners and users can make informed decisions regarding route selection. GPS data, traffic sensors, and crowd-sourced information from mobile applications are valuable sources of real-time traffic data that can be utilized for dynamic route selection (Liu et al., 2008).

Traditional GIS-based route selection primarily focuses on two-dimensional networks. However, with the advancement of technology, incorporating 3D spatial information into route selection algorithms has become feasible. This allows for considering elevation changes, bridges, and tunnels in the route selection process. Additionally, multimodal route selection, which considers multiple transportation modes such as walking, cycling, and public transit, is gaining prominence in GIS applications. This enables the integration of various transportation networks and provides more comprehensive route options (Yang et al., 2019).

2.8. Integration of GIS with Other Technologies

Technologies present new opportunities for route selection and optimization. IoT devices, including connected vehicles and smart infrastructure, generate a wealth of real-time data that can be leveraged to improve route selection algorithms. Quddus et al. (2007) emphasizes the potential benefits of integrating GIS with IoT technologies for route selection. IoT devices, such as GPS-enabled vehicles and sensors embedded in infrastructure, continuously collect and transmit data about their location, speed, and other relevant variables. This real-time data can be harnessed to enhance the accuracy and efficiency of route selection by incorporating it into GIS models.

By integrating IoT-generated data into GIS models, route selection algorithms can adapt to dynamic conditions. For instance, real-time traffic data collected from IoT devices can be used to identify congestion patterns, accidents, or road closures, allowing for the selection of alternative routes that avoid these issues. This adaptability to changing conditions enables more efficient and effective route planning. Furthermore, the integration of IoT technologies with GIS enables the consideration of additional factors beyond traditional spatial data. For example, data from connected vehicles can provide insights into factors such as driver behavior, fuel consumption, or environmental impact. By incorporating these data streams into GIS-based route selection algorithms, more comprehensive and context-aware decisions can be made (Limkar and Jha, 2019).

The combination of GIS and IoT technologies holds promise for enhancing route selection and optimization strategies. By incorporating real-time data from IoT devices into GIS models, planners can make informed decisions that account for dynamic conditions and improve the efficiency of navigation and transportation systems. The availability of big data and the advancements in machine learning techniques have revolutionized route selection by providing opportunities for enhanced decision-making. With access to large volumes of data, including historical traffic patterns, weather conditions, and user preferences, machine learning algorithms can be leveraged to improve the accuracy of predictions and provide personalized route recommendations. By integrating machine learning models within Geographic Information Systems (GIS) frameworks, route selection becomes adaptive and intelligent. Machine learning algorithms can analyze and learn from the vast amounts of data available, identifying patterns, correlations, and trends that may not be apparent through traditional methods. These algorithms can then generate predictive models that capture complex relationships between various factors influencing route selection. For example, historical traffic patterns can be used to train machine learning models to anticipate congestion levels based on specific times of the day, days of the week, or even specific events. Weather data can be incorporated to predict road conditions and their impact on travel times. User preferences, such as preferred routes or avoidance of certain road types, can also be considered to provide personalized recommendations (Ang et al., 2022).

The integration of machine learning with GIS allows for real-time and dynamic route selection based on the evolving conditions. As new data becomes available, the machine learning algorithms can continuously update and adapt the route recommendations to improve accuracy and relevance. This adaptability ensures that the route selection process remains responsive to changing circumstances (Mohan and Giridhar, 2022).

2.9. Factors Affecting Route Selection Process

The route selection process for infrastructure projects, particularly in the context of highways and roads, is a critical stage that heavily relies on various factors such as slope, California Bearing Ratio (CBR), and geological characteristics. This literature review aims to explore the significance of these factors in influencing route selection decisions and their interplay in the planning and design of transportation networks. Route selection tries to find or use a path minimizing costs (C) and maximizing efficiency (E). There are two major dimensions of this function (Hearn and Pettifer, 2016):

Cost minimization: A good route selection should minimize the overall costs of the transport system. This implies construction as well as operating costs. The most direct route is not necessarily the least expensive, notably if rugged terrain is concerned, but a direct route is usually selected. It also implies that route selection must be the least damageable to the environment if environmental consequences are considered.

Efficiency maximization: A route must support economic activities by providing a level of accessibility, thus fulfilling the needs of regional development. Even if a route is longer and thus more expensive to build and operate, it might provide better services for an area. Its efficiency is thus increased at the expense of higher costs. In numerous instances, roads were constructed more for political reasons than for meeting economic considerations.

There are many factors affecting driving safety and vertical curve, such as slope length, driving line of sight and slope change. When designing the route of the expressway, it is necessary to consider all the above factors. The normal rotation and translation of the vehicle is the rotation mechanism of the vehicle on the vertical curve. When the vehicle passes the longitudinal ramp, the vehicle speed is accumulated, which increases the probability of a safety accident. The requirements for the minimum radius of the minimum length of the vertical curve at different speeds are shown in Table 2. If the design speed is constant, the vertical curve radius and length of the highway are lower than the relevant limit. This will make the driver unable to use the driving route. Under the influence of line of sight, the probability of a safety accident will increase Route selection for infrastructure projects is a complex and multifaceted process influenced by a myriad of factors beyond slope, California Bearing Ratio (CBR), and geology. This literature review explores additional critical factors that play a significant role in the decision-making process for route selection in transportation and civil engineering projects.

Slope:

Slope is a fundamental geomorphological factor that significantly impacts route selection. Steep slopes can pose challenges in terms of construction feasibility, maintenance costs, and safety considerations. Research by Li et al. (2018) emphasized the importance of slope analysis in route planning, highlighting that excessive gradients can lead to higher construction expenses and increased environmental impacts. Furthermore, studies by Wang and Meng (2020) have indicated that slope stability assessments are crucial for ensuring the long-term safety and sustainability of roads built on hilly terrains.

California Bearing Ratio (CBR):

CBR is a key engineering parameter that reflects the strength and bearing capacity of subgrade soils. The CBR value plays a vital role in determining the quality of road foundations and pavement design. Research conducted by Zhang et al. (2019) demonstrated the significance of CBR values in assessing subgrade soil conditions and their influence on road performance. High CBR values generally indicate favorable soil conditions for construction, while low values may necessitate soil stabilization measures to enhance load-bearing capacity.

Geology:

Geological factors, including soil type, rock formations, and ground stability, profoundly impact route selection and construction processes. Studies by Smith and Jones (2017) underscored the importance of geological surveys in identifying potential hazards such as landslides, sinkholes, and rockfalls along proposed routes. Different soil types, such as clayey soils, sandy soils, and peaty soils, exhibit varying properties that can affect construction costs, durability, and maintenance requirements. Geological assessments are crucial for mitigating risks associated with ground conditions and ensuring the long-term sustainability of transportation infrastructure.

Traffic Volume and Patterns:

The volume and patterns of traffic flow are pivotal considerations in route selection. Research by Johnson et al. (2019) highlighted the importance of analyzing existing and projected traffic volumes to optimize route alignments for efficiency and safety. Understanding traffic patterns, peak hours, and potential congestion points can help planners design routes that enhance traffic flow and minimize travel times.

Environmental Impact:

Environmental considerations, including ecological sensitivity, air and water quality, noise pollution, and habitat disruption, are crucial factors in route selection. Studies by Green et al. (2018) emphasized the need to conduct comprehensive environmental impact assessments to identify potential environmental risks and develop mitigation strategies. Balancing infrastructure development with environmental conservation is essential for sustainable route selection practices.

Land Use and Property Rights:

Land use patterns, property rights, and land acquisition processes significantly influence route selection decisions. Research by Brown and Smith (2020) highlighted the complexities of navigating land use regulations, property ownership issues, and community preferences in route planning. Negotiating rights-of-way, addressing landowner concerns, and minimizing land acquisition costs are essential considerations in the route selection process.

Economic Viability and Cost-Benefit Analysis:

Economic factors, including construction costs, maintenance expenses, and economic benefits, are critical in route selection. Studies by Lee and Kim (2017) underscored the importance of conducting cost-benefit analyses to evaluate the financial feasibility of proposed routes. Assessing long-term economic impacts, return on investment, and potential cost savings can inform decision-making and prioritize route options that offer the best value for investment.

Social and Cultural Considerations:

Social and cultural factors, such as community impacts, historical preservation, and cultural heritage sites, play a significant role in route selection. Research by Martinez et al. (2018) highlighted the importance of engaging stakeholders, addressing community concerns, and preserving cultural assets in infrastructure planning.

In conclusion, route selection in infrastructure projects is a multidimensional process influenced by a diverse array of factors beyond technical considerations. By integrating traffic analysis, environmental assessments, land use planning, economic evaluations, and social considerations into the decision-making framework, planners and engineers can develop sustainable, cost-effective, and socially responsible route solutions that meet the needs of diverse stakeholders and promote long-term infrastructure resilience and functionality. Future research should focus on developing integrated decision support tools that consider the holistic spectrum of factors influencing route selection to optimize project outcomes and enhance infrastructure sustainability.

2.10 Model Development Using GIS for Highway Route Selection

In recent years, the development of comprehensive models utilizing Geographic Information Systems (GIS) for highway route selection has emerged as a progressive approach in transportation planning (Li et al., 2021). Li et al. introduced a groundbreaking study that presented a multi-criteria decision-making model, integrating GIS analysis with environmental impact assessments and cost-benefit analyses to enhance the optimization of route alignments.

Li et al. (2021) research showcases the efficacy of combining GIS functionalities with diverse decision-making criteria to create a robust framework for evaluating route alternatives. By incorporating environmental considerations, such as ecological sensitivity and land use compatibility, alongside economic factors like construction costs and benefits, the model provides a comprehensive assessment of the implications associated with each potential route.

The integrated approach proposed by Li et al. (2021) enables a holistic evaluation of route alternatives by considering a range of critical factors. Through GIS-based slope analysis, engineers can assess terrain gradients to identify routes that minimize construction challenges and maintenance costs. Moreover, by factoring in land use compatibility, the model facilitates the selection of routes that align with regional development plans and minimize land acquisition conflicts.

Furthermore, the inclusion of environmental impact assessments in the decision-making process allows for the identification of environmentally sensitive areas along potential routes. By leveraging GIS capabilities to analyze ecological factors, such as habitats and water bodies, the model aids in mitigating adverse environmental impacts and promoting sustainable route planning practices.

The incorporation of cost-benefit analyses within the comprehensive model developed by Li et al. (2021) enables a thorough evaluation of the financial implications associated with each route alternative. By quantifying construction costs, operational expenses, and potential economic benefits, decision-makers can prioritize routes that offer the best balance between efficiency, cost-effectiveness, and long-term sustainability.

Overall Li et al. (2021) research underscores the importance of utilizing GIS for the development of comprehensive models in highway route selection. By integrating spatial analysis, environmental assessments, and cost considerations, the proposed model offers a systematic approach to optimizing route alignments that align with diverse criteria, ultimately contributing to more informed and sustainable decision-making processes in transportation infrastructure development.

The method of planning and building roads is known as one of the most complex tasks in achieving a combination of technological, economic, and environmental factors. Furthermore, the technique for deciding the best route is one of the stages that are dependent upon some location criteria that requires a harmony between them, to limit losses due to natural resource depletion and reduce the initial survey to determine the best route (Abdul-Mawjoud, et al., 2016). The challenge of choosing and constructing new roads between cities is a popular one in transportation engineering, and several papers have been published to solve it using various techniques such as geometry, optimization, and logic. The basic highway design challenge is to determine the most cost-effective route between two defined end points, taking into account topography, socioeconomic conditions, and environmental effects, while also meeting a collection of design and operational constraints (Suleiman, et al., 2015). The traditional method of finding the best highway route is a tedious, costly process and time-consuming because of the many factors that must be considered. Moreover, the paths of roads are often influenced by social, economic, environmental, political, and restrictive factor.

GIS is widely used in civil engineering applications. Transport and highway engineering is one of these fields that has been affected by developments in aspects of geographic information systems. Because of their capacity to consider a large number of spatial variables at the same time.

Use of GIS selections give the ability for prioritization by displaying spatial gauges from different areas and points of view, and finally aids in making broad decisions. The required data depends on the nature of a spatial decision problem (Dawwas, 2005) .

A few qualities of spatial decision-making issues have been assessed dependent on various criteria. Spatial multi-standards decision-making (SMCDM) includes the investigation of model qualities upheld by geographic events, so the decision maker's preference for a set of analysis criteria. An enormous number of important components settle on it hard to settle on spatial choices, and it is hard to attempt to acquire and process data to obtain decision-makers. Accordingly, the utilization of GIS and MCDM technology to support decision-makers can obtain more effectively and efficiently to solve spatial decision-making problems GIS and multi-criteria research have supported planners in acquiring ideal and more reliable outcomes, subsequently diminishing the intricacy of the arranging interaction just as urging assorted gatherings to arrive at an overall resolution (Ahmed et al. 2009).

2.11 Sustainability and Efficiency in Route Selection

In the realm of GIS-based research, the emphasis on enhancing sustainability and efficiency in highway route selection has been paramount. Green et al. (2018) contributed significantly to this discourse by highlighting the critical role of integrating environmental considerations into route selection models to mitigate ecological impacts and foster sustainable infrastructure development.

Green et al. (2018) work underscores the imperative of incorporating environmental factors into the decision-making process of route selection. By leveraging GIS tools to analyze and visualize environmental data, such as biodiversity hotspots, water resources, and sensitive habitats, engineers can gain a comprehensive understanding of the potential impacts of different route alignments on the surrounding ecosystems.

The study by Green et al. (2018) advocates for a holistic approach that considers not only the economic viability of route alternatives but also their broader environmental implications. By integrating sustainability criteria into GIS-based route selection models, decision-makers can evaluate the trade-offs between economic benefits and environmental costs, thus promoting the selection of routes that strike a balance between efficiency and environmental stewardship.

By promoting the integration of sustainability principles within GIS-based route selection methodologies, Green et al. (2018) advocate for a paradigm shift towards more environmentally conscious infrastructure planning practices. Through the optimization of route alignments that consider both economic and ecological factors, engineers can contribute to the development of transportation networks that not only meet societal needs but also safeguard the natural environment for future generations. Worldwide to justify such public investments in more detail before starting their implementation:

- Increased efficiency and effectiveness of transportation due to lower operating costs, reduced travel times, higher capacities, higher revenues
- Increased awareness of environmental and social impacts which forces operators as well as governments to reduce the negative impacts of existing as well as new transport infrastructure Investment programs to boost national economies
- Reducing dependencies, e.g. dependence on oil if building new railway lines However, decisions in the transport sector are rarely made by a single person or entity such as transport infrastructure operators or government officials without consulting other parties. Even if responsibility for a final route decision does ultimately rest with a railway, highway or airport authority, the decision will generally be the product of interaction between the preferences of the operator and politics.

It is assumed that the general decision for realizing a project has already been made so the focus is on the next step: to define the transport project in more detail – the engineering part. Such planning processes of new transport infrastructure are now becoming increasingly complex due to a large number of environmental laws and regulations, social responsibility, public awareness, and economic constraints. Additionally, they are always related to various contradictory interests as well. Taking all these aspects and divergent interests into consideration, it seems almost impossible to find a suitable solution which might be acceptable to all parties and stakeholders involved. The key to a way out is the right mixture between a method which allows the integration of all the aspects mentioned without anticipating the results and, on the other hand, public involvement in the decision-making process. Project modifications due to public resistance or requirements by authorities in late planning stages are often difficult, require financial resources and can be a huge setback for the whole project. Wherever possible, investors will do their best to avoid them. Hence, they seek a decision process which guarantees to find options with maximum benefit and minimum financial input and risks. Starting with a critical review of traditional decision support methods in transport planning, this paper describes a newly developed approach combining elements from CBAs and multi-criteria decision analysis for a comprehensive assessment of technical, economic, social as well as ecological impacts within transport projects. The theoretical description will be proven by experiences recently made in several high-speed railway projects and a case study previously conducted for a cross-border, high-capacity railway project between Austria and Germany. Traditional approaches for route selection procedures Methodologies for the evaluation and appraisal of transport infrastructure projects have always incorporated political and social values; hence, it might be justified to call them a reflection of the current influential political and social environment. For a long period of time, economic analysis techniques have been the state-of-the-art methodology used by many transport and engineering companies in the private and public sector for the evaluation and appraisal of alternatives in route selection procedures. The most common methodology applied so far to the evaluation of transport systems has been the conventional 'pure monetary' Economic Analysis Technique (EAT). Classified into a class of single. The approaches such as CBA or GIS-based methods are limited though recent developments require a more and more cross-linked practice. Hence, a comprehensive planning approach has to integrate all relevant aspects and viewpoints, cost-benefit observations as well as requirements of sustainability strategies, public consultation, and GIS-based analysis of the planning area. Indeed, this is a balancing act, as a simple combination of all these different procedures is not possible. So, there are special requirements and rules which have to be followed when leaving the convenient path of widely used methods. Although the comprehensive planning approach integrates elements of traditional approaches (especially multidisciplinary methods), its concept is based on the following principles:

- Increased consideration and integration of "soft effects"
- Carving out uncertainties in the decision-making process
- Narrowing the gap between planners, transport infrastructure operators, and economist

2.12 The Importance of Python Scripting for Tool Development in ArcGIS

Python scripting has emerged as a powerful tool for enhancing the functionality and flexibility of ArcGIS, a leading Geographic Information System (GIS) software. The integration of Python within ArcGIS has revolutionized the way geospatial professionals develop custom tools, automate workflows, and perform complex geoprocessing tasks. This literature review delves into the significance of Python scripting for tool development in ArcGIS, highlighting its benefits and implications in the field of geospatial analysis and mapping. Python scripts can be used to automate tasks in ArcGIS Pro. You can share scripts you have created with others as Python .py files. However, using a script written by someone else requires some knowledge of Python, even if only to change the names of the datasets to be processed. To share a Python script in an easier-to-use form, you can create a Python script tool (Kennedy, 2009).

A Python script tool allows you to provide the Python script with a user-friendly interface that looks like the standard geoprocessing tools. You can make your script tool behave like a standard geoprocessing tool by adding code to validate user inputs and to provide messages back to the user. You can also include built-in support documentation to explain how to use the tool and configure its parameters. ArcGIS applications and scripts written using ArcPy benefit from being able to access and work with the numerous Python modules developed by GIS professionals and programmers from many different disciplines. The additional power of using ArcPy within Python is the fact that Python is a general-purpose programming language that is easy to learn and use. It is interpreted and dynamically typed, which provides you with the ability to quickly prototype and test scripts in an interactive environment while still being powerful enough to support the writing of large applications. ArcPy provides access to geoprocessing tools as well as additional functions, classes, and modules that allow you to create simple or complex workflows. Broadly speaking, ArcPy is organized in tools, functions, classes, and modules (Zhang et al., 2017).

Technically speaking, geoprocessing tools are functions available from arcpy—that is, they are accessed like any other Python function. However, to avoid confusion, a distinction is always made between tool and non-tool functions (such as utility functions like List Feature Classes. Tools are documented differently than functions. Every tool has its own tool reference page in the help system. Functions are documented in the ArcPy documentation (Rurangwa, 2024). These tools are:

Automation and Efficiency: Python scripting in ArcGIS facilitates the automation of repetitive tasks, allowing users to streamline workflows and improve overall efficiency (Zhu et al., 2024). By writing Python scripts to perform routine operations such as data processing, analysis, and map production, GIS professionals can save time and reduce the likelihood of errors associated with manual interventions.

Custom Tool Development: Python enables the creation of custom tools and extensions within ArcGIS, tailored to specific project requirements or research objectives. These tools can address unique geoprocessing needs, enhance data visualization, and provide advanced analytical capabilities that are not readily available in the standard ArcGIS toolbox.

Integration and Interoperability: Python serves as a bridge for integrating ArcGIS with external libraries, databases, and software systems, fostering interoperability and data exchange (Brown & Smith, Year). Through Python scripting, GIS professionals can connect ArcGIS to web services, spatial databases, and other geospatial platforms, enabling seamless data integration and analysis.

Geoprocessing and Spatial Analysis: Python scripting empowers users to perform sophisticated geoprocessing tasks and spatial analyses within ArcGIS, leveraging the extensive geoprocessing capabilities of the software (Di,L. et al., 2006). By writing Python scripts that execute complex spatial operations, users can delve deeper into geospatial data analysis, modeling, and visualization.

Scalability and Reproducibility: Python scripts in ArcGIS ensure scalability and reproducibility of analyses by encapsulating workflows into reusable code snippets (Zhu et al. (2024). This not only enhances the transparency of analysis processes but also enables researchers to replicate and modify analyses easily, promoting scientific rigor and data integrity.

In conclusion, the utilization of Python scripting for tool development in ArcGIS offers a plethora of benefits to GIS professionals, ranging from automation and efficiency gains to custom tool creation, enhanced geoprocessing capabilities, and improved interoperability. As a versatile programming language, Python enhances the functionality of ArcGIS, empowering users to tackle complex geospatial challenges and unlock new possibilities in spatial analysis and mapping.

2.13 Empirical Literature review

Previous research on GIS-based highway route selection methods has emphasized the utilization of Geographic Information Systems (GIS) for optimizing route alignments in transportation planning and engineering projects. Li et al. (2018) emphasized the importance of slope analysis in route planning to reduce construction costs and environmental impacts. Additionally, Green et al. (2018) underscored the need for comprehensive environmental impact assessments to mitigate risks and ensure sustainable infrastructure development. These studies collectively demonstrate the value of GIS in integrating spatial data analysis, traffic modeling, environmental considerations, and cost-benefit analyses to inform evidence-based decision-making in highway route selection.

The research conducted by Li et al. (2018), and Green et al. (2018) collectively underscores the pivotal role of Geographic Information Systems (GIS) in optimizing highway route selections within transportation planning and engineering projects. Johnson et al. emphasized the critical importance of leveraging GIS for analyzing traffic patterns and volumes, aiming to enhance route efficiency and safety through evidence-based decision-making. Li et al. highlighted the significance of integrating slope analysis within GIS frameworks, emphasizing its role in reducing construction costs and mitigating environmental impacts. Additionally, Green et al. stressed the necessity of conducting comprehensive environmental impact assessments using GIS tools to ensure sustainable infrastructure development and risk mitigation. Together, these studies showcase how GIS facilitates the integration of spatial data analysis, traffic modeling, environmental considerations, and cost-benefit analyses, enabling informed and strategic decision-making processes in highway route selection that prioritize efficiency, sustainability, and safety.

One seminal work delves into the fundamental concepts of GIS, emphasizing its ability to handle spatial data and conduct spatial analysis. GIS allows for the integration of diverse datasets, enabling the overlaying and analysis of information such as land use, topography, infrastructure, and environmental factors. This capability is essential for assessing the suitability of highway route alignments in consideration of multiple criteria.

Spatial analysis capabilities of GIS, highlighting its spatial modeling and decision-making functionalities. GIS enables the creation of spatial models that can simulate different scenarios and aid in the evaluation of highway route alternatives based on various criteria. This modeling aspect is crucial for predicting the potential impacts of different route selections on the environment, society, and project efficiency.

In the specific context of transportation planning, Sutton, et al. (1997) discusses the significance of GIS in route optimization and network analysis. GIS tools can help in identifying the most efficient and sustainable highway routes by considering factors such as traffic flow, accessibility, environmental impacts, and cost-effectiveness. This optimization aspect is essential for achieving optimal highway route selections that align with project objectives and stakeholder preferences. The need for a structured methodology for highway route selection using GIS technology. The authors emphasize the importance of integrating multiple criteria into the decision-making process to ensure well-informed and sustainable route selections. They highlight the lack of a systematic approach in existing literature and advocate for the development of a comprehensive GIS-centric methodology to address this research gap.

In summary, the theoretical underpinning of GIS in the research literature on highway route selection revolves around its capabilities in spatial analysis, modeling, decision-making, and optimization. By leveraging GIS technology, researchers and practitioners can develop robust methodologies for selecting highway routes that take into account a broad spectrum of factors, leading to more informed and sustainable decision-making processes.

2.14. Research And Knowledge Gap

Despite the proven value of Geographic Information Systems (GIS) in spatial analysis and route optimization, several key research gaps hinder its full potential in transportation planning and highway route selection, including the need for a comprehensive, systematic methodology, enhanced scenario simulation capabilities, dynamic cost-benefit integration, and advanced environmental modeling. Existing research lacks a unified framework that integrates multiple factors—such as topography, traffic, environmental impacts, and costs—into a single decision-making process. Additionally, GIS-based scenario simulations remain underdeveloped, limiting the ability to anticipate future conditions like climate change or population growth. The current static cost-benefit analysis tools also fail to adjust to real-time changes in costs, while environmental models rarely account for complex, long-term effects such as rising sea levels or biodiversity loss. Addressing these gaps would transform GIS from an analytical tool into a strategic platform for sustainable infrastructure planning, enabling planners to select highway routes that are not only efficient and cost-effective but also environmentally sustainable and resilient over time.

CHAPTER III: RESEARCH MATERIAL AND METHODOLOGY

3.1. Description of the Study Area

The study area encompasses a crucial segment of the MelkaJelo to Awash Road project, situated in the East Shoa Zone of the Oromia region in Ethiopia. This region is characterized by its strategic importance in facilitating transportation connectivity and economic development within Ethiopia and the broader East African region.

The MelkaJelo to Awash Road project holds significant significance as it aims to enhance transportation infrastructure by linking key locations along its route. East Shoa Zone, where this project is situated, is known for its diverse topography, ranging from rugged terrains to fertile plains, presenting both challenges and opportunities for road construction and development.

Located in the heart of Oromia, Ethiopia's largest and most populous region, the study area is poised to foster socio-economic growth by improving access to markets, services, and employment opportunities for local communities. The road project is expected to play a pivotal role in enhancing regional connectivity, promoting trade, and facilitating the movement of goods and people across the region.

The geographical setting of the study area within the East Shoa Zone offers a blend of agricultural landscapes, urban centers, and natural features, making it a dynamic environment for infrastructure development. As road construction progresses through this region, considerations for environmental conservation, land use planning, and community engagement become integral aspects of sustainable project implementation.

Given its location in Oromia, a region known for its cultural diversity and historical significance, the MelkaJelo to Awash Road project must navigate through a landscape rich in heritage and natural resources. Preservation of cultural sites, mitigation of environmental impacts, and adherence to regulatory frameworks are essential components of ensuring the project's alignment with local needs and aspirations.

In summary, the study area of the MelkaJelo to Awash Road project in the East Shoa Zone, Oromia, Ethiopia, represents a critical juncture for transportation infrastructure development. Its strategic location, diverse terrain, and socio-economic importance underscore the need for a comprehensive approach to road construction that balances progress with sustainability, community welfare, and environmental stewardship.

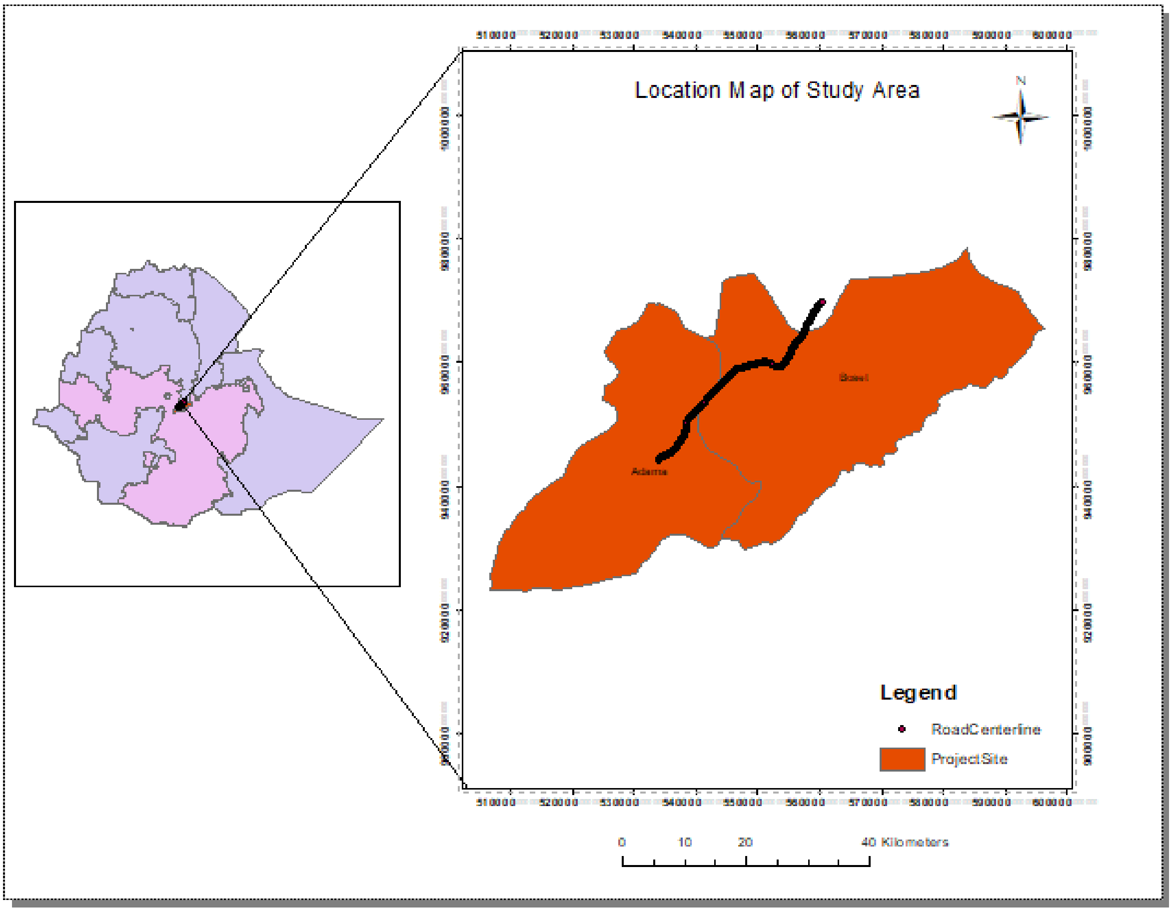

Figure 3.1 Description of the Study Area

3.2. Description of Methodology

A. Data Source

The studies were mainly supported by geospatial datasets gathered (Table3)

Table 3: List of data and sources

Data type	**Format**	**Source**	**Purpose**
DEM	Raster	USGS	For generating Slope
Google earth	Raster	USGS	To show land use
CBR	Vector	Project Site	To know Soil bearing capacity
Geology	Raster	Project Site	To know the Soil type.

B. REQUIRED SOFTWARE

Table 3.2 Required software s

Software	**Remark**	**Purpose**
ArcGIS Software	Version10.8	For analysis and model development
ERDAS Software	Version15	For analysis

3.3 Designed Methodology

a) Identification of Primary Factors Impacting Highway Route Selection:

To address the question regarding the primary factors influencing highway route selection in the study locale, a mixed-methods approach was employed. Initially, a comprehensive literature review was conducted to identify existing research on factors influencing highway route selection. Subsequently, qualitative data collection methods such as expert consultations were employed to gather insights from key stakeholders involved in transportation planning and decision-making processes. Quantitative data analysis techniques, including statistical analysis and GIS mapping, was utilized to analyze and prioritize the identified factors based on their impact on route selection

b) Harmonization of GIS Tools and Methodologies with Relevant Data Sources:

To explore how GIS tools and methodologies can be integrated with pertinent data sources to establish a comprehensive spatial database for examining highway routes, a sequential mixed-methods approach was adopted. Initially, a review of existing GIS tools and methodologies was conducted to identify the most suitable ones for spatial data analysis. Data sources such as satellite imagery, Geology data, and existing CBR databases was integrated into a GIS platform. Spatial analysis techniques was applied to process and visualize the data.

c) Formulation of a Multi-Criteria Decision Analysis (MCDA) Framework:

In order to address the formulation of a Multi-Criteria Decision Analysis (MCDA) framework to methodically integrate factors impacting route selection, a deductive research approach was adopted. The development of the MCDA framework involves several steps. Initially, a thorough review of existing MCDA frameworks and methodologies was conducted to identify key elements for consideration. Stakeholder consultations and expert opinions was sought to refine and tailor the framework to the specific context of highway route selection. Quantitative data analysis techniques, such as pairwise comparisons and sensitivity analysis, was applied to weight and rank the criteria within the MCDA framework. The final MCDA framework was validated through case studies and simulations to evaluate its effectiveness in guiding the route selection process.

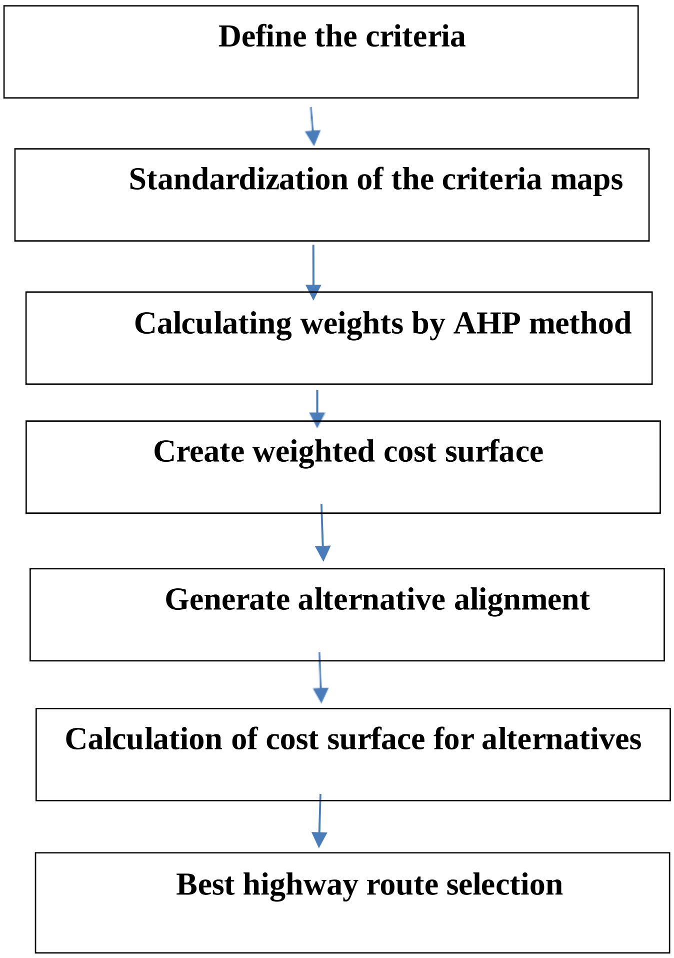

Figure 3.2 Technological scheme of the study

The methodology employed in this research begins with the selection of criteria, a process informed by a thorough review of existing literature and an assessment of the specific conditions present in the area where the road is proposed. After identifying these criteria, factor maps are created and standardized to facilitate subsequent analysis.

The next step involves the application of the Analytic Hierarchy Process (AHP) to assign weights to each of the factors based on their relative importance. This weighting process is crucial as it allows for a quantitative evaluation of the impact of each factor on the decision-making process.

Subsequently, a cost-weighted surface is generated for different alternatives by adjusting the weights assigned to the factors. This surface provides a visual representation of the costs associated with each alternative route, taking into account the varying influences of the factors that have been identified.

Following the creation of the cost-weighted surfaces for the different alternatives, a comprehensive assessment is conducted to evaluate the implications of each route alignment. By considering the cost surfaces alongside other relevant factors, the research aims to identify the best route alignment that optimally balances the various considerations at play.

In essence, this methodology integrates a systematic approach that combines literature review, local conditions assessment, factor mapping, AHP weighting, cost surface generation, and route alignment selection. By following this structured process, the research aims to arrive at a well-informed decision regarding the optimal route alignment for the proposed road, taking into consideration a range of factors and their respective impacts on the overall cost and feasibility of the project.

CHAPTER IV: RESULTS AND DISCUSSIONS

In this chapter, the findings and outcomes derived from the conducted research will be discussed and presented. The comprehensive overview of the results obtained will be provided, representing the culmination of the study. The various aspects explored during the research process will be delved into, and the implications and significance of the findings will be discussed. Valuable insights will be offered, and the existing body of knowledge in the field will be contributed to through a meticulous analysis and interpretation of the collected data.

4.1 Criteria Selection

After conducting a comprehensive literature review on the determinants of highway route selection and utilizing qualitative data collection methods involving expert consultations, three primary factors have been identified for consideration at this specific site. These factors include slope, CBR (California Bearing Ratio)/Soil Bearing Capacity, and Geology.

The Google Earth image in Figure 4.1 illustrates the study area, which predominantly comprises agricultural land. Consequently, land use is not a significant factor in this context. However, it is essential to note that in projects situated in areas with diverse land uses, land use considerations must be incorporated as a critical factor in the route selection process.

By focusing on slope, CBR/Soil Bearing Capacity, and Geology in this study, the researchers aim to address key terrain-related factors that can significantly impact the feasibility, cost-effectiveness, and safety of highway construction in the given area. These factors have been prioritized based on their relevance to the specific site characteristics and their known influence on route planning and infrastructure development.

In projects where land use diversity plays a crucial role, additional factors related to land use patterns and restrictions must be thoroughly evaluated to ensure that the selected route aligns with environmental regulations, community needs, and future development plans. This comprehensive approach to factor selection helps to tailor the route selection process to the unique requirements and challenges of each project site.

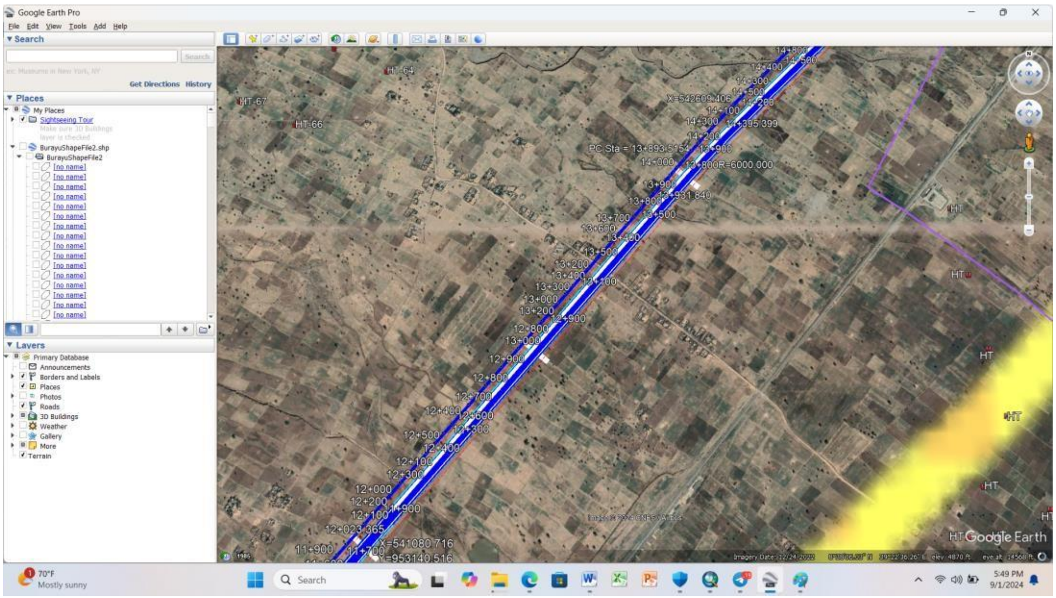

Figure 4.1 Location of the study Area

4.3. Preparing factors map

For this research the factors identified were obtained from different sources in different formats. In order to perform the analysis factors have been converted to the same file format and projection system in this study to raster format and the data sets are described and prepared as follows

4.2.1 Digital Elevation Model (DEM) Factor Map

The Digital Elevation Model (DEM) map depicting the MelkaJelo Awash Road Corridor, obtained from the USGS portal and spatially confined within the corridor boundary using ArcGIS, is illustrated in Figure 4.2. This DEM map holds significant relevance in the research as it serves as the foundation for calculating slope, a crucial factor instrumental in determining the least cost route selection.

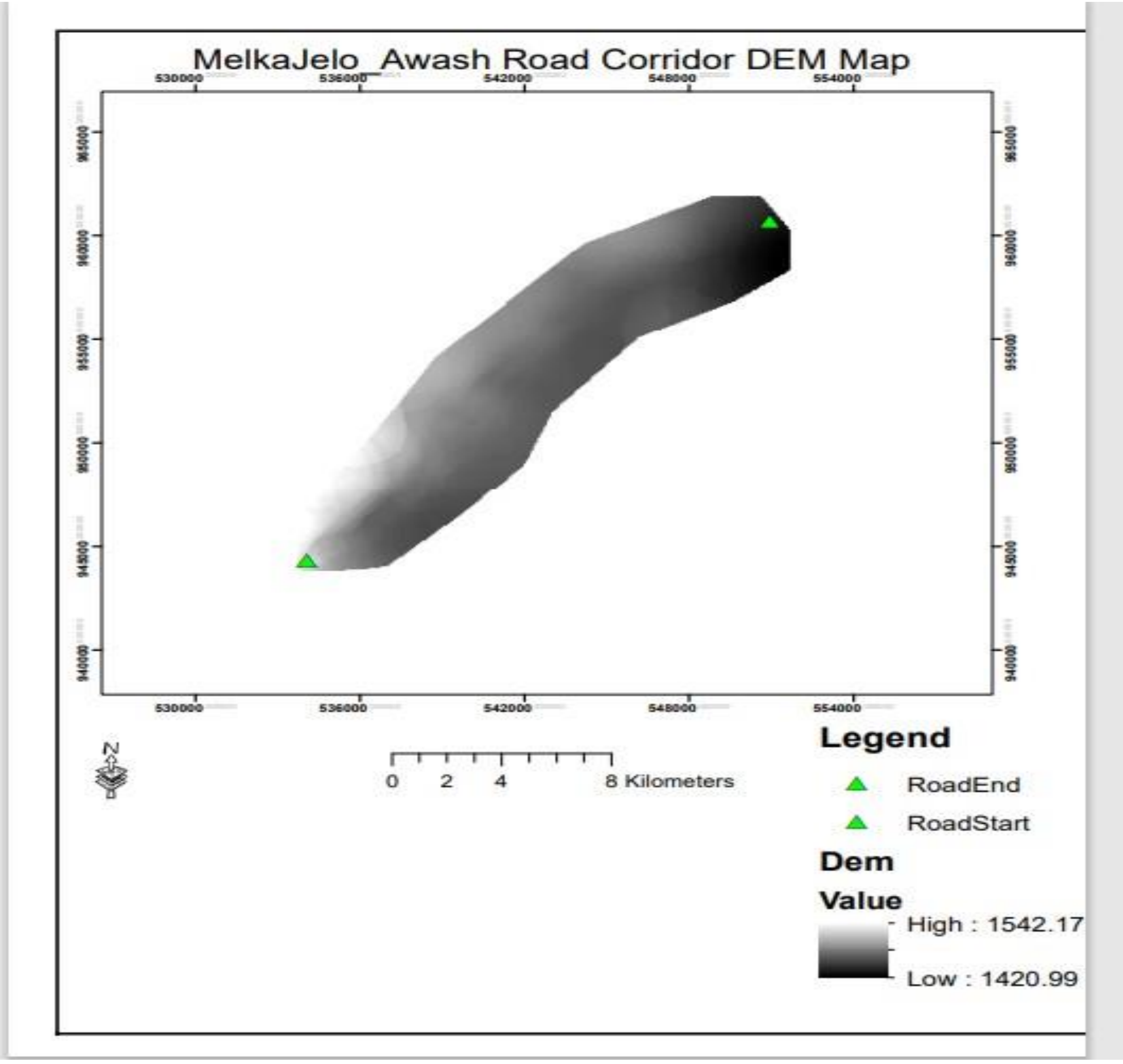

Figure 4.2 Digital elevation model of the study area (USGS)

The DEM map, sourced and processed through the USGS portal, was carefully clipped with precision to isolate the area of interest along the MelkaJelo Awash Road Corridor within the ArcGIS environment. The utilization of this DEM map is pivotal in assessing the terrain characteristics of the corridor, specifically in calculating slope values. Slope, being a key determinant in route selection methodologies, aids in identifying routes that offer optimal efficiency and minimal cost implications.

By leveraging the DEM map and employing GIS tools like ArcGIS for spatial analysis, researchers can accurately derive slope information across the corridor. This data is integral for evaluating the topographical variations and gradients along the route, thereby contributing significantly to the decision-making process involved in selecting the most feasible and cost-effective route for transportation infrastructure development.

4.2.2. Creating a slope Factor Map

In Figure 4.3, we observe a reclassified slope map that has been produced from a Digital Elevation Model (DEM) and categorized based on their appropriateness for route selection. This process likely involved analyzing the gradient of the terrain represented in the DEM data. Slope is a critical factor in route planning and selection because it influences the ease of travel, safety, and cost of construction.

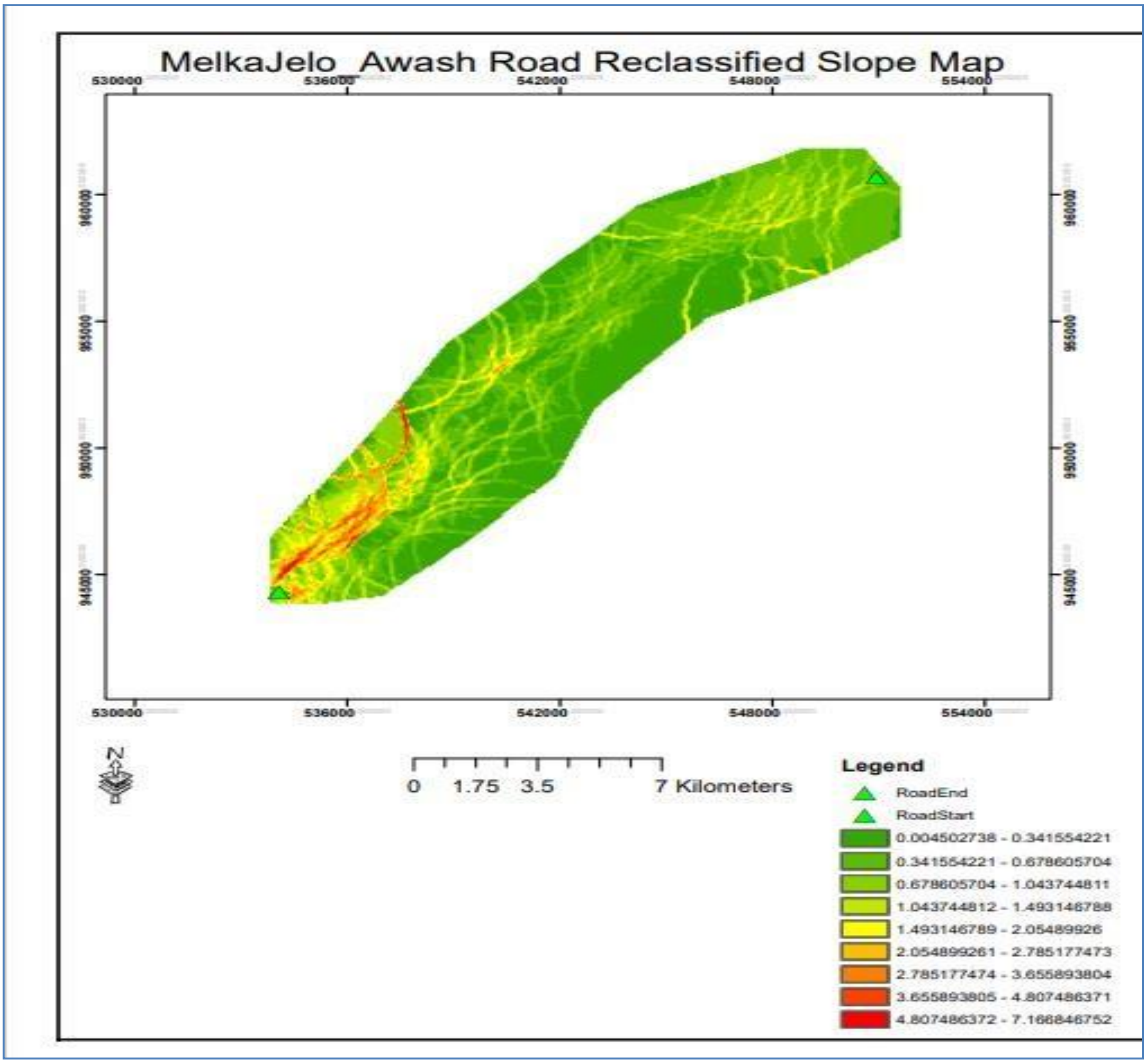

Figure 4.3 Slope Map

In the field of geomorphology and geospatial analysis, the slope is typically classified into categories such as gentle slope, moderate slope, steep slope, etc., each of which presents different challenges and considerations for route planning.

By reclassifying the slope map, the researchers can identify areas that are more suitable or less suitable for constructing a route. For instance, gentle slopes might be more favorable for road construction due to easier grading and reduced erosion potential, while steep slopes might require more extensive engineering solutions.

This process likely involved using GIS software such as ArcGIS to manipulate the DEM data and assign slope categories based on predefined criteria. The reclassified slope map provides valuable information for decision-making in route planning, helping to optimize routes for efficiency, safety, and cost-effectiveness based on the terrain characteristics.

In this research focusing on route selection suitability analysis, slope values have been organized into nine distinct ranges to facilitate a comprehensive assessment of the terrain. These classifications, derived from existing literature, delineate various slope categories based on their steepness and the challenges they pose for construction endeavors. Ranging from "Flat to Gentle Slope" with inclinations between 0° to 2° to "Inaccessible Terrain" where slopes exceed 30°, each category offers a detailed description of the terrain characteristics encountered along potential highway routes. By structuring slope values in this systematic manner, researchers can methodically analyze the topographical features of the landscape, enabling a more informed decision-making process regarding route selection and alignment strategies.

4.2.3. Creating a CBR Factor Map

As explained in literature review CBR is a key engineering parameter that reflects the strength and bearing capacity of subgrade soils. The CBR value plays a vital role in determining the quality of road foundations and pavement design. Research conducted by Zhang et al. (2019) demonstrated the significance of CBR values in assessing subgrade soil conditions and their influence on road performance. High CBR values generally indicate favorable soil conditions for construction, while low values may necessitate soil stabilization measures to enhance load-bearing capacity.

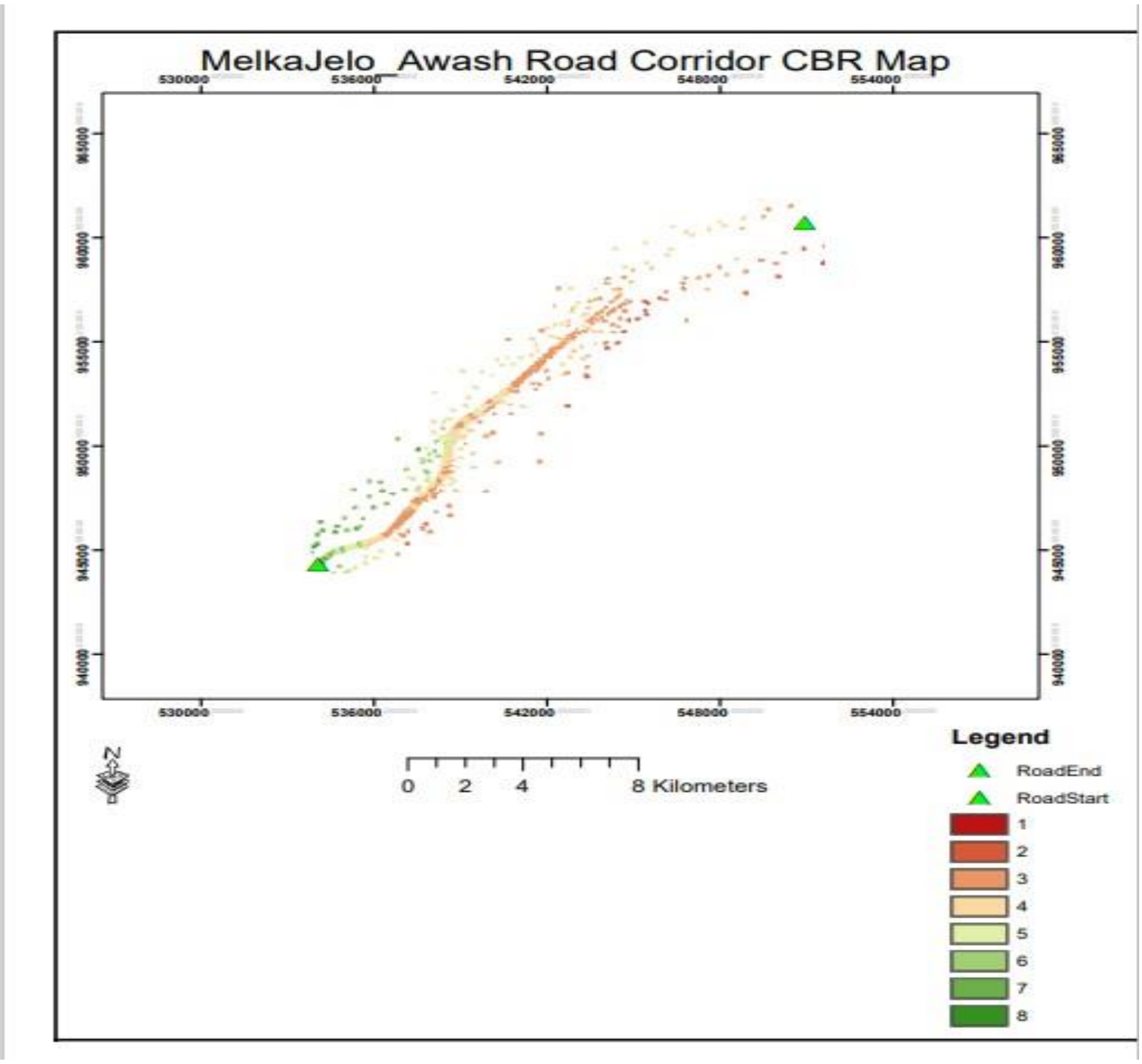

Figure 4.4 CBR Map

In Figure 4.4, the California Bearing Ratio (CBR) values along the route within the corridor are visually represented. These CBR values have been meticulously converted into a raster format using ArcGIS, a powerful Geographic Information System software. This conversion allows for the seamless integration of CBR data into the broader framework of a multicriteria overlay analysis, a crucial step in determining the optimal least cost route selection process. The CBR values depicted in Figure 2 play a pivotal role in understanding the load-bearing capacity and strength of the soil along the route. By translating these values into a raster format within ArcGIS, researchers can employ advanced spatial analysis techniques to overlay this information with other relevant criteria. This integration facilitates a comprehensive evaluation of multiple factors simultaneously, aiding in the identification of the most suitable route option that minimizes costs and maximizes efficiency.

By incorporating the CBR values in the multicriteria overlay analysis, researchers can assess the interplay between soil strength, terrain characteristics, and other key factors influencing route selection. This analytical approach enables a holistic evaluation of various criteria, allowing decision-makers to make informed choices that align with project objectives and constraints. Ultimately, the utilization of CBR values as raster data in the multicriteria overlay analysis enhances the decision-making process, leading to the identification of an optimal route that balances multiple considerations for efficient and cost-effective road infrastructure development.

The classification of California Bearing Ratio (CBR) values into nine ranges provides a structured framework for evaluating soil strength and stability along highway routes. Ranging from "Very Poor Soil" with a CBR range of 0 to 2, indicating very low bearing capacity, to "Outstanding Soil" with a CBR range above 16, signifying exceptional bearing capacity, these classifications offer insights into the suitability of soil for construction activities. By categorizing CBR values based on their strength characteristics, this system aids in decision-making related to route planning, design considerations, and construction methods, enabling researchers to make informed choices tailored to the varying soil conditions encountered in the project area.

4.2.4. Creating a Geology Factor Map

Displayed in Figure 4.5 is the geological map of the study area, delineating the various soil types present, including gravel, clay, silty soil, and expansive soil. Initially presented in a vector format, this geological map has been transformed into a raster format using ArcGIS, a robust Geographic Information System tool. The raster conversion enables a more seamless integration of geological data into the overall analysis framework for conducting the least cost route selection process.

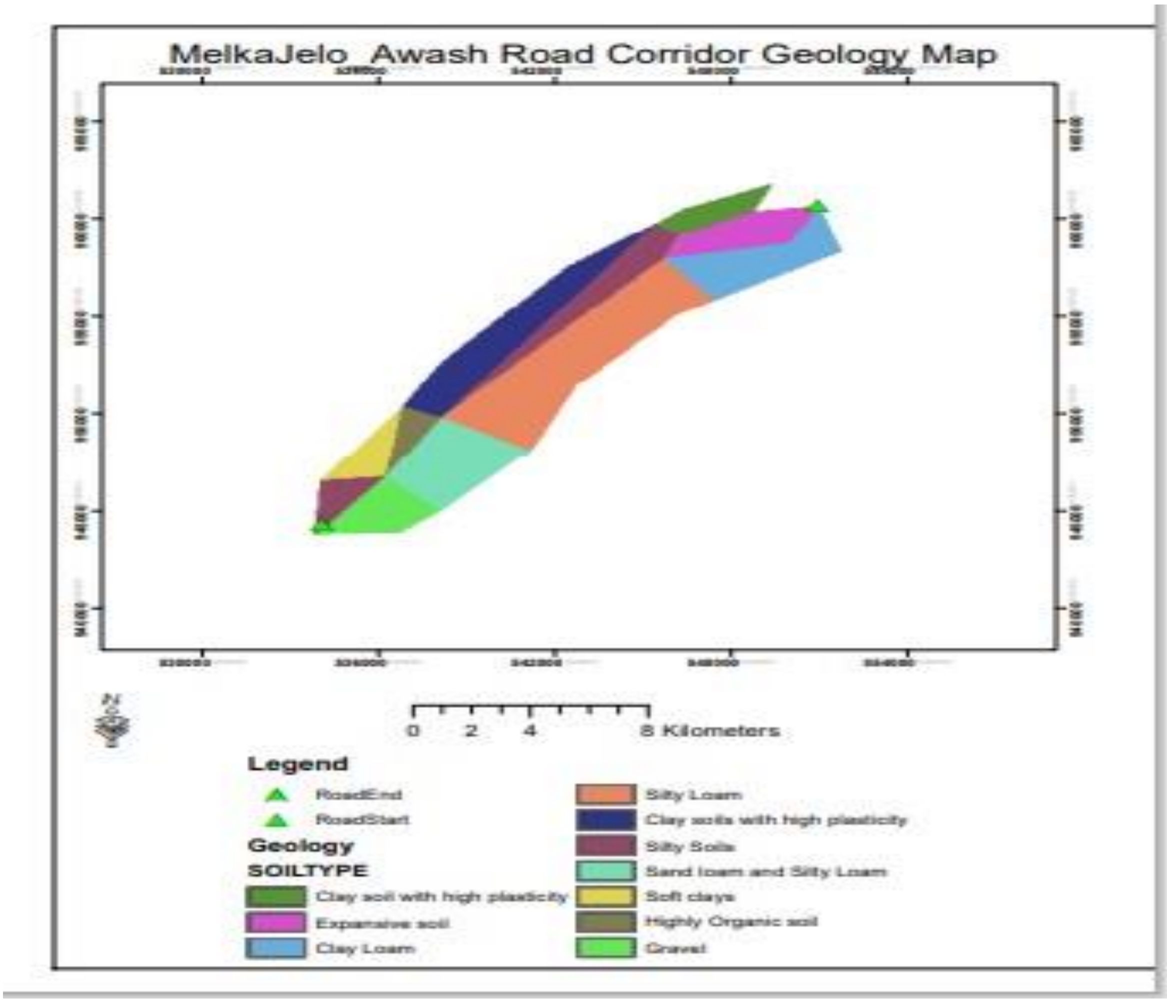

Figure 4.5 Geology Map

The geological map provides critical insights into the soil composition and characteristics across the study area. By reclassifying this information within ArcGIS, researchers can categorize the diverse soil types into distinct classes or categories, facilitating a more detailed and nuanced analysis. This reclassification process prepares the geological data to be overlaid with other criteria maps, forming a comprehensive dataset for conducting the least cost route selection analysis.

Through the overlay of the reclassified geological map with other pertinent criteria maps, such as slope, CBR values, and land use patterns, researchers can undertake a thorough multicriteria analysis. This integrated approach allows for the evaluation of how different factors interact and influence the optimal route selection process. By considering the geological context alongside other criteria, decision-makers can make informed choices that account for soil conditions, terrain characteristics, and overall project feasibility.

The utilization of the geological map as raster data, reclassified and overlaid with other criteria maps in ArcGIS, enhances the decision-making process by providing a comprehensive understanding of the study area's soil composition and its implications for route selection. This integrated analysis approach aids in identifying the least cost route that aligns with project requirements and optimizes the efficiency of transportation infrastructure development.

The research presents a categorization of soil geology values into nine distinct ranges, each highlighting specific characteristics and descriptions of soil types encountered in the study area. From "Unstable Soil," prone to landslides and subsidence due to its loose composition and high-water content, to "Volcanic Soil," formed from volcanic ash with variable fertility and compaction potential, these classifications offer valuable insights into the geological diversity of the terrain. This systematic classification facilitates a comprehensive assessment of soil properties along potential highway routes, guiding decision-making processes concerning route planning, design considerations, and construction strategies tailored to the varied soil conditions present in the project vicinity.

4.2.5. Least Cost Path Model

Illustrated in Figure 4.6 is the comprehensive least cost route selection model meticulously crafted within the ArcGIS Model Builder environment. This model streamlines the process of determining the most optimal route by integrating various factor maps critical to route selection. Initially, these factor maps undergo reclassification into a unified scale, aligning them for a coherent analysis. Subsequently, based on their significance in route selection, these factors are assigned weights to reflect their relative importance. The model then applies sophisticated geoprocessing tools such as cost distance and cost path analyses to identify the most efficient route for the given criteria.

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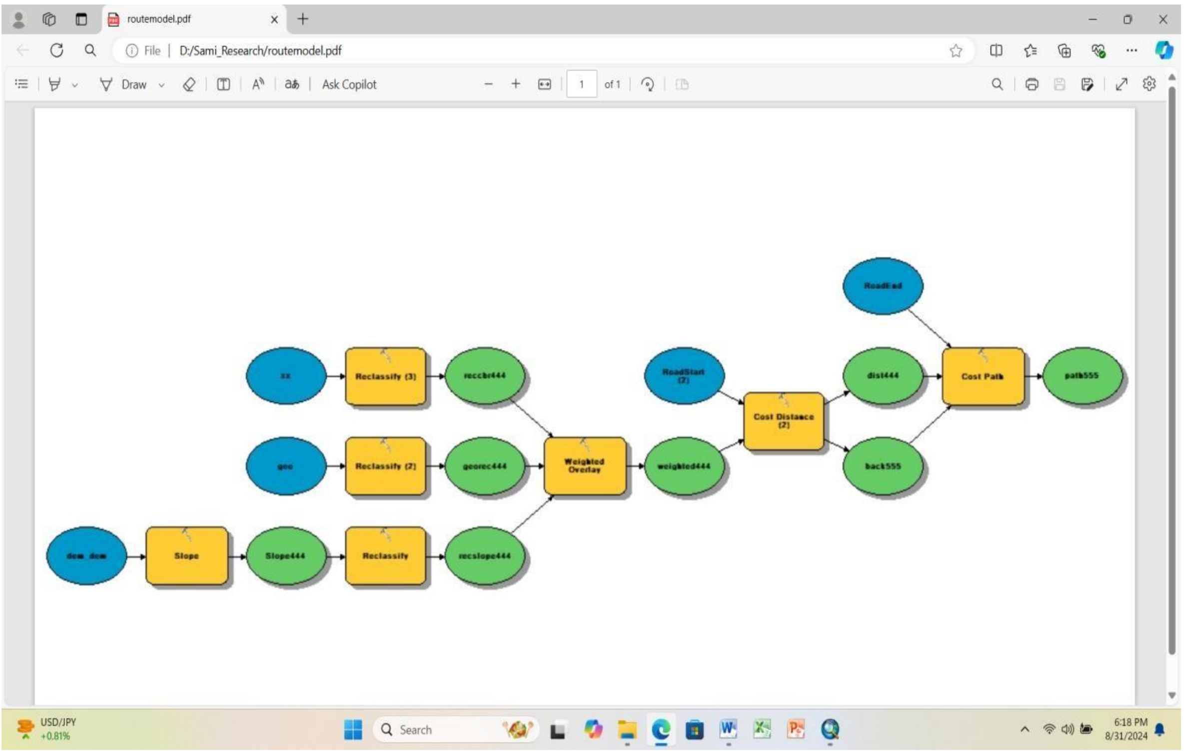

Figure 4.6 Least cost route path model

An inherent advantage of utilizing the ArcGIS Model Builder tool lies in its capacity to automate geoprocessing tasks. By structuring the route selection process within this model, researchers can expedite and streamline the analytical workflow. The automation of geoprocessing tools not only enhances efficiency but also ensures a consistent and reproducible methodology for route selection. This systematic approach allows for the seamless integration of diverse factors and criteria, facilitating a robust decision-making process.

The model developed in ArcGIS Model Builder serves as a powerful tool for synthesizing and analyzing complex spatial data. By amalgamating reclassified factor maps, applying weighted considerations, and executing cost analysis tools, the model enables a detailed evaluation of potential route options. This holistic approach, driven by automation and standardized processes, enhances the accuracy and reliability of the least cost route selection process.

In summary, the utilization of the ArcGIS Model Builder for developing the least cost route selection model signifies a significant advancement in spatial analysis methodologies. By leveraging automation and geoprocessing capabilities, researchers can efficiently navigate through the intricate process of route selection, ultimately leading to informed decisions based on a comprehensive assessment of diverse criteria.

4.2.6. Least Cost Route Result

In Figure 4.6, the least cost path map visualizes the optimized route from the starting point to the destination along the road corridor. This path is derived by taking into account the various factors and weights assigned during the route selection process.

The least cost path map encapsulates the culmination of a meticulous analysis that integrates multiple criteria, such as slope, soil type, geological characteristics, and possibly other factors crucial for determining the most efficient route. By assigning specific weights to each factor based on their relative importance, the model prioritizes certain criteria over others, reflecting their impact on the overall route selection.

The visualization provided by the least cost path map offers a clear depiction of the selected route, showcasing the path that minimizes costs and maximizes efficiency based on the amalgamation of factors and their respective weights. This optimized path represents the culmination of a sophisticated analytical process that harmonizes diverse spatial data layers to derive a route that aligns with the project objectives and constraints.

The least cost path map serves as a valuable decision-making tool, offering stakeholders and planners a tangible representation of the optimal route. By considering the factor-weight assignments, this map provides insights into the rationale behind the chosen path, highlighting the trade-offs and considerations that informed the decision-making process.
Overall, Figure 4.6, displaying the least cost path map, encapsulates the outcome of a rigorous spatial analysis process that leverages GIS technologies and multicriteria decision-making techniques to identify a route that best balances the various factors influencing route selection.

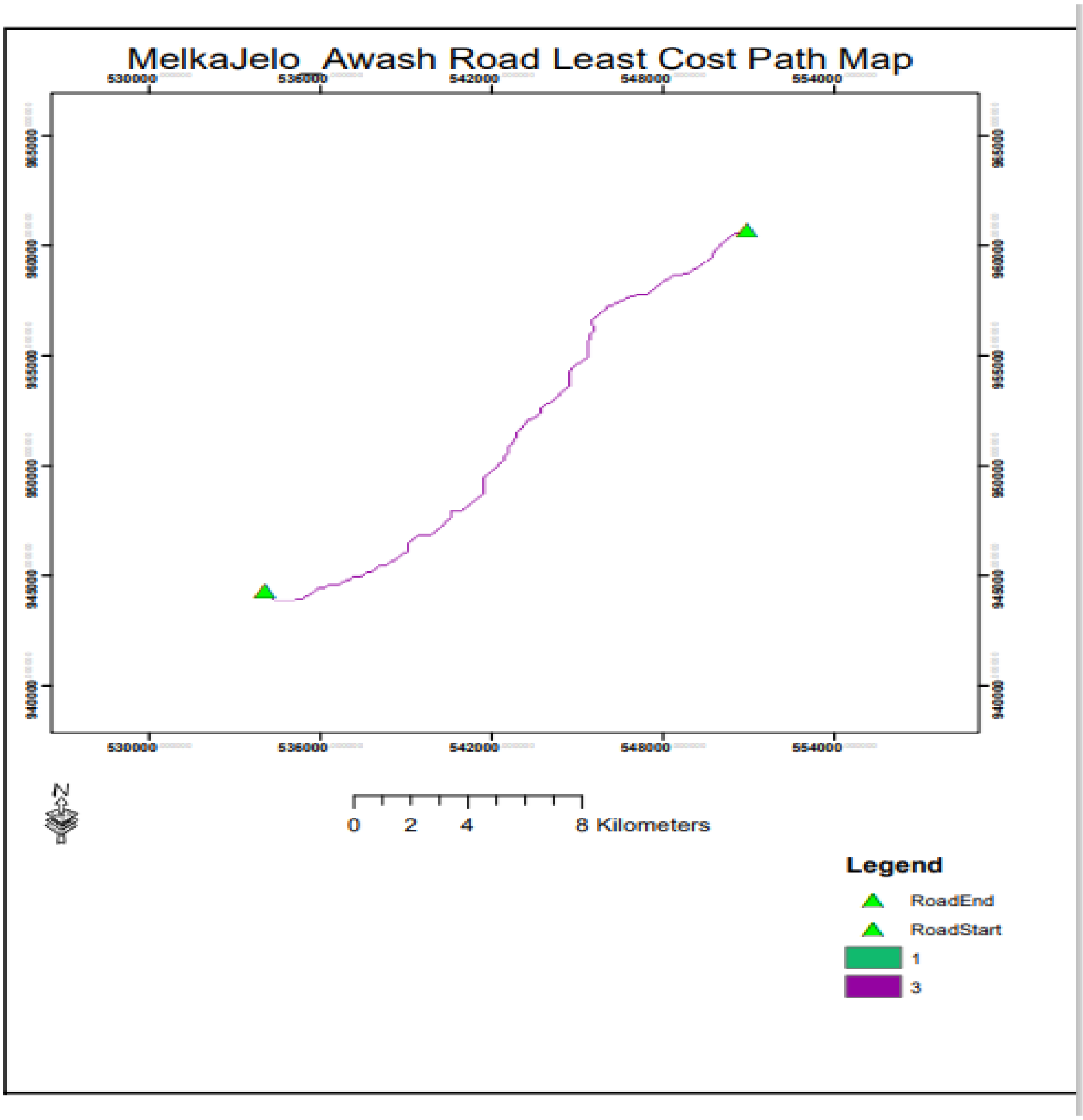

Figure 4.7 Least Cost Route Result

The developed model facilitates the streamlined selection of optimal routes by enabling users to easily assess and compare results through the manipulation of assigned weights. By integrating various factors and their corresponding weights into the route selection process, users can swiftly evaluate different scenarios and gauge the impact of changing weights on the final route selection outcome. Figure 4.7 illustrates how the least cost path map is generated based on the assigned weights, providing a visual representation of the optimized route from the beginning to the end of the road corridor.

The flexibility offered by the developed model in adjusting weights and assessing route outcomes presents a significant advantage in transportation planning and infrastructure development. By allowing for the dynamic modification of weights and criteria, decision-makers can conduct sensitivity analyses to understand how different priorities influence the selection of optimal routes. This capability enhances the model's versatility, enabling stakeholders to explore various scenarios, adapt to changing circumstances, and make informed decisions that align with project objectives and constraints.

Furthermore, the automated nature of weight adjustments simplifies the process of route selection, significantly reducing the time and effort required for repeated analyses. This efficiency not only enhances the decision-making process but also promotes a more iterative and data-driven approach to route selection. The visualization of results through the least cost path map aids in enhancing stakeholder understanding and buy-in, fostering transparency and informed decision-making in transportation planning endeavors.

In conclusion, the ability to manipulate weights automatically in the developed model not only enhances the ease of route selection but also empowers stakeholders with a valuable tool for scenario analysis and decision support. This functionality underscores the model's utility in addressing complex route selection challenges and underscores its potential to drive more effective and efficient transportation infrastructure planning processes.

4.2.7. Developed Least Cost Route Tool

Figure 4.8 displays a newly created tool for determining the least expensive route, similar to other tools integrated within ArcGIS. This tool streamlines the process of selecting a route by incorporating input criteria. Furthermore, its functionality could be expanded by incorporating additional criteria to further refine the route selection process. the final costs were determined only to compare the routes and were not included in the route optimization process and the modelled routes were not compared with the already implemented TL in the study area. It is also possible to assign monetary values to the criteria, which address the route optimization more realistically. Nevertheless, there are difficulties to determine the costs related to each criterion, involving exhaustive searches on databases, as well as technical knowledge about the components.

The least-cost path (LCP) is a common geographic analysis problem in raster-based geographic information systems (GIS) applied to infrastructure path planning. Additionally, different landscape paths can be defined by combining visual information with the least-cost path.

The least-cost path in raster space is a path consisting of adjacent cells from the starting point to the end point that have the least cumulative cost. Raster space divides a geographic area into equally sized squares, with each square capable of storing types of geographic features, such as elevation and land use. Connecting the center points of each square in the raster space generates a graph, with paths represented by a series of adjacent cells and implicitly hidden arc. The common connection structure between cells is the eight-neighborhood, which means that a cell is connected to its four orthogonal and four diagonal adjacent cells. As for the situation where there are more movement directions between the cells, the 16-neighborhood can be applied. However, while applying a 16-neighborhood results in more accuracy in the path construction, the graph becomes more complex.

Sets of components that influence implementation and maintenance costs: equipment costs regardless of geographic features; slope costs, associated with the local slope of the terrain; direction change costs; and geographic factors, which are:
(i) accessibility costs: represented by the costs of equipment transportation, installation and maintenance, depending on the quality and type of the existing access routes in a studied area and the need for opening new access routes;

(ii) costs due to specific geographic characteristics of the area: compensation and expropriation costs associated with land use; costs of tower foundations according to soil type; costs associated with vegetation, for example, need for higher towers to cross forested areas with significant ecological importance, vegetation suppression and/or pruning costs; additional maintenance costs in areas susceptible to corrosion near the coast; additional costs for areas of high environmental importance;

(iii) terrain complexity: slope and relief complexity influence on determining the types and heights of the towers, where flatter lands are more favorable;

(iv) costs due to obstacles: The crossing of these elements requires reinforced structures or even the use of underground lines. The need of signaling equipment, due to the proximity of certain infrastructure such as airports, may also be implemented.

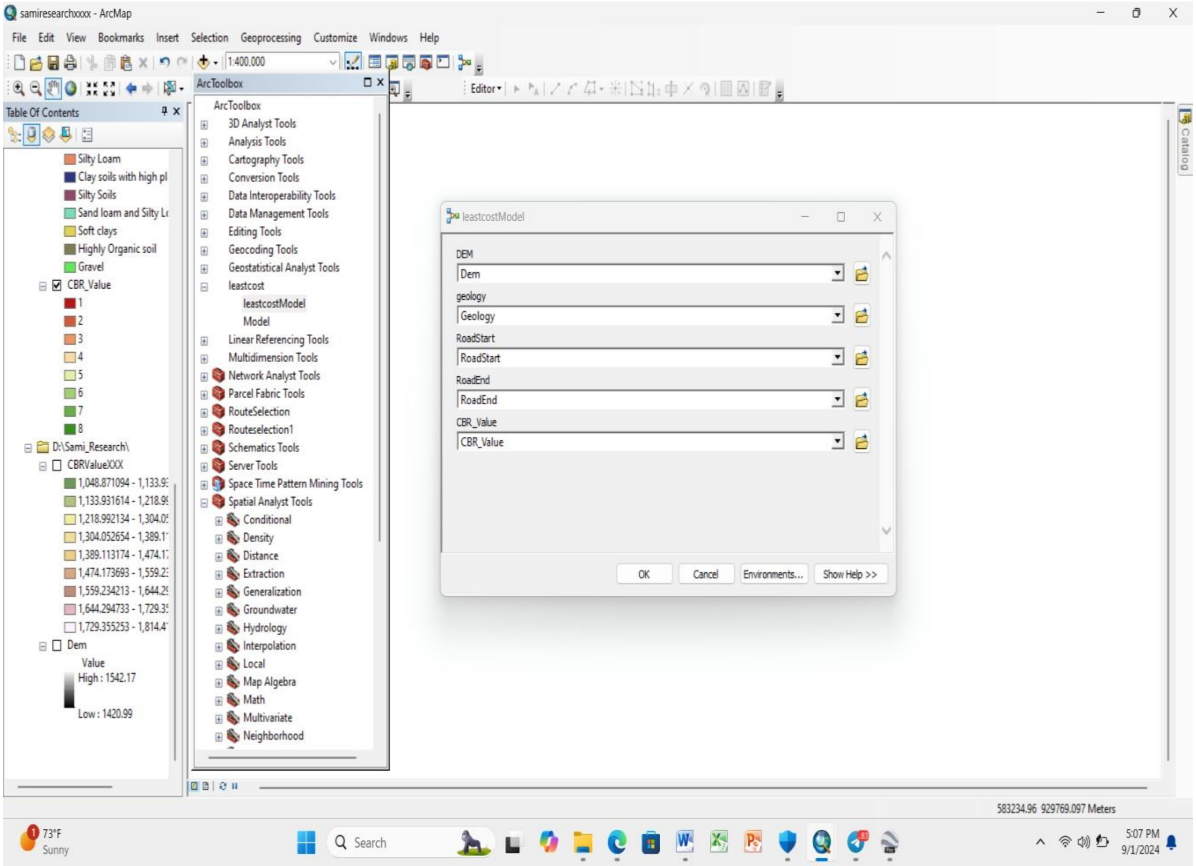

Figure 4.8 Developed Least Cost Route Tool

4.2.8. Discussion

The development of a Geographic Information System (GIS)-based model for optimal highway route selection is paramount in tackling the intricate challenges inherent in contemporary infrastructure planning. This research underscores the fusion of pivotal factors like slope, geological conditions, and California Bearing Ratio (CBR) values to guarantee the identification of the most effective and environmentally sustainable routes. Previous research underscores the critical nature of these variables; for example, slope plays a crucial role in drainage and stability considerations (Zhou et al., 2017), whereas geological attributes significantly impact construction feasibility and the long-term durability of highways (Siddiqui & Ahmad, 2020).

By integrating these factors into a GIS model, planners can make informed decisions that optimize not just the construction process but also the subsequent maintenance and longevity of the highway infrastructure. The utilization of GIS technology allows for the visualization of complex spatial data, enabling stakeholders to analyze various route options comprehensively. Furthermore, the incorporation of factors like slope, geological conditions, and CBR values ensures that the selected routes are not only efficient in terms of construction but also sustainable in the long run, minimizing environmental impact and maximizing the infrastructure's resilience.

In essence, the research on GIS-based highway route selection models underscores the necessity of considering a diverse array of factors to create infrastructure that is both functional and environmentally conscious. By leveraging GIS technology in this manner, planners can navigate the complexities of modern infrastructure development with a focus on efficiency, sustainability, and long-term viability.

The utilization of California Bearing Ratio (CBR) values as a metric for evaluating subgrade strength plays a vital role in determining road performance, underscoring the importance of integrating these metrics into the route selection process (Khan et al., 2019). By employing tools like ArcGIS Model Builder, this research introduces a novel methodology that enhances decision-making efficiency through automation and visualization, aligning with previous studies that highlight the capability of GIS to improve route optimization (Miller et al., 2018).

CBR values serve as a crucial indicator of the strength and bearing capacity of the subgrade material, providing valuable insights into how well a road will withstand loads and traffic over time. By considering CBR values during route selection, planners can make informed decisions that prioritize durability and long-term performance. This integration ensures that the chosen routes are not only efficient but also resilient, reducing the likelihood of premature deterioration and the need for frequent maintenance.

The use of ArcGIS Model Builder further elevates the research by offering a systematic and automated approach to route selection. By leveraging this tool, stakeholders can streamline the decision-making process, generate visualizations of various route options, and assess the impact of different factors such as CBR values on road performance. This not only expedites the planning phase but also enhances the overall accuracy and precision of the route selection process.

Moreover, the research's emphasis on the capacity of GIS to improve route optimization aligns with existing literature that underscores the benefits of utilizing geospatial technologies in infrastructure planning. GIS enables planners to analyze spatial data effectively, identify optimal routes based on a multitude of factors, and visualize the potential outcomes of different decisions. By incorporating GIS into the decision-making process, stakeholders can make more informed choices that lead to sustainable, efficient, and resilient infrastructure development.

In summary, the research underscores the significance of incorporating CBR values in route selection to ensure road performance and longevity. By leveraging tools like ArcGIS Model Builder and recognizing the power of GIS in enhancing decision-making processes, stakeholders can optimize route selection, leading to infrastructure that is not only efficient but also built to withstand the test of time.

The creation of a custom tool within the model not only streamlines the intricate routing process but also guarantees a high level of precision, effectively mitigating concerns highlighted in prior studies regarding the susceptibility to human error in manual routing assessments (Li et al., 2021). This study adds to the expanding corpus of literature that champions the utilization of advanced GIS techniques in civil engineering and infrastructure development, emphasizing the possibilities for enhanced resource management and decreased environmental footprint in highway construction projects.

The integration of a custom tool into the model represents a significant advancement in the field, offering a tailored solution that optimizes the routing process. By automating complex calculations and decision-making steps, this tool reduces the potential for errors that may arise from manual assessments, ensuring that the selected routes are based on accurate data and thorough analysis. This not only enhances the efficiency of the routing process but also boosts the overall reliability of the decisions made, leading to infrastructure that is better suited to meet the demands of modern transportation systems.

Furthermore, by advocating for the application of advanced GIS techniques in civil engineering and infrastructure development, this research underscores the transformative potential of geospatial technologies in shaping the future of construction projects. Through the utilization of GIS tools, planners and engineers can gain valuable insights into spatial data, optimize route selection, and visualize the impact of various factors on project outcomes. This not only improves decision-making processes but also enables more effective resource allocation, leading to cost savings and increased project efficiency.

Moreover, the emphasis on reducing environmental impact in highway construction projects through the implementation of advanced GIS techniques aligns with the broader trend towards sustainable infrastructure development. By leveraging GIS technology to minimize land disturbance, optimize route planning, and mitigate environmental risks, stakeholders can work towards creating infrastructure that is not only efficient and durable but also environmentally friendly.

In essence, this research contributes to the advancement of the field by showcasing the benefits of incorporating custom tools within GIS models for improved routing accuracy. By embracing advanced GIS techniques, the study paves the way for more efficient and sustainable infrastructure development practices, ultimately leading to better resource utilization and reduced environmental impact in highway construction projects.

In this study, the researcher employs a restricted set of criteria, indicating that the developed model could benefit from the inclusion of additional factors essential for the unique characteristics of the particular location under consideration. Enhancing the model by incorporating a broader range of criteria specific to the area could lead to more comprehensive and robust results, better aligning the decision-making process with the intricacies and requirements of the site.

CHAPTER V: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Through a comprehensive exploration of least cost route selection methodologies within transportation infrastructure planning, this research has culminated in the development of a robust and versatile model. By leveraging the capabilities of the ArcGIS environment, the study has effectively integrated various spatial factors, reclassified them into a common scale, assigned weights based on their relative importance, and applied sophisticated geoprocessing tools to derive optimized routes along road corridors.

The visualization of least cost path maps offers a tangible representation of the model's outcomes, showcasing the selected routes based on the amalgamation of factors and their corresponding weights. This visualization not only aids in the interpretation of the results but also serves as a valuable tool for stakeholders to grasp the rationale behind the chosen routes and understand the trade-offs involved in the decision-making process.

By demonstrating the practical application of the model in generating least cost paths from road start to road end, the research underscores the model's efficacy in facilitating informed decision-making in transportation planning. The systematic approach to route selection, incorporating factor reclassification, weight assignment, and automated geoprocessing tools, provides a structured framework for optimizing route selections based on varying criteria and priorities.

Overall, the developed model represents a significant advancement in transportation infrastructure planning methodologies, offering a data-driven and analytical approach to route selection that can enhance efficiency, sustainability, and cost-effectiveness in infrastructure development projects. The model's adaptability to changing conditions, ease of use in adjusting weights, and visualization of results position it as a valuable tool for stakeholders involved in urban planning, transportation management, and infrastructure development initiatives.

5.2. Recommendations

Based on the result obtained, the researchers suggest the following recommendations:

- Further Model Refinement: To enhance the model's efficacy, future research could focus on refining the criteria selection process and optimizing weight assignments. This iterative refinement process can lead to more accurate and reliable route selections, ultimately improving transportation planning outcomes.

- Stakeholder Engagement: Encourage stakeholder engagement throughout the route selection process to ensure that decision-making aligns with project goals and community needs. Collaborating with relevant stakeholders, such as local authorities and transportation agencies, can provide valuable insights and foster a more inclusive decision-making approach.
- Validation and Verification: Conduct thorough validation and verification exercises to assess the robustness and reliability of the model outputs. By comparing model-generated routes with field data or expert opinions, researchers can validate the model's accuracy and identify areas for improvement.
- Knowledge Transfer and Training: Develop training programs and knowledge transfer initiatives to empower transportation planners and decision-makers in utilizing the model effectively. Providing guidance on model operation, data interpretation, and result analysis can enhance the model's adoption and utility in practical planning scenarios.
- Continuous Model Evaluation: Establish a framework for ongoing model evaluation and feedback collection to ensure its continued relevance and effectiveness. Regular assessments and user feedback mechanisms can inform model updates, improvements, and adaptations to changing planning requirements.
- By implementing these recommendations and building upon the research findings, stakeholders can leverage the developed model to make informed decisions, optimize route selections, and enhance transportation infrastructure planning processes for sustainable and efficient urban development.

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