

Assessment of Optimal Route Selection for Roads Construction Using Geospatial
Technologies: A Case of Dembidollo - Mettu, Oromia, Ethiopia



Tolasa Turuna Teshoma

A Thesis Submitted to the Department of Geomatics Engineering
School of Civil Engineering & Architecture and Presented in Partial Fulfillment of the
Requirement for the Degree of Master's in Geoinformatics Engineering

Office of Graduate Studies

Adama Science and Technology University

July, 2023

Adama, Ethiopi

Assessment of f Optimal Route Selection for Roads Construction Using Geospatial
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Advisor: Getachew Berhanemeskel (PHD)

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DECLARATION

I hereby declare that this Master Thesis entitled “Assessment of f Optimal Route Selection for Roads Construction Using Geospatial Technologies: A Case of Dembidollo - Mettu, Oromia, Ethiopia” 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 thesis have been duly acknowledged through citation.

Name of the student

Signature

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RECOMMENDATION

I, the advisor of this thesis, hereby certify that we have read the revised version of the thesis entitled “Assessment of f Optimal Route Selection for Roads Construction Using Geospatial Technologies: A Case of Dembidollo - Mettu, Oromia, Ethiopia” prepared under our guidance by Tolasa Turuna submitted in partial fulfillment of the requirements for the degree of Mater’s of Science in Geoinformatics Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Major Advisor

Signature

Date

APPROVAL SHEET

I, the advisor of the thesis entitled “Assessment of f Optimal Route Selection for Roads Construction Using Geospatial Technologies: A Case of Dembidollo - Mettu, Oromia, Ethiopia” and developed by Tolasa Turuna, 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	Signature	Date
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We, the undersigned, members of the Board of Examiners of the thesis by Tolasa Turuna have read and evaluated the thesis entitled “Assessment of optimal road route selection using geospatial technologies: case of Dembidollo to Mettu, Oromia, Ethiopia” 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.

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LIST OF ACRONYMS

AHP	Analytical Hierarchy Process
CR	Consistency ratio
DEM	Digital Elevation Model
EGSA	Ethiopian Geology Survey Agency
ERA	Ethiopian Road Authority
GIS	Geographic Information System
GPS	Global Positioning System
LCPA	Least Cost Path Analysis
LiDAR	Light Detection and Ranging
LULC	Land use/land cover
MCDA	Multi criteria decision analysis
MCE	Multi criteria evaluation
MOWIE	Minister of water and irrigation energy
UAV	Unmanned Aerial Vehicle
USGS	United State geological survey

ABSTRACT

The absence of a direct and well-maintained road between Dembidollo and Mettu towns in the Oromia Zones of Ethiopia resulted in prolonged travel times, increased costs, and hindered movement. This study aimed to utilize geospatial technologies to select the best route alignment that would efficiently connect the two towns. Through geospatial analysis, a suitable route alignment was identified, and the economic, technical, and environmental aspects of the proposed alignments were evaluated. High-resolution Digital Elevation Model (DEM) data and Sentinel 2A imagery were employed for generating slope, elevation, drainage order, and land use and land cover (LULC) classification. Data processing and analysis were conducted using geospatial software such as ArcGIS, ENVI, Idrisi Selva, Global Mapper, and Google Earth. A systematic method was followed, encompassing data collection and processing, criteria prioritization using the Analytical Hierarchy Process, weighted overlay of thematic maps, least cost path generation, and evaluation based on preferred theme maps. The analysis emphasized the significance of economic factors in route selection, giving the highest weight to the economically preferred least cost path. The findings demonstrated a substantial improvement offered by the proposed route alignment, resulting in a remarkable distance reduction from 271 km to 96.46 km. The recommended route alignment proved to be cost-effective, safe, and resilient by avoiding higher-order drainage and minimizing disruptions. Adoption of this route alignment was recommended, as it would bring benefits such as reduced travel costs and time, improved community services, enhanced economic opportunities, and affordable transportation of goods. In conclusion, the effectiveness of geospatial technologies and multi-criteria evaluation methods in selecting the optimal road route alignment is showed. The integration of remote sensing and GIS proved highly efficient and cost-effective for large-area imaging. By considering multiple parameters and incorporating multi-criteria evaluation, a comprehensive assessment of the proposed alignments was achieved, highlighting the practicality and effectiveness of geospatial technologies in road infrastructure development. These insights provide valuable guidance for future studies and contribute to the development of economically viable and sustainable transportation networks.

Keywords: *Economic viability, Geospatial technologies, Multi-criteria evaluation, Road route selection, Sustainable transportation networks*

CHAPTER I: INTRODUCTION

The development of efficient road infrastructure is vital for promoting economic growth and enhancing connectivity between cities and towns. However, the selection of optimal road alignments is a complex task influenced by various factors such as topography, soil composition, distance from settlements, and environmental considerations. In Ethiopia, the need for well-planned road networks is particularly critical for socioeconomic development. To address this challenge, the integration of geospatial technologies and advanced data analysis techniques offers new opportunities for effective road route selection. This study aims to identify and analyze the factors influencing road alignment selection and propose alternative alignments using geospatial technologies, thereby contributing to the enhancement of road infrastructure planning in Ethiopia.

1.1. Background of the study

Road transport is a vital catalyst for economic development, facilitating the movement of people and goods. Beyond its economic impact, well-developed road networks also serve various other purposes. They play a crucial role in military operations, provide access to education and essential services, promote tourism and recreation, foster social connectivity and community development, and support sustainability efforts. By investing in road infrastructure and considering these multifaceted applications, we can create a smart and efficient transportation system that enhances accessibility, safety, and quality of life for all (Ivanová & Masárová, 2013; Jana et al., 2017a). And in order to develop a high-quality road network, the selection of an appropriate road path is of great significance. This process involves evaluating social, economic, and technical factors to determine the optimal road alignment. During the planning phase of highway expansion, careful evaluation and decision-making are essential (Tae-Ho et al., 2008). However, road route selection is a complex task due to the multitude of variables that need to be considered (Suleiman et al., 2015). Physical factors such as topography, soil characteristics, and nearby land use play a role, along with technical, economic, environmental, and stakeholder considerations (Poudel & Kumar, 2022).

Ethiopia's road network is a valuable national asset that requires joining to complete standards in design, construction, and maintenance to ensure a high level of service. With the continued

expansion of the road network, the need for effective preservation methods becomes increasingly crucial. Adhering to appropriate standards not only ensures road durability but also minimizes the need for frequent repairs and replacements, optimizing resource allocation and reducing maintenance costs. By making informed choices in road design, construction, and maintenance, Ethiopia can safeguard the integrity of its road network and maximize its contribution to economic development and social well-being. Implementing sound practices in road infrastructure management is essential for the network's long-term sustainability and continuous improvement (ERA Manual, 2013).

The selection of the optimal road route requires careful consideration of various criteria to ensure direct connectivity between cities, towns, or villages while minimizing transport, construction, and maintenance costs. In Ethiopia, the criteria for route selection include factors such as minimum route length, construction and maintenance costs, cumulative rise and fall, length of steep gradients, constraints due to topography, required bridges, ease of construction and technology, environmental and social impacts, socio-economic benefits, geological conditions, and availability of construction materials (ERA Manual, 2013).

Choosing the best route is a complex task that involves analyzing diverse data sets and considering multiple variables. However, the integration of geospatial technologies, including remote sensing, geographic information systems, and global positioning systems, has significantly facilitated this process (Mondal et al., 2021). Geospatial technologies encompass a range of mapping and surveying techniques, employing data from remote sensing platforms and employing principles from disciplines such as digital cartography, photogrammetry, surveying, and automated data capture systems. These technologies enable the acquisition, processing, manipulation, and analysis of spatial data, empowering decision-makers to address regional and environmental challenges effectively. By handling both spatial and non-spatial data, geospatial technologies play a vital role in data acquisition, management, analysis, display, and dissemination. The advancement of electronic networks has further amplified the potential of geospatial technologies, attaching the vast amount of digital data and computational power available (Reddy, 2018).

The information generated through conventional methods, remote sensing, and GPS techniques could be used effectively to create database in GIS and perform variety of spatial analysis in

sustainable management of land resources and generate environment-friendly action plans. Some of the applications of geospatial technologies are digital terrain modeling, geomorphological mapping, soil resource inventory and mapping, soil-landscape modeling, land use/land cover mapping, croplands mapping, spatial decision support systems, etc., which have a far-reaching impact on mapping, monitoring, and management of land resources on sustainable basis (Reddy, 2018). By incorporating Geographic Information Systems and Multi-Criteria Decision Analysis, planners can enhance the precision and desirability of road route selection outcomes. This integration reduces the elaboration of the planning process and facilitates agreement among diverse stakeholders (Sameer et al., 2021). Multi-criteria evaluation within GIS involves allocating land based on a set of attributes that selected areas should ideally possess to fulfill specific objectives. However, it is worth noting that different approaches employed in vector and raster systems often yield distinct solutions, as evidenced by studies (Eastman, 1999).

1.2. Statement of the problem

The absence of a direct and well-maintained road between Dembidollo and Mettu towns in the Oromia Zones of Ethiopia hampers socioeconomic integration and restricts access to essential services. The local population is compelled to rely on alternative routes that require rehabilitation and are affected by political conflicts. Consequently, individuals face prolonged travel times and increased costs, hindering their ability to move conveniently and efficiently between the two towns.

To further emphasize the problem, it is crucial to consider the significant socio-economic integration between Dembidollo and Mettu. Residents frequently travel between the towns for various purposes, including education, commerce, visiting relatives, military activities, and entertainment. However, the lack of a direct road exacerbates travel challenges and adds to the financial burden. Additionally, the inadequate transportation infrastructure impedes market access, limiting the economic opportunities available to individuals and inhibiting regional growth. Moreover, the existing road connections to other towns are in need of rehabilitation and are subject to political conflicts. These conditions compromise the safety and reliability of travel options, further impeding the ease of transportation. The inadequate road network also hampers the provision of crucial government services, such as healthcare and education, leaving residents

with limited access to quality facilities and hindering their overall quality of life. Addressing this problem is pivotal to foster socioeconomic development, improve community services, and enhance the well-being of the population in Dembidollo and Mettu. By acknowledging the specific travel patterns, purposes, and duration of travel between the towns, a comprehensive road infrastructure plan can be formulated. This plan should prioritize the establishment of a direct and efficient road, enabling seamless access to essential services, reducing travel costs, and unlocking economic opportunities for the residents.

The problem at hand calls for urgent action to improve road connectivity and infrastructure, thereby driving economic growth, enhancing community services, and elevating the overall quality of life for the residents of Dembidollo and Mettu towns.

1.3. Objective of the study

1.3.1. General Objective

The aim of this research is to select the best route alignment location using geospatial technologies to connect Dembidollo and Mettu town.

1.3.2. Specific objective

The particular objective of this research is to:

- Analyze factors affecting road alignment selection between Dembidollo and Mettu towns.
- Formulate and present alternative road alignments, taking into account technical, environmental, and economic criteria.
- Assess and compare the proposed alternative alignments using the defined criteria to identify the most suitable route.
- Showcase the effectiveness and practicality of using geospatial technologies in the route selection process for road infrastructure development in Ethiopia.

1.4. Research question

This research is hoped to answer the following question.

- What are the factors that significantly impact road alignment selection between Dembidollo and Mettu towns?

- How can alternative road alignments be formulated, considering technical, environmental, and economic criteria?
- How can the proposed alternative alignments be assessed and compared using defined criteria to determine the most suitable route?
- What is the effectiveness and practicality of utilizing geospatial technologies in the route selection process for road infrastructure development in Ethiopia?

1.5. Significance of the Study

Finding a new and optimized route alignment between Dembidollo and Mettu towns will have significant benefits in terms of reducing travel costs and time for the local population. This research highlights the crucial role of geospatial technologies in conducting route selection analysis, enabling the identification of geographically suitable, shortest, safe, and cost-effective paths. The chosen route will facilitate improved community services, such as enhanced economic opportunities, time-efficient travel, and affordable transportation of goods between the towns. The proposed road alignment, will benefit not only the local population but also the broader region by improving connectivity and fostering socio-economic development.

1.6. Scope of the study

Geographically, this study is conducted in the Ethiopia Oromia region, specifically focusing on the South-West area between the towns of Dembidollo and Mettu. The study involves the analysis of factors that affect route selection, including the processing, preprocessing, and interpretation of geospatial data. The ultimate goal is to select the shortest and lowest cost route by employing a multicriteria approach with the use of geospatial technology for the case of Dembidollo and Mettu.

1.7. Limitations

The absence of advanced imaging technologies, such as Lidar and UAVs, which could have provided more detailed and precise data on the study area are considered as limitation for this study. This constraint restricted the level of detail and accuracy that could be achieved in mapping and evaluating the road route selection. Despite efforts to mitigate this limitation using available data and geospatial technologies, the absence of advanced imaging technologies may have impacted the comprehensiveness and accuracy of the analysis.

CHAPTER II: LITERATURE REVIEW

2.1. General overview

Roads play a vital role in the modern economy, and effective integration and planning are crucial for their success (Sunusi et al., 2015). When choosing a highway route, the physical characteristics of the area, such as topography, soil conditions, and surrounding land use, are significant factors to consider (Isah O. Anavberokhai, 2008; Mahavar & Pham, 2019; Suleiman et al., 2015). These factors encompass gradients, available land-use and soil type, construction and maintenance costs, length, number of curves, user cost, connectivity, community or national landmarks, and governmental interests.

The complex environmental structure presents challenges in highway route design, particularly due to topography and natural geographical obstacles (Sarı & Sen, 2017). To overcome these challenges, the availability of surface terrain information is crucial for economically siting new road alignments. This information aids in identifying and evaluating alternative routes and optimizing alignments and grades for the selected alternative (Veneziano et al., 2004). However, there is a conflict between economic and environmental perspectives in road alignment planning. Cost considerations can negatively impact the environment and habitats, leading to deforestation, altered water resources, construction waste, air pollution, and noise. Conversely, environmentally-focused highway projects can increase costs due to steeper slopes, increased height, and longer routes (Sarı & Sen, 2017).

To address the environmental and cost priorities of road projects, the most suitable road routes should be determined using methodologies such as Analytical Hierarchy Process and Least-cost path analysis (Effat & Hassan, 2013). AHP helps in determining suitable locations based on various criteria, while LCPA aids in deciding the route by considering the weights of parameters calculated through AHP. By integrating AHP and LCPA, cost surfaces and parameter-oriented approaches can be utilized to determine the desired routes (Sarı & Sen, 2017).

The complexity of route selection arises from various considerations and conflicting interests, making the planning process challenging (Sameer et al., 2021). The use of Geographic Information System and Multi-Criteria Decision Analysis assists planners in achieving detailed and desirable results, reducing complexity, and enabling stakeholders to reach common

conclusions (Poudel & Kumar, 2022). GIS facilitates the incorporation of ground information for spatial analysis, contributing to informed decision-making (Poudel & Kumar, 2022).

2.2. Road Alignment selection

Road route selection is a complex task that presents challenges to industry professionals. (Zhao et al., 2019) highlight the need for an effective method to identify the optimal path connecting specified points. Traditional approaches to road alignment selection are slow and error-prone, leading to the development of new tools and algorithms (Bongiorno et al., 2019).

In the context of new highway planning,(Mondal et al., 2021) utilized GIS techniques for connecting two cities. They considered various governing parameters such as land use, slope, aspect, soil, geology, and drainage maps. By assigning scales to subunits and using weighted cost distance and direction functions in ArcGIS, they successfully plotted the shortest path from source to destination.

(Poudel & Kumar, 2022) incorporated remote sensing and ancillary data sources, including USGS, Sentinel-2, and Copernicus, in the road alignment selection process. They employed the Analytic Hierarchy Process (AHP) to determine criteria weights and generated theme maps through weighted overlay in ArcGIS. Optimal alignments were derived from cost surfaces, with the shortest route selected based on the technical theme.

(Sekulic et al., 2022) adopted a multi-Criteria Evaluation approach as part of an Environmental Impact Assessment to identify optimal by-pass alignments in the Tlokweng Planning area of Botswana. They classified thirteen criteria maps into economic, environmental, and social themes, successfully finding optimal alignments using the MCE approach.

Overall, these studies highlight the importance of developing efficient methods and utilizing GIS techniques, remote sensing data, and decision-making approaches such as AHP and MCE for road route selection.

2.3. Road route selection approach in developing countries

In developing countries, the route selection process for linear engineering structures, such as roads, often relies on classical methods based on medium-scale topographic maps, with slope data being the primary consideration (Yildirim et al., 2006). However, when it comes to selecting road alignments, it is essential to align traffic flows within a road network and

determine the locations of passage points along the way. This requires a comprehensive evaluation of social, economic, and technical factors to identify the most suitable road alignments based on the evaluation results.

In terms of social factors, it is crucial to recognize the significance of improving road traffic networks within local societies and assess the social impacts on communities, taking into account other development projects in the area. Economic factors play a role in assessing the reasonableness of road plans in terms of investment considerations, such as construction costs, maintenance, and management expenses, as well as the economic benefits associated with those investments. Technical factors related to road plans encompass both traffic-technical and structure-technical aspects, which are evaluated separately. Traffic-technical aspects focus on managing the flow of automobile traffic, while structure-technical aspects involve adapting road plans to natural conditions and ensuring structural stability (Tae-Ho et al., 2008).

By considering these multidimensional factors in the road alignment selection process, it becomes possible to make informed decisions that contribute to the development and sustainability of transportation networks in developing countries.

2.4. Geospatial technologies for route selection

The role of geospatial technology in route selection has been transformative, thanks to modern technologies such as high-resolution satellite data, GPS, GIS, and information technology. These advancements have revolutionized land resource inventory, monitoring, and management processes. Satellite data, with its integrated information on land characteristics, has proven invaluable in assessing and analyzing various factors that influence route selection (Poudel & Kumar, 2022).

High-resolution satellite data offers a comprehensive view of the landscape, providing details on landforms, geological structures, soil types, erosion patterns, land use/land cover, surface water bodies, and even qualitative assessments of groundwater potential. These data sources, when combined with information derived from conventional methods, remote sensing, and GPS techniques, allow for the creation of a robust and accurate database within a Geographic Information System (GIS) platform. The integration of these technologies facilitates sophisticated spatial analysis for route selection. GIS enables the overlaying and analysis of multiple datasets, providing insights into factors such as terrain conditions, environmental

sensitivity, accessibility, and infrastructure availability. By considering these diverse variables simultaneously, stakeholders can make informed decisions that optimize route selection based on specific criteria, such as technical feasibility, economic efficiency, and environmental compatibility (Reddy, 2018).

Geospatial technology also allows for dynamic monitoring and evaluation of selected routes. By employing real-time or periodic data updates, changes in land characteristics, road conditions, or environmental factors can be promptly identified and incorporated into decision-making processes. This enables adaptive management strategies, ensuring that selected routes remain optimized and responsive to evolving circumstances (Jana et al., 2017b).

Furthermore, geospatial technology facilitates effective communication and stakeholder engagement. Visualizations and maps generated through GIS can enhance the understanding and communication of complex spatial information, enabling stakeholders to actively participate in the route selection process. This inclusivity promotes transparency, collaboration, and the incorporation of diverse perspectives in decision-making (Çalışkan et al., 2019; Mahavar & Pham, 2019; Mondal et al., 2021).

Remote sensing technology enables the observation of Earth's features from space and offers several techniques to differentiate the collected information on land, vegetation, water bodies, and more (Reddy, 2018). And also GIS, on the other hand, is a computer-based system that captures, organizes, stores, edits, analyzes, displays, and plots geographically referenced data (Zhao et al., 2019). It serves as a powerful platform for integrating and managing spatial data, enabling efficient data analysis and decision-making processes.

GPS technology plays a crucial role in mapping and monitoring by allowing precise locational information to be collected during surveys (Reddy, 2018). This enhances the accuracy of mapping and monitoring activities compared to conventional surveying techniques.

In summary, in addition to road route selection, the integrated approach of remote sensing, GPS, and GIS has a wide range of applications in various fields, including digital terrain analysis, geomorphological mapping, soil resource inventory and mapping, soil-landscape modeling, land use/land cover mapping, cropland mapping and monitoring, assessment and monitoring of droughts, soil erosion assessment, mapping and monitoring of land degradation, identification

and mapping of perspective groundwater potential zones, watershed management, and development of agricultural land use plans at different scales.

Remote sensing and GIS technology in route selection: RS and GIS techniques play a crucial role in addressing various challenges related to transportation engineering and terrain. Through remote sensing observations, valuable spatial data on Earth resources can be obtained, enabling the integration of different types of spatial data and characteristics for engineering purposes. Remote sensing information allows for the derivation of important topics such as terrain, geology, hydrological drainage, and land use. These thematic data can be combined and utilized to effectively solve road alignment planning issues. The applications of GIS and remote sensing extend to various engineering projects including housing, sanitation, energy, water systems, effluent disposal, urban growth, irrigation project design, planning, and new road alignment. By integrating information on natural resources, demographic and socioeconomic data with satellite data in a GIS domain, development models can be generated. Additionally, remote sensing and GIS technologies have proven effective in mapping landslides in mountainous areas and identifying land-prone areas that are susceptible to significant losses (Wahdan et al., 2019).

(Yildirim et al., 2006) emphasize that determining the optimal route through an area has long been a spatial problem, and recent advancements in GIS and remote sensing technologies have effectively addressed this challenge. The GIS approach, utilizing ground/underground parameters and raster network analysis, facilitates the identification of suitable routes between two points. Furthermore, (Mahavar & Pham, 2019) demonstrate the application of developed GIS models for selecting the least-cost path for road planning, considering topography and land use/land cover patterns. This model can also account for other factors such as railway lines, high-security areas, and national parks. (Sunusi et al., 2015) highlight the ability of GIS to easily expand and accommodate additional data layers such as population, traffic, and geological features, enabling a comprehensive representation of the real world where the highway will be aligned. These studies collectively underscore the valuable contributions of remote sensing and GIS technologies in route selection and planning.

2.5. Multi-Criteria GIS Analysis

Effective decision-making in environmental projects necessitates the careful consideration of socio-political, environmental, and economic impacts, while also addressing diverse stakeholder

perspectives. In this context, multi-criteria decision analysis has emerged as a valuable formal methodology for integrating technical information and stakeholder values to support decision-making processes across various fields, including environmental decision making (Huang et al., 2011). Spatial decision problems present unique characteristics that require evaluation based on multiple criteria. Spatial multi-criteria decision models involve the analysis of geographic events supported by criterion values and the preferences of decision-makers with respect to a set of analysis criteria. The complexity of spatial decision problems arises from the multitude of factors involved, making data acquisition and processing challenging. However, the integration of GIS and MCDM techniques offers enhanced effectiveness and efficiency in addressing spatial decision problems, providing decision-makers with comprehensive support throughout the intelligence, design, and choice phases of the decision-making process (Gyabeng, 2020).

One of the key aspects in MCDM is determining the relative importance of criteria, which is typically accomplished by assigning weights to each criterion. These weights reflect the significance of each criterion compared to others under consideration, allowing decision-makers to prioritize and evaluate alternatives accordingly (Wahdan et al., 2019). By employing MCDM techniques coupled with GIS capabilities, decision-makers can effectively navigate the complexities of multi-criteria decision problems and make informed choices that balance various factors and stakeholder perspectives.

2.5.1. Analytical Hierarchy Process

The Analytic Hierarchy Process is a widely used tool in multiple criteria decision-making, finding applications in various domains (Vaidya & Kumar, 2006). This mathematical method allows for the determination of priorities among different decision alternatives. The popularity of AHP stems from its simplicity, promising accuracy, theoretical robustness, ability to handle both tangible and intangible criteria, and its capacity to measure the inconsistency of judgments provided by respondents (Piantanakulchai & Saengkhao, 2003).

AHP captures both subjective and objective components of decision-making, as highlighted by Poudel & Kumar (2022). Through the comparative matrix of criteria, weights are calculated for each criterion. According to (Tae-Ho et al., 2008), the AHP enables the consideration of multidimensional variables when evaluating alternatives for a specific purpose. It allows for the

simultaneous utilization of qualitative and quantitative standards, providing a rational and mathematical approach to decision-making. Essentially, the AHP functions as a decision-making system structured in a tree-like fashion, progressively breaking down factors into smaller sub-factors to achieve a final goal. The analytic hierarchy process follows three fundamental principles that can be applied to decision-making scenarios.

2.5.2. Least Cost Path Method

Least-cost path analysis is a powerful approach that allows designers to determine the most cost-effective route between two locations while considering various factors such as environmental impact and economic investment. By combining multiple criteria and creating a cost surface, LCPA calculates the "cheapest" path within a Geographic Information System framework (Bagli et al., 2011). This method has been extensively utilized in the planning and design of different linear infrastructures, including roads.

The implementation of the Least Cost Path Algorithm enables the investigation of the least cost path for road alignment. The cost parameter assigned to LCPA represents the expenses associated with construction, such as avoiding steep slopes and swampy areas, or the consideration of environmental aspects, such as preserving forests and agricultural lands (Sari & Sen, 2017). Once the cost parameter is established, LCPA calculates the least cost path from the origin point to the destination. This approach has demonstrated success in avoiding high slopes, costly areas, ecologically significant zones, and achieving overall objectives within the constraints of available data and criteria (Suleiman et al., 2015). By leveraging the capabilities of modern GIS technologies, LCPA provides a valuable tool for optimizing road alignments and considering various factors, ensuring the selection of routes that align with project goals and requirements.

2.6. Criteria identification for route selection

In the "Criteria identification for route selection" step (Wahdan et al., 2019), the aim is to identify the necessary data sets for accurate route selection. This involves evaluating user data through expert questionnaires and a literature review to enhance current practices by automating tasks and considering important factors that may be overlooked. The criteria for evaluation include slope, land use, hydrology, geology, faults, natural protectorates, archaeological sites, and sand dunes data. A Multi-Criteria Evaluation model is employed to develop the highway

LCP, assigning weighted cost factors for various features and calculating a path of least resistance across a cumulative weighted cost surface.

Furthermore, assigning specific weights to the criteria factors in each alternative is essential (Sameer et al., 2021) due to their varying priorities aligned with specific goals and objectives. Determining individual weights for these factors is necessary to appropriately reflect their relative importance in the decision-making process.

2.7. Factor affecting road alignment selection

When selecting the alignment for a road project, it is important to consider various factors that can significantly impact the success and sustainability of the project. The alignment should not only meet technical requirements but also minimize adverse effects on the environment and maximize socio-economic benefits. To ensure a comprehensive evaluation, the following factors play a crucial role in the decision-making process:

Environment: Assessing the potential impacts of the proposed route on the surrounding environment is essential. This includes evaluating factors such as built-up areas, existing infrastructure, agriculture lands, forest areas, water bodies, local government boundaries, elevation, and origin and destination coordinates (Sarı & Sen, 2017). By understanding these environmental criteria, it becomes possible to prioritize the protection of natural resources and habitats during the road construction process.

Terrain: The elevation and topography of the terrain significantly influence road projects (Ouma et al., 2014). Analyzing terrain information, particularly through digital elevation models, helps identify suitable areas that meet technical requirements for road alignment. Understanding the terrain can aid in determining the feasibility of construction and optimizing the route design.

Slope: The slope of the land surface is another crucial factor in road alignment selection. Steep slopes can present challenges in terms of construction, safety, and user comfort. Evaluating and avoiding high slopes as much as possible can contribute to the overall success of the road project (Mondal et al., 2021; Ouma et al., 2014; Poudel & Kumar, 2022; Sekulic et al., 2022; Sunusi et al., 2015).

Geology: Geology plays a vital role in route selection by affecting constructability, foundation suitability, and the overall economic efficiency of the project (Tae-Ho et al., 2008; Taylor et al., 2008; Usikov & Ozaryan, 2021). It influences aspects such as earthworks, excavation ease, topographic features, potential geo-hazards (e.g., landslides), problematic soils, and availability of suitable construction materials. Considering geology helps mitigate risks and ensures the long-term stability and durability of the road (ERA Manual, 2013).

Land Use/Land Cover: Consideration of land use and land cover is essential to assess the environmental and socio-economic impacts of a road project. Complex environmental studies should be carried out to evaluate these impacts and determine the compensation required for any acquired land. Historical and cultural resources in the area should be preserved or avoided during corridor selection (ERA Manual, 2013; Sunusi et al., 2015).

Existing Road Network: The evaluation of the existing road network is important as it affects the connectivity of the proposed route. Minimizing the need for roundabouts and related road furniture can be achieved by avoiding crossing or closely passing existing major roads (Ouma et al., 2014).

Drainage Pattern (Rivers and Streams Network): Understanding the drainage patterns, including the presence of permanent rivers and streams, is crucial to avoid disruptions caused by high floods. Incorporating appropriate drainage solutions into the road design can minimize potential damages and ensure the road's resilience (Jana et al., 2017a; Mondal et al., 2021; Poudel & Kumar, 2022).

Soils: Soil characteristics have a significant impact on construction feasibility and long-term road performance. Considering soil types helps assess factors such as constructability, soft ground relations, drainage conditions, and overall economic and technical feasibility (Poudel & Kumar, 2022; Tae-Ho et al., 2008). By thoroughly considering these factors and incorporating them into the decision-making process, a holistic evaluation of road alignment selection can be achieved. This approach ensures that the chosen alignment balances technical requirements, environmental considerations, and socio-economic factors, resulting in a sustainable and successful road project.

CHAPTER III: MATERIALS AND METHODOLOGY

3.1. Study area

3.1.1. Study area description

Location: the study area focuses on the route connecting Dembidollo town, the capital of Kelem Wollega Zone in the Oromia Region, to Metu, the capital of Illubabor Zone. The study area is extended between 8°32'N 34°48'E & 8°18'N 35°35'E and altitude 1701 to 1827 meters above sea level. The study area covers the area of 23103 square kilometer. It has been mapped and can be visualized in figure below. See fig 1 below for visual representation of the geographical positions of Dembidollo and Metu within the Oromia Region of Ethiopia.

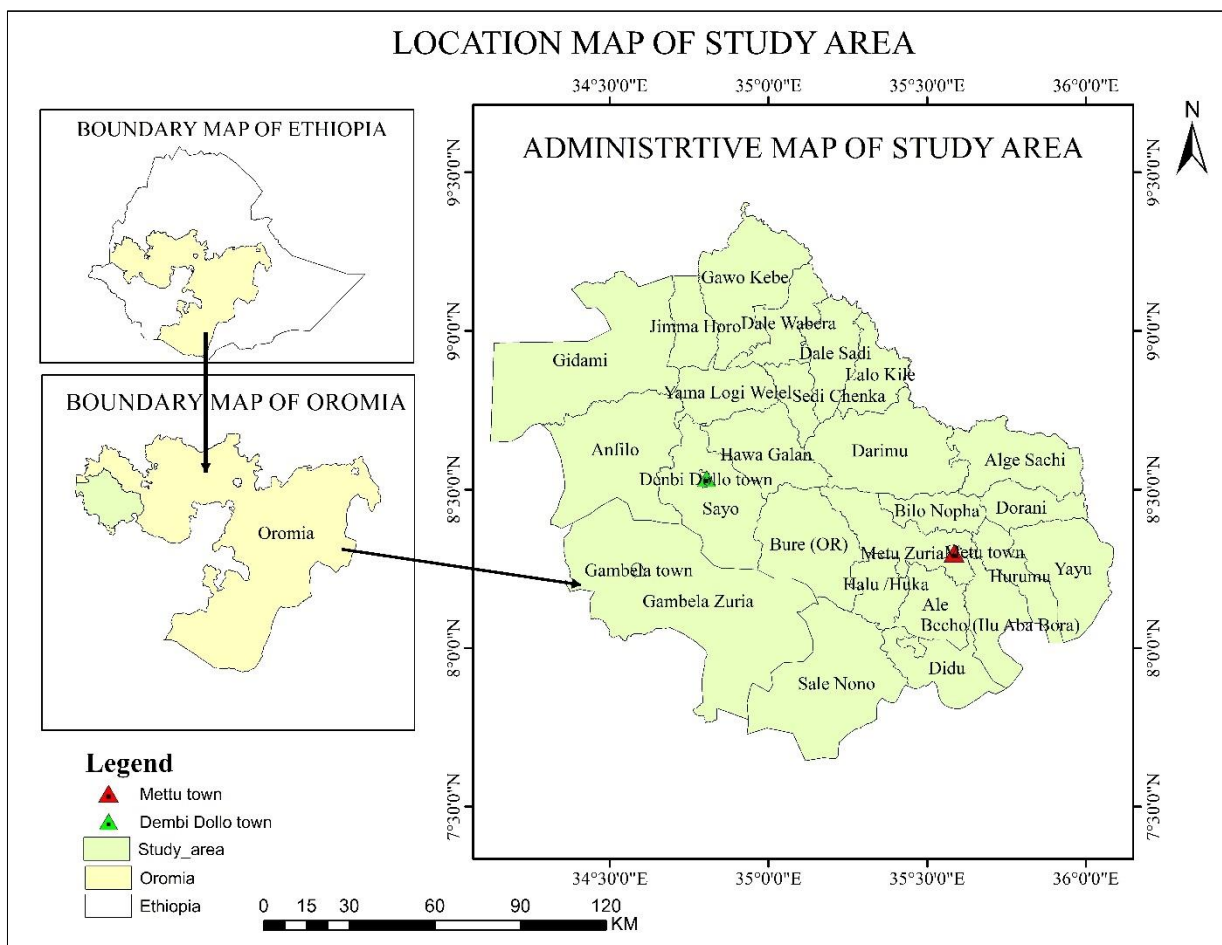


Figure 1: Location map of study area (Source: ESSGI)

Population: in the study area, the total population amounts to 2,350,527 individuals, with 1,171,796 females and 1,178,731 males. Among the regions within the study area, Darimu woreda stands out as having a particularly large population. The distribution of the population

between males and females provides valuable insights into the gender demographics of the area. Understanding these population characteristics is crucial for conducting various analyses, such as socio-economic assessments, resource allocation, and infrastructure planning. This knowledge allows planners to prioritize the provision of services to densely populated regions. The map displays the population density across different areas of the study area, indicating whether there are many people living closely together or if they are more spread out. See fig 2.

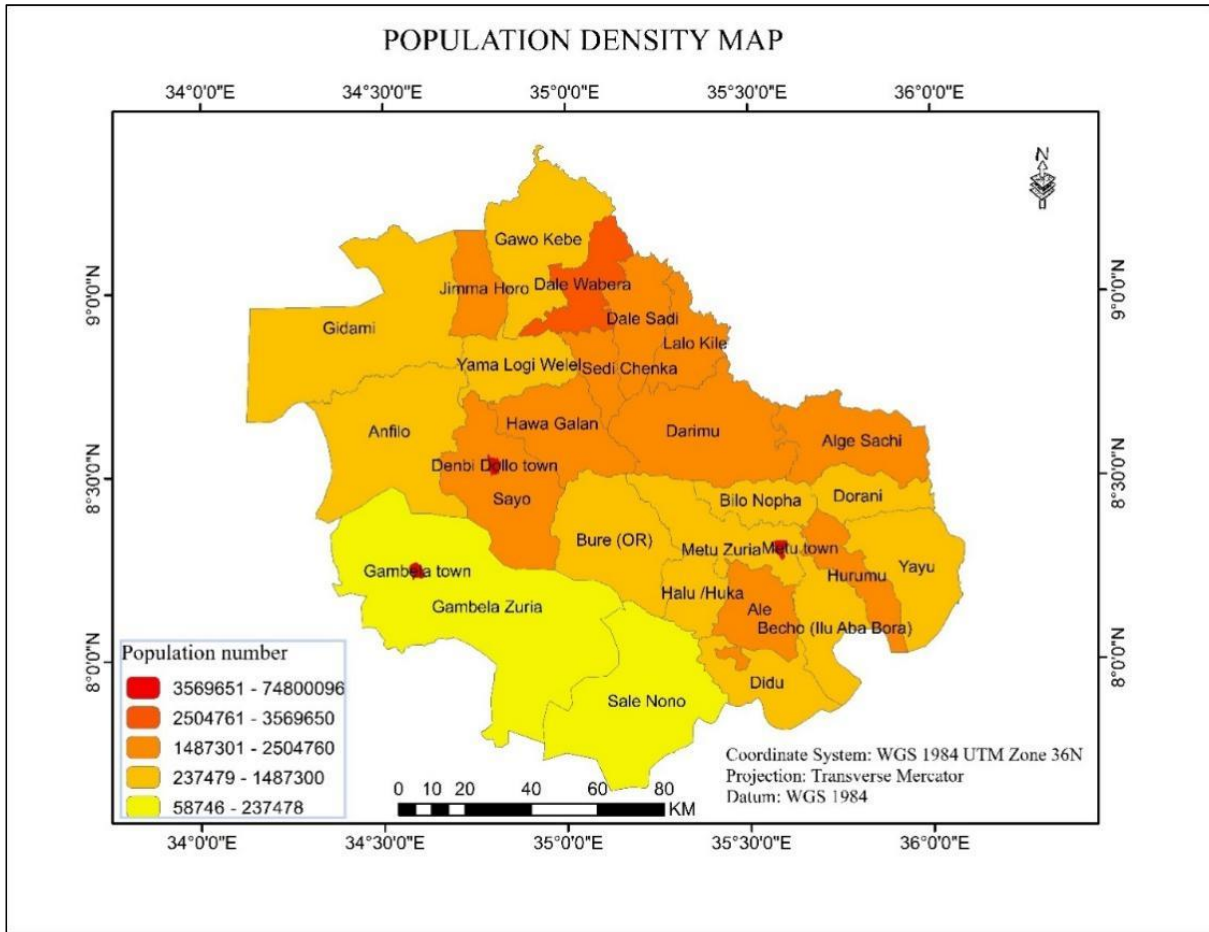


Figure 2: Population density map of the study area (Source: humdata.org)

Topography: The study area features a diverse topography with elevations ranging from 403 meters to 3258 meters. It includes valleys, hills, and potentially mountains, offering a varied landscape. The lower-lying regions display flat or gently sloping terrain, while the higher elevations showcase steeper slopes and rugged surfaces. This wide range of elevations indicates significant variations in the landscape, creating a diverse and dynamic topographic profile. The topography of the study area, as depicted on the map, showcases these landforms and elevation

changes. It provides valuable information to understand the spatial distribution and navigate through the area. The valleys, hills, and mountains contribute to the visual appeal, ecological diversity, and potential recreational opportunities of the study area. Elevation is supported with contour. See appendix VI.

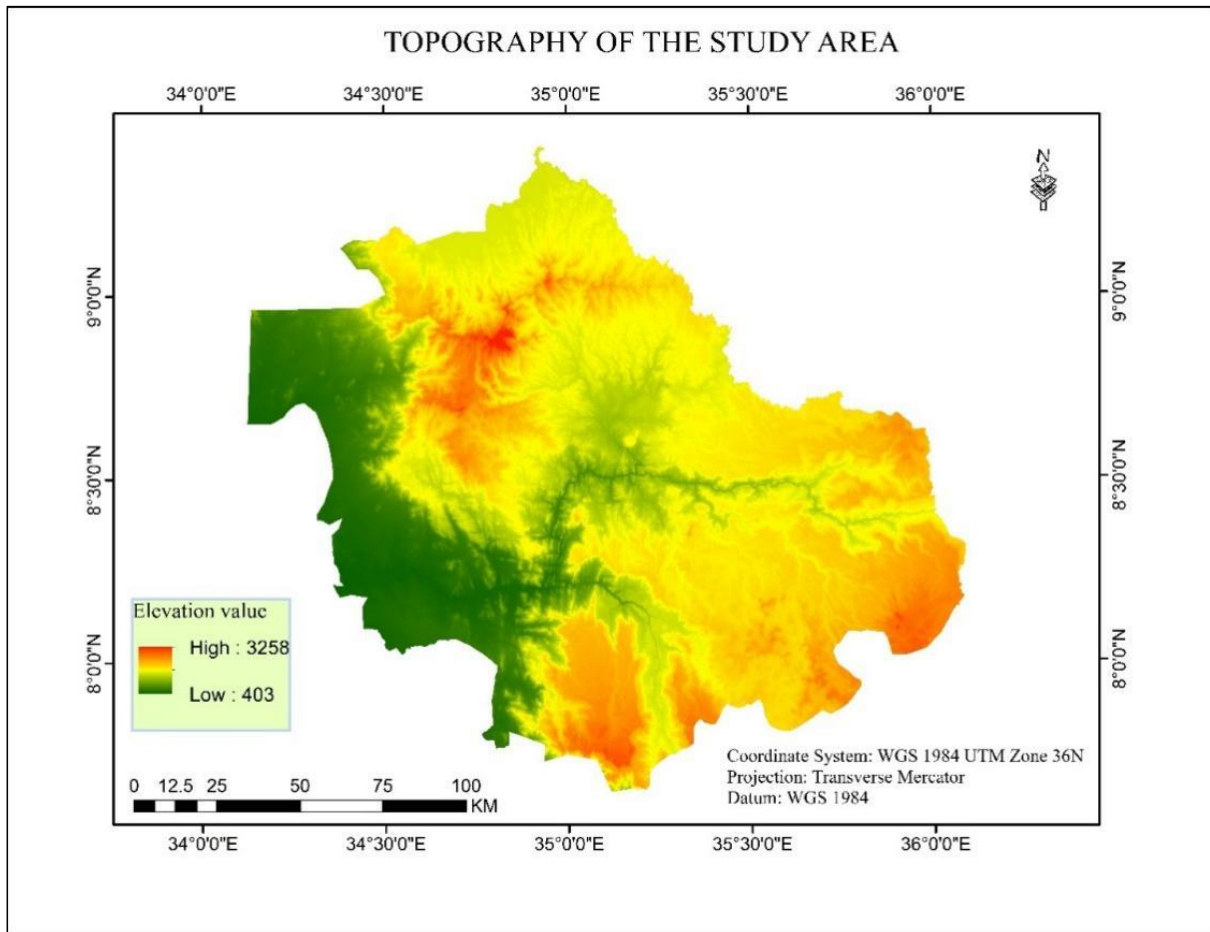


Figure 3: Topography of the study area (Source: ALOS DEM)

Hydrology: the study area is abundant in both surface and underground water, hosting numerous rivers within its boundaries. These water resources play a vital role in the hydrology of the region. Among the major rivers that flow through the area, the Baro River stands out as a prominent waterway. Originating from the Ethiopian Highlands, it traverses the study area, defining part of the Ethiopian border with South Sudan. The Baro River ultimately joins the Pibor River at their confluence, marking the beginning of the Sobat River, a significant tributary of the White Nile. The study area falls within the Baro Akobo basin, contributing to the overall

hydrological dynamics and emphasizing the importance of understanding the water systems for effective water resource management and environmental considerations.

3.2. Data source and material used

3.2.1. Data type and source

To choose the best road alignment, both geographical and socioeconomic data are considered. This study combines information collected from different sources to achieve its goal. See table 1 below which clearly displays the data used, the source of data, and the purpose for what data is needed for both geographical and socioeconomic factors.

Table 1: Data used and its source

S/N	Data	Source	Data type	Cell size	Purpose
1	Road network	ERA	Shapefile	-	To acquire up-to-date road information
2	Sentinel 2A	USGS (February 2, 2023)	Tiff	10m	To create a map of land use and land cover
3	Geologic map	USGS	Shapefile	-	To extract a geological map of study Area
4	DEM	PLASAR https://search.asf.alaska.edu/#/USGS_ALOIS	Raster	12.5m	To extract the drainage pattern, aspect, and slope
5	Soil Map	FAO	Shapefile	-	To classify and map soils
6	Population data	humdata.org	Excel data	-	To prepare a map displaying population density
7	Administrative boundary	ESSGI	Shapefile	-	For mapping study area

3.2.2. Software used

In this study, a suite of software tools was utilized to support various stages of the research process. These software applications played a crucial role in data organization, analysis, interpretation, and presentation. Through ArcGIS, ENVI, ERDAS IMAGINE, and IDRISI Selva, spatial data was effectively managed, manipulated, and analyzed, enabling the researchers to extract valuable insights and generate thematic maps. Global Mapper further contributed to the visualization and analysis of elevation data. MS Word and Excel facilitated the documentation and organization of research findings, allowing for efficient data interpretation and presentation. While data collection was not directly conducted through these software tools, their comprehensive functionalities greatly enhanced the research workflow, contributing to the overall success of the study. The table below offers a comprehensive summary of the different software applications employed in this study and their respective purposes. See table 2.

Table 2: Software used and their use

S/N	Software	Use
1	ArcGIS 10.4.1	For the preparation of all thematic layer for the research works
2	ERDAS, IMAGINE 2015	For image preprocessing
3	ENVI 5.3	For image classification
4	Global mapper 24.1	It is used to create maps that show drainage order, slope, and aspect.
5	IDRISI Selva 17.0	Employed for decision making purposes.
6	Microsoft Word and Excel 2019	Writing the report and document format and integrate data.

3.3.3. Criteria for road alignment selection

Slope : The most important and the almost unique criterion in highway alignment determination process is slope (Yakar & Celik, 2014). Slope is considered as a factor that affects road alignment selection because it impacts the safety, comfort, and cost of constructing and maintaining roads. Roads with steep slopes require more engineering and construction effort,

which translates into higher costs. They also pose a greater risk of accidents, especially during adverse weather conditions, such as rain, snow, or ice.

Furthermore, steep slopes may lead to increased wear and tear on vehicles, as well as increased fuel consumption. Therefore, it is considered as governing criteria in selecting a road alignment to ensure that it provides a safe and efficient transportation route while minimizing the construction and maintenance costs. The slope map is supported with contour. See appendix VI.

In this study slope with 12.5m x 12.5m grids size is created from digital elevation model that was prepared for the study area. It is classified based on the degree of inclination. See fig 4.



Figure 4: Slope map of the study area (Source: ALOS DEM)

Aspect: Aspect is a crucial environmental factor considered during route selection prior to construction. It refers to the direction a slope faces and impacts sunlight exposure, precipitation, and wind effects (Mondal et al., 2021).

Considering aspect during route selection allows planners to evaluate the potential impact on the surrounding environment. By understanding how aspects influence temperature, moisture levels, and vegetation growth, planners can make informed choices to minimize environmental disruption. Additionally, analyzing aspect helps identify areas prone to soil erosion and water runoff, enabling the implementation of appropriate measures to mitigate erosion risks and maintain road stability. Overall, aspect serves as an important criterion to ensure the sustainable and environmentally responsible construction of roads. The aspect map is prepared from DEM data of the study area.

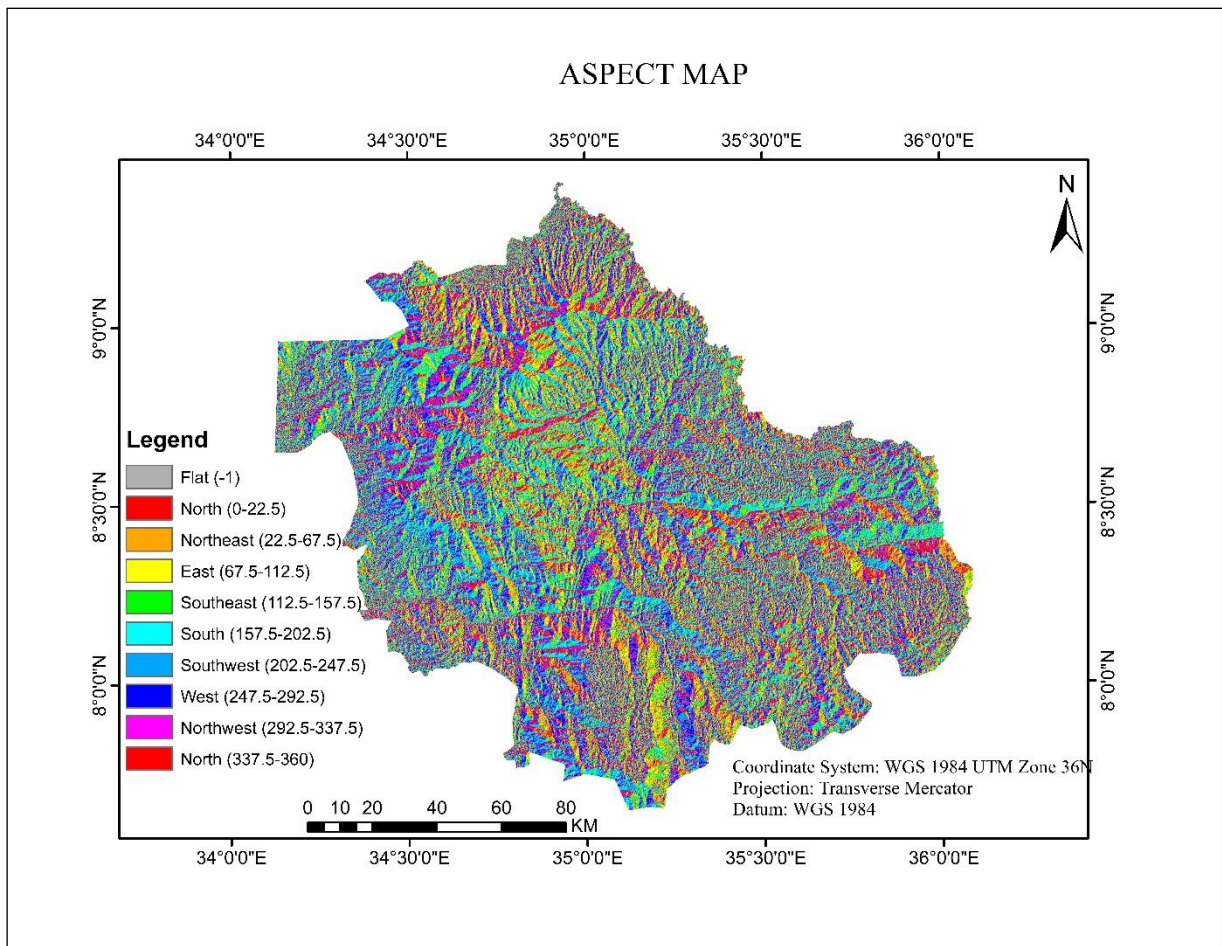


Figure 5: Aspect map of the study area (Source: ALOS DEM)

Elevation: Elevation is a significant factor that influences road projects, posing various geotechnical challenges. It plays a crucial role in road construction and maintenance, determining the suitability of areas based on technical requirements in optimal route design. To fully model the land surface, elevation should be represented as a continuous phenomenon rather

than discrete objects. This importance is further emphasized in the road route selection process, where elevation analysis informs decisions on slope design, earthwork operations, and the road's overall foundation. Proper assessment and understanding of elevation ensure the road's structural integrity and long-term stability. (Jana et al., 2017a) and (Ouma et al., 2014) considered elevation during road selection, to optimize design and construction, minimizing risks and maximizing efficiency and safety in the road infrastructure.

Drainage order: During route alignment selection, drainage serves as a critical parameter that directly impacts construction costs (Mondal et al., 2021) due to that it is essential to consider drainage networks, which portray the distribution of major rivers in the study area. This factor holds significant importance as it directly influences the expenses associated with bridge construction (Ouma et al., 2014)

The proper consideration and design of drainage is a critical factor in the selection of road alignment, as it plays a vital role in ensuring road safety, durability, cost-effectiveness, environmental protection, and accessibility. Inadequate drainage can lead to the deterioration of road surfaces, making them unsafe and costly to maintain, while proper drainage ensures that roads remain accessible during and after heavy rainfall, reducing the risk of damage to the surrounding environment.

In the study area, the proper consideration and design of drainage involve multiple orders to ensure road safety, durability, cost-effectiveness, environmental protection, and accessibility. The drainage system encompasses various features, including first-order channels to collect surface water, second-order structures for efficient flow, third-order retention facilities to manage peak flows, fourth-order systems for directing water to larger bodies, fifth-order integration of natural drainage patterns, sixth-order sustainable stormwater management techniques, and seventh-order maintenance programs. Understanding of this helps to establish a comprehensive and resilient system that minimizes flooding risks, prevents road deterioration, protects the environment, and promotes long-term sustainability.

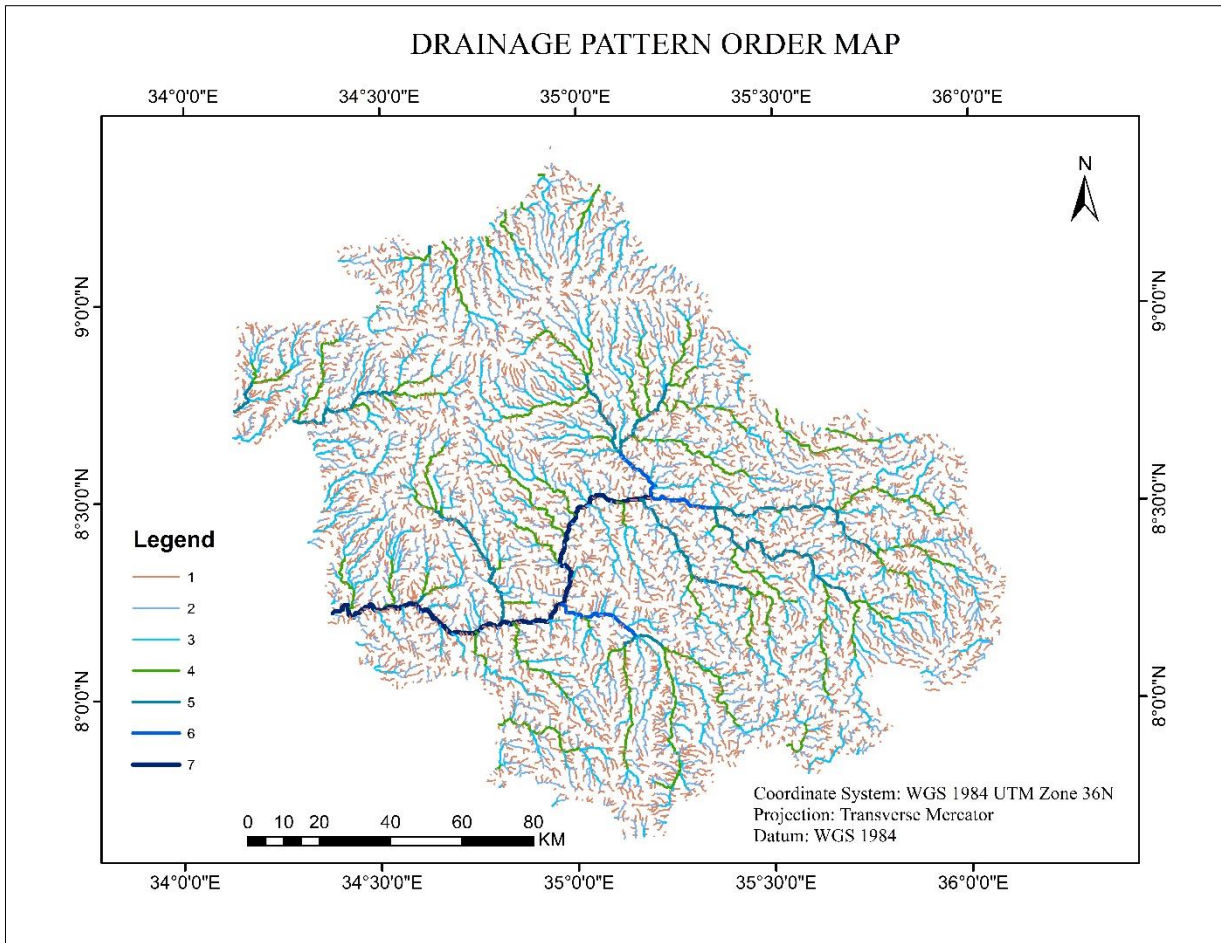


Figure 6: Drainage pattern order map of the study area (Source ALOS DEM)

Geology: Geological data is very important for the identification of the alignment of a route, especially in mountainous areas. Ignoring the geology in such regions may lead to disruptions in the form of landslides (Mondal et al., 2021). The characteristics of geological features impact the ease of construction on soft ground, the suitability of foundations, and the cost-effectiveness of blasting during construction (Tae-Ho et al., 2008). As a result, geology is considered a critical factor that affects both the technical and economic aspects of a project.

A thorough understanding of the study area's geology is vital for selecting an optimal road route, considering the presence of various rock types. The study area exhibits a diverse range of rock types that contribute to its geological composition. These rock types include Quaternary Alluvium, Tertiary Volcanics, Pre-Cambrian Metamorphic, and Quaternary Volcanics.

Quaternary Alluvium refers to sediment deposits formed during the Quaternary period, often consisting of sand, silt, clay, and gravel carried by rivers and streams. Tertiary Volcanics signify volcanic rocks formed during the Tertiary period, which can encompass various types such as lava flows, ash deposits, and volcanic breccias. Pre-Cambrian Metamorphic rocks have undergone extensive changes due to high pressure and temperature over long periods, resulting in altered mineral composition and distinct textures. Lastly, Quaternary Volcanics represent volcanic activities occurring during the Quaternary period, encompassing lava flows, pyroclastic deposits, and volcanic ash (Kazan-ankara, 2006; Lai et al., 2010; Sherrod & Smith, 1980).

Below is the geological map of the study area, displaying the distribution of rock types and highlighting the region's geological composition. This map provides valuable information about the area's geological characteristics and helps understand its geological history. It serves as a useful tool for analyzing the study area's geological features and characteristics:

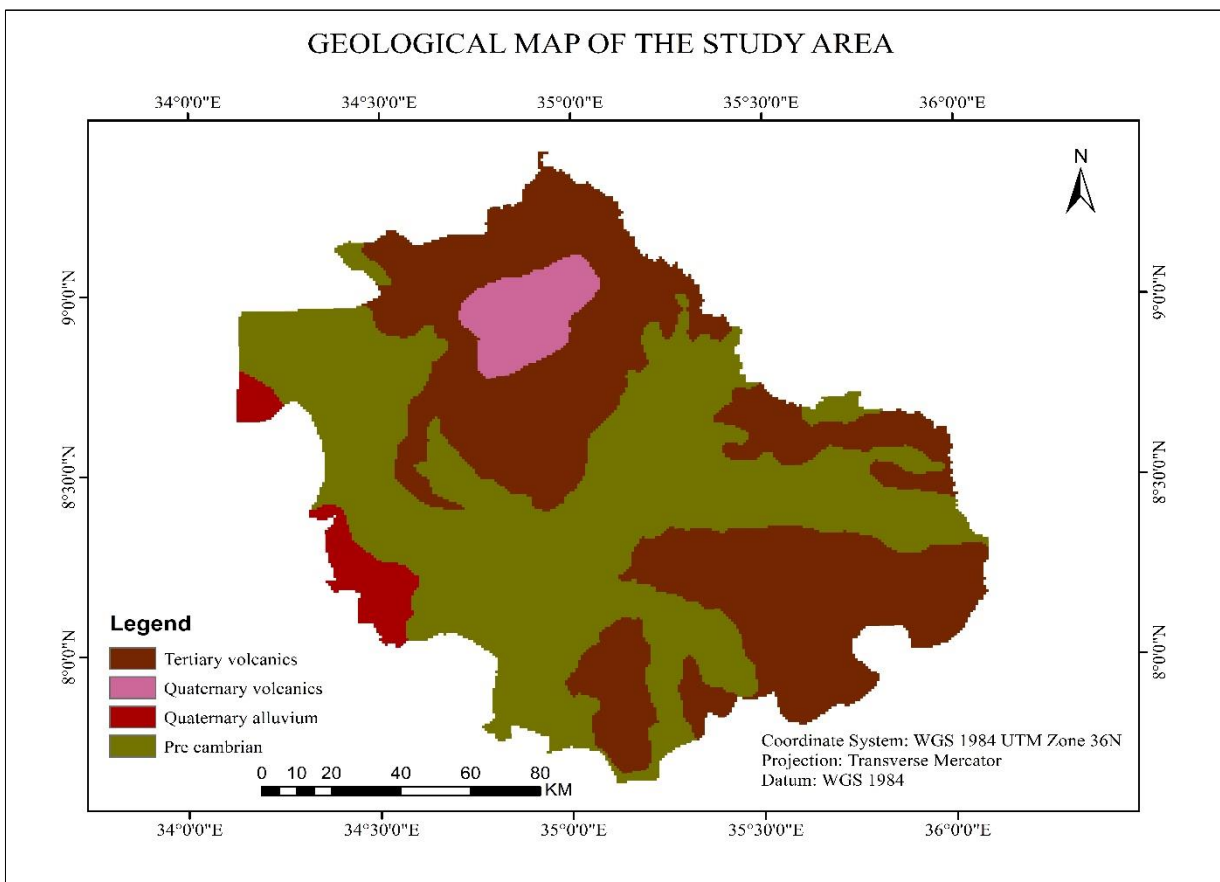


Figure 7: Geological map of the study area (Source: USGS)

The map provides a visual representation of the distribution of various rock types in the study area. Analyzing this map allows to make informed decisions. Understanding the geological composition is crucial for assessing the feasibility, stability, and cost-effectiveness of the chosen route.

Land use land cover: LULC data are essential for assessing the environmental impacts of a proposed highway, determining compensation for acquired land, and understanding the economic, societal, and environmental aspects affected by different land uses. By considering the classification of land use based on environmental effects and land prices, decision-makers can make informed choices that promote sustainable land-use planning and minimize potential negative consequences on the environment and society (Ouma et al., 2014; Tae-Ho et al., 2008).

The study area's land use land cover (LULC) classification process involved utilizing imagery from Sentinel 2A, specifically the data acquired on February 2, 2023. These satellite images offered a spatial resolution of 10 meters, allowing for detailed analysis of the land cover features within the study area. In order to capture the entirety of the study area, a total of eight scene images were carefully mosaicked together. This merging process seamlessly combined the individual images into a comprehensive and continuous representation of the study area.

To derive the LULC classification, a supervised classification approach was employed. This method involves training the classification algorithm using a set of pre-defined classes or training samples. These training samples are selected based on known characteristics and representative examples of each land cover type of interest. The algorithm then analyzes the spectral information and other relevant features present in the satellite imagery to classify each pixel into one of the predefined land cover classes.

To evaluate the accuracy of the LULC classification results, a satellite image retrieved from Google Earth, featuring the research area, was used as a reference. The Google Earth image was particularly useful for this purpose due to its minimal cloud cover, ensuring a clearer and more accurate representation of the land cover in the study area. By comparing the classification results with the reference image, the accuracy and reliability of the classification process were assessed, providing confidence in the final classification outcome. See fig 8 below to understand the LULC classification of the study area.

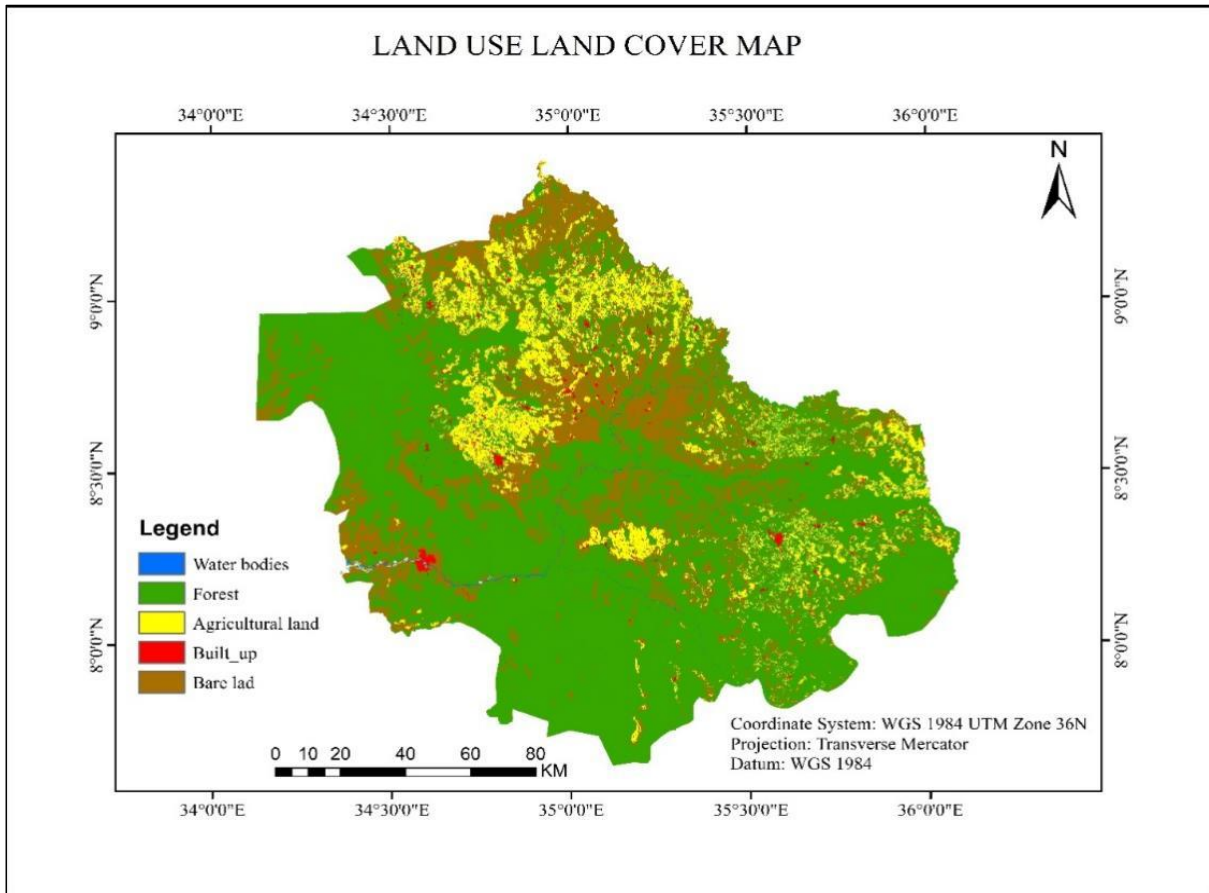


Figure 8: Land use land cover map of the study area (Source: Sentinel 2A)

Existing road network: While the construction or extension of a road is crucial for improving connectivity, it is equally important to consider the accessibility it provides to other existing roads. Neglecting this aspect could result in isolated road networks and hinder overall transportation efficiency and connectivity in the region. (Tae-Ho et al., 2008) therefore, this study estimates the relative importance weights of road networks with respect to the accessibility of road by classifying roads into major roads, minor roads, and track road.

Existing roads in the study area serve as crucial criteria for route selection. They provide insights into connectivity, traffic flow, infrastructure capacity, safety considerations, environmental impact, cost-effectiveness, and land use. By utilizing the current road network, we can optimize route selection in the study area, ensuring both efficiency and sustainability in transportation planning. This approach capitalizes on existing infrastructure, minimizing the need for extensive construction and reducing environmental impact.

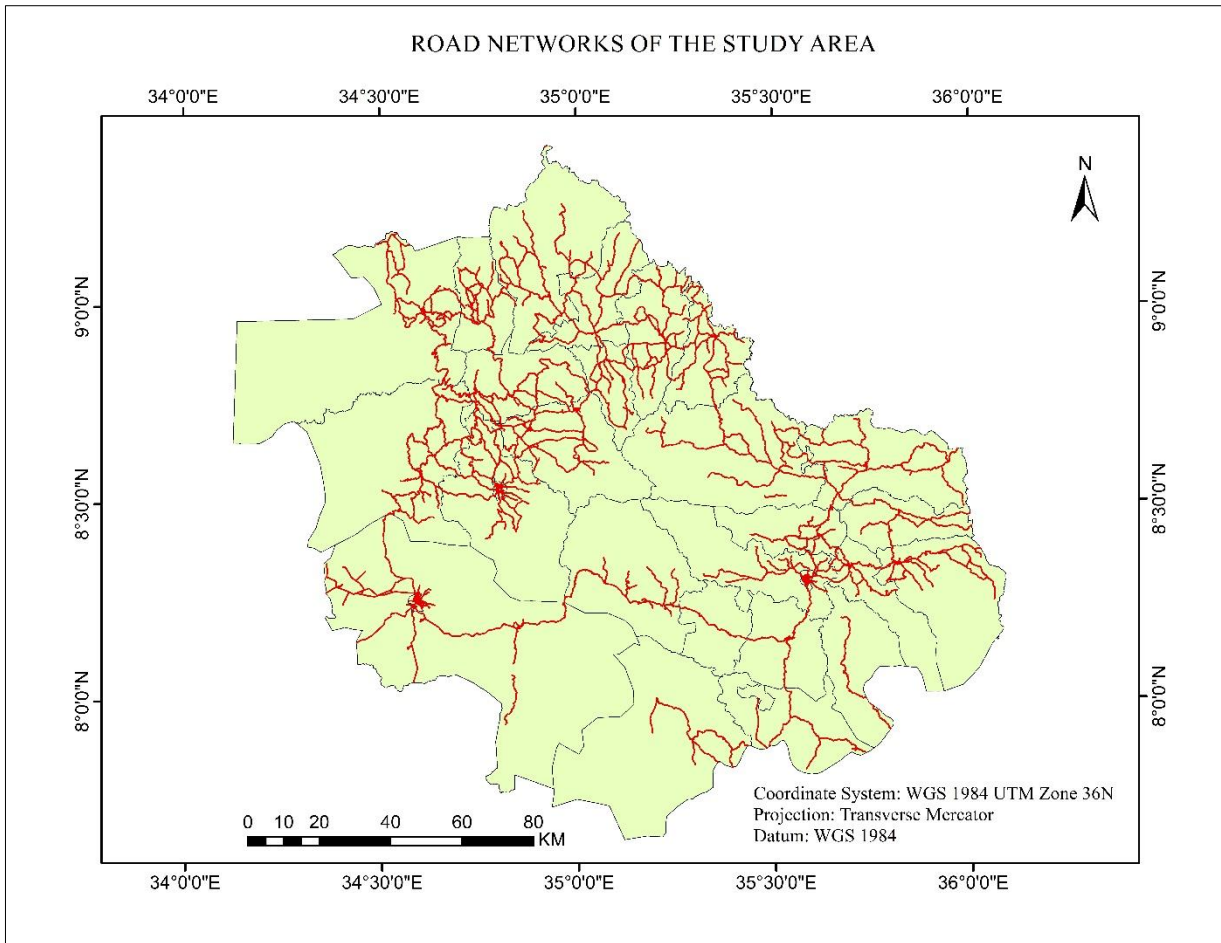


Figure 9: Road network map of the study area (Source: ERA)

Soil: The study area encompasses a diverse range of soil types that significantly influence road construction and its long-term feasibility. These soil types include Vertic Cambisol, Bathurst, Anthrosol, Bedrock, and Neosol. Vertic Cambisol is prone to soil movement and instability, requiring special attention during road construction. Bathurst, on the other hand, provides a stable foundation for roads. Anthrosol, Bedrock, and Neosol necessitate assessment and stabilization measures before road construction (Mck, 2010; Mohanty et al., 2020; Soil & Reports, 2015; Stratigraphy & Zone, n.d.).

Each soil type exhibits specific characteristics such as clay movement, distinct color and texture, human activity influence, and the presence of underlying rock formations. Furthermore, the study area demonstrates various soil textures, including clay, clay-loam, and loam. Clay soils have small particles and high water-holding capacity, while clay-loam soils strike a balance

between water retention and drainage. Loam soils, composed of sand, silt, and clay, provide favorable conditions for plant growth with good drainage and nutrient retention.

The composition of soil, including its type and properties, plays a significant role in construction feasibility, ground stability, drainage management, and overall sustainability of road systems. Evaluating soil data is a critical aspect of route selection in the engineering field as it provides valuable insights into the soil's suitability for road construction, settlement potential, bearing capacity, and drainage characteristics. This information guides engineers in choosing the least costly path while ensuring the long-term performance and feasibility of the road infrastructure (Jana et al., 2017a).

The consideration of soil composition is of utmost importance when designing road networks that are not only safe and durable but also economically viable and sustainable. In the study, soil is recognized as a critical factor in the selection of road routes, as it significantly influences the feasibility, safety, and long-term performance of the road project.

Understanding the properties of the soil in the study area is crucial for making informed decisions during the route selection process. Various soil characteristics, such as bearing capacity, compaction ability, stability, permeability, and erosion potential, need to be thoroughly evaluated to determine their suitability for road construction. Assessing these properties, helps to identify the soil types that are most suitable for supporting road infrastructure and withstanding the expected traffic loads and environmental conditions.

The study places a particular emphasis on selecting routes that have soil compositions capable of providing a solid foundation for the road. Soils with good bearing capacity are desirable to ensure that the road can support heavy vehicles and withstand the repetitive stresses caused by traffic. Moreover, the compaction ability of the soil is evaluated to ensure proper compaction during the construction phase, which contributes to the road's stability and longevity.

The permeability of the soil is also a critical consideration. It determines how well the soil can drain excess water, preventing waterlogging and potential damage to the road structure. By selecting routes with soils that have suitable permeability, the study aims to minimize the risk of water accumulation, which can lead to pavement deterioration and decreased road safety.

Furthermore, the potential for soil erosion is taken into account. Routes that traverse areas with highly erodible soils may require additional erosion control measures to mitigate the negative impact of water runoff and ensure the stability of embankments and slopes. By considering erosion potential, the study seeks to prevent soil loss and preserve the integrity of the road infrastructure.

By prioritizing soil considerations in the route selection process, the study aims to ensure the long-term feasibility and performance of the road project. Designing roads that are compatible with the soil conditions in the study area promotes sustainable construction practices, reduces the risk of premature failures, and minimizes the need for costly maintenance and repairs. Ultimately, by accounting for soil composition, the study aims to create road networks that are not only safe and sustainable but also economically viable for the communities they serve.

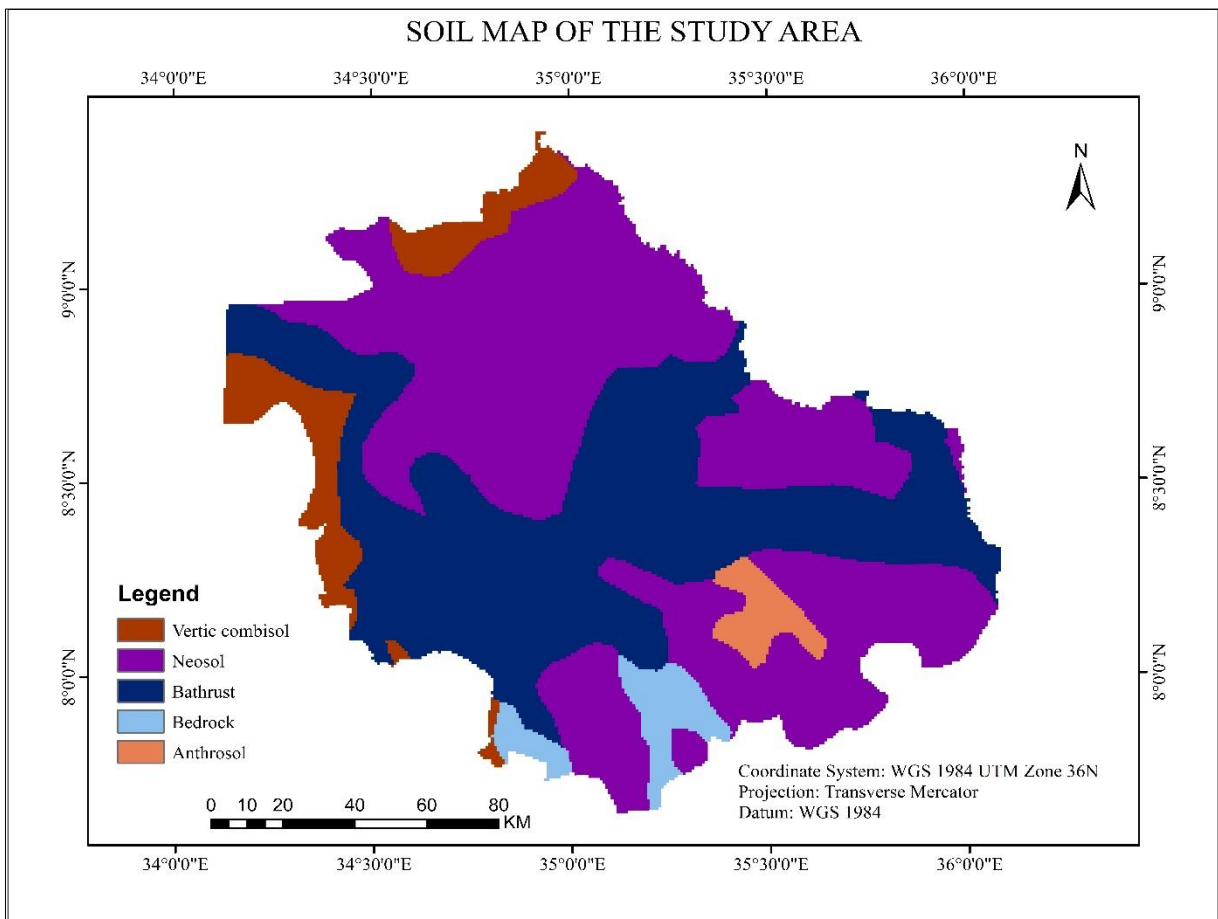


Figure 10: Soil map of the study area (Source: FAO Soil)

3.3. Methods

The research methodology for this study involved the implementation of a systematic approach to achieve the research objectives. It encompassed a series of general methods that were carefully executed to ensure reliable and meaningful results. The step-by-step process of the methodology was carefully designed and followed to maintain consistency and rigor throughout the research. This systematic workflow served as a roadmap, guiding the researcher through the various stages of data collection, processing, analysis, and interpretation. By adhering to this well-defined methodology, the study was able to effectively address the research questions and produce valuable insights. The workflow, which captured the sequential progression of the methodology, is presented on flowchart of research methodology as a visual representation of the research process.

3.3.1. Data collection method

The data collection for the study area involved gathering spatial information in the form of shapefiles and raster datasets. These datasets encompassed a wide range of geospatial information that played a crucial role in the route selection analysis. Specifically, the digital elevation model data was utilized to derive essential terrain attributes, including slope, aspect, and drainage order. These attributes provided a comprehensive understanding of the topographic characteristics within the study area.

Various ancillary datasets, including Land Use Land Cover, soil, road network, geological, and population density maps, were incorporated into the analysis, providing insights into land cover, soil types, road infrastructure, geological features, and population distribution. This diverse dataset facilitated a thorough assessment of the study area and played a pivotal role in the subsequent route selection process.

3.3.2. Data preparation and processing:

The collected data was cleaned, organized, and preprocessed to ensure consistency and compatibility. This included data extract, clip, mosaicking, classification, data integration, and data quality checks. The data was prepared in a format suitable for analysis. All the data collected were analyzed through visual inspection and exploratory data analysis techniques. High resolution google earth images were used to verify the actual data value on the field for satellite image.

Rasterization: The selection criteria maps, which were originally in a different format, were changed to a grid-like format called raster. This conversion divided the maps into smaller cells or pixels, where each cell represented a specific location. Rasterization made it easier to store and analyze the maps, and also made them compatible with other data that uses the same grid format.

Resampling: The vector-based selection criteria maps were first converted into a grid-like raster format through a process called rasterization. This allowed the maps to be divided into smaller cells or pixels, simplifying storage and analysis. However, after rasterization, the criteria maps may have had different spatial resolutions or cell sizes. To ensure consistency and alignment among the maps, a process called resampling was carried out. Resampling involved adjusting the resolution or cell size of the raster data to a desired spatial resolution. In this case, all the criteria maps were resampled to a resolution of 10 meters. This ensured that all the maps had the same level of detail and allowed for proper integration and analysis of the criteria maps.

Reclassification: After converting the criteria maps into raster format and adjusting their cell sizes, the next step was reclassification. In this step, the cells were assigned new values or categories based on specific criteria. Cells with similar characteristics were grouped together into distinct classes or categories. Reclassification simplified and standardized the criteria maps, making them suitable for the overlay analysis that would follow. This process helped to organize and categorize the data, facilitating effective comparison and analysis of all criteria. Different criteria Maps are reclassified to the range accordingly and respective cost is assigned. See appendix II, III, and V.

Accuracy assessment: Accuracy evaluation or validation plays a crucial role in the processing of remote sensing data (Macarringue et al., 2022). It serves as a means to determine the degree of "correctness" in a classification result. Prior to utilizing the classification outcome for data analysis and scientific investigation, it is essential to assess the accuracy of a remote sensing image classification (Brinkhoff et al., 2020). This evaluation ensures the reliability and validity of the classification output, providing confidence in the subsequent analyses and applications of the data.

The classified image was subjected to an accuracy assessment to evaluate its performance and reliability. This involved comparing it with reference or ground truth data obtained from high-

resolution Google Earth images, serving as an independent and reliable source for validation. By comparing the classified image with the ground truth data, the study assessed agreement levels, identified discrepancies or errors, and measured the overall classification accuracy. The primary objective of the accuracy assessment was to select pixels based on identification from Landsat, Google Earth, and Google Maps for land cover classification. Google Earth served as the reference data and visual interpretation tool. The study area was divided into five major classes: water body, bare land, built-up, agriculture, and forest.

Table 3: LULC accuracy assessment

Classified map	Referenced data						Total	User accuracy	Commission error
	LULC class	Water body	Forest	Agricultural land	Built-up area	Bare land			
Water body	62	1	0	0	0	63	0.984	0.016	
Forest	0	55	6	0	0	63	0.873	0.127	
Agricultural land	0	5	56	0	2	63	0.889	0.111	
Built-up area	0	0	0	58	5	63	0.921	0.079	
Bare land	0	0	2	1	60	63	0.952	0.048	
Total	64	61	64	59	67	315			
Producer accuracy	0.969	0.902	0.875	0.983	0.896				
Omission error	0.031	0.098	0.125	0.017	0.104				
Overall accuracy = 92.4%			Chance agreement = 18%			Kappa coefficient = 90.7%			

The accuracy assessment results revealed varying levels of accuracy for different land cover classes. The water body class exhibited the highest accuracy with a user's accuracy of 98.4%. Conversely, the forest class had the lowest accuracy at 87.3%. The accuracies for the bare land,

built-up, and agriculture classes were determined to be 95.2%, 92.1%, and 88.9%, respectively. The lower accuracy values in certain classes can be attributed to misclassification caused by spectral similarities among different land cover classes, making it challenging to distinguish between them. The evaluation of classification performance utilized the producer's accuracy, calculated as the ratio of correctly classified pixels to the total number of reference data pixels in each class. These accuracy values were derived from the classification results presented. See table 3.3 above, which provide a detailed overview of the accuracy assessment for the land use and land cover classification.

The computed kappa coefficient for the classification results is 0.907, signifying a high level of agreement between the classified and reference images. This demonstrates the effectiveness of the classification method employed in this study. The chance agreement, which represents the level of agreement expected by chance alone, stands at 18%. Consequently, the classification results significantly surpass random chance, indicating the reliability of the classification approach. The overall accuracy of the classification stands at 92.4%, exceeding the acceptable threshold of 85%. Furthermore, non-diagonal elements in the error matrix highlight instances of classification errors. A kappa coefficient above 0.8 indicates strong agreement, while values between 0.4 and 0.8 suggest moderate agreement, and values below 0.4 signify poor agreement (Congalton, 2001; Landis & Koch, 1977).

To ensure a representative assessment, the study employed an equalized stratified random sampling strategy and utilized the ArcGIS toolbox. This approach minimized potential biases and enabled a reliable evaluation of the classification results.

Preparation of cost distance raster

The cost weighted distance function was applied to the cost raster of preferred theme and the source location, resulting in an output raster where each cell was assigned a value indicating the least accumulated cost distance across the cost surface to the specified source locations. In the cost weighted raster, each cell was assigned a value representing the total minimum travel cost required to return to the nearest source location.

The cost distance analysis incorporated three preferred themes, namely Economic, Technical, and Environmental. This resulted in the generation of three distinct cost distance maps each

corresponding to one of the themes. These maps played a crucial role in identifying the least cost path by taking into account the prioritized factors within each theme. The Economic theme focused on financial considerations, evaluating the economic viability and potential benefits of different route alignments. The Technical theme considered technical parameters such as slope and existing infrastructure, ensuring the feasibility and efficiency of the chosen path. The Environmental theme assessed environmental impacts and biodiversity significance, enabling the selection of routes that minimize negative consequences. By integrating these themes into the cost distance analysis, decision-makers were able to comprehensively evaluate and compare the various route options, leading to an informed decision based on a holistic assessment of economic, technical, and environmental factors.

Preparation of backlink raster

In the process of generating the cost weighted distance raster, an additional program, known as the backlink raster, was introduced. This program utilized both the cost raster and the source raster. The backlink raster consisted of values ranging from 0 to 8, indicating the direction to follow from each cell in the cost distance raster to trace the cumulative cost path back to the source point. The algorithm involved assigning each cell a value representing the direction towards the nearest and most cost-effective cell.

Analytical Hierarchy Process

AHP offers a systematic framework for quantifying the comparison of decision elements and criteria by considering them in pairs. This pairwise comparison greatly simplifies the complexity involved in decision-making, making it more straightforward. The concept of AHP was first introduced by Saaty in 1980, where the relative ratings of two criteria are measured on a scale ranging from 1 to 9, as depicted. See table 4 below.

The AHP methodology facilitates the incorporation of both subjective and objective aspects into the decision-making process. The weights assigned to each criterion are derived from the comparative matrix of criteria. The calculation of a Consistency Index is then performed, and if the calculated value falls within a weight range threshold of 10%, the assigned weight is considered acceptable. This approach ensures a balanced consideration of various factors and promotes consistency in decision-making.

Table 4: Comparison scale for AHP rating

AHP scale of Importance for pairwise comparison	Numeric rating	Reciprocal
Extreme importance	9	1/9
Very strong to extremely	8	1/8
Very strong importance	7	1/7
Strongly to very strong	6	1/6
Strong importance	5	1/5
Moderately to Strong	4	1/4
Moderate importance	3	1/3
Equally to moderately	2	1/2
Equal importance	1	1

3.3.3. Method of data analysis

The process of analyzing the data and determining the optimal route alignment involves several steps. It begins with data collection and preprocessing, which involves gathering remote sensing data and maps and processing them using geospatial software. This ensures that accurate and reliable data is available for analysis. The next step is criteria prioritization, where evaluation criteria are identified and assigned weights using the Analytical Hierarchy Process. This step helps prioritize the criteria based on their relative importance in the decision-making process. Following criteria prioritization, the reclassification and weighted overlay step is performed. Maps associated with the criteria are reclassified based on specific thresholds or classes. These reclassified maps are then overlaid, considering their respective weights. This generates preferred theme maps that highlight areas meeting the desired criteria.

Next, road alignment alternatives are assessed based on the preferred theme maps generated in earlier steps. This assessment process takes into account the criteria and their corresponding maps, enabling informed decisions to be made regarding the optimal route alignment. By following this systematic approach, from data collection and preprocessing to the prioritization of criteria, reclassification and weighted overlay of maps, and assessment of road alignment alternatives based on preferred theme maps, a comprehensive analysis is conducted to determine

the optimal route alignment based on the specified criteria and preferences. The flow work below shows the overall procedures followed in this study.

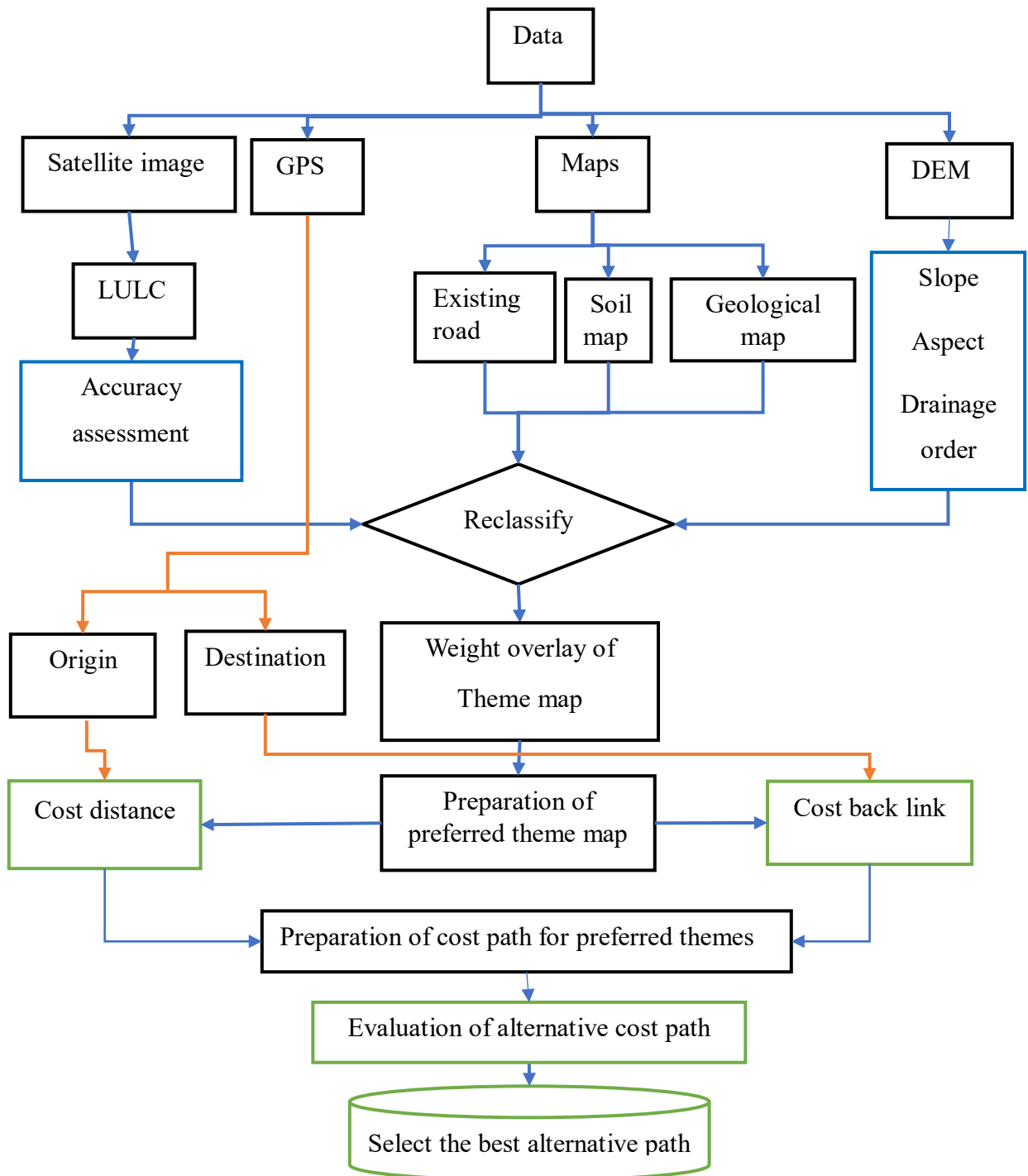


Figure 11: Flowchart of research methodology

3.4. Criteria determination and weight assignment

In criteria, mapping process weight was assigned for the factors to combine in the raster calculator. If the study area has very steep slopes, a high weight will be set to the slope raster value, giving it a higher weight, more attention is given to avoid a steep slope. To reduce the effect of different technical, economic and environmental parameters on the road, three suitable surfaces were prepared to define the least cost routes. All criteria were derived through literature review, expert consultation (personal discussion), and ERA design and route selection manually also used.

Technical theme

The technical theme, which encompasses the physical aspects and engineering considerations of road construction, plays a vital role in route selection. It takes into account several factors, including elevation, that have a significant influence on road construction and influences slope, which directly impacts road stability.

Additionally, it affects geology, determining the appropriate construction techniques based on the types of rocks and soil encountered. Soil, influenced by elevation, also plays a crucial role as it determines the road's foundation and overall stability. By considering elevation alongside other technical factors, such as slope, geology, and soil, road planners can ensure proper construction, safety, and durability. This comprehensive approach enables effective management of water flow, stability, and overall functionality of the road.

To create the engineering suitability surface slope has been classified into four classes(ERA Manual, 2013) to avoid the steep area for road alignment and the geology of the study area has been classified based on the suitability of foundation and the soil has been classified as per texture and suitability of dominant soil for the foundation since it controls the bearing capacity of sub-grade material.

Likewise, the elevation is classified based on the required amount of cut and fill and also to give good driving comfort. Medium elevation is chosen for road alignment due to its balanced advantages, including improved safety with manageable gradients, cost-effectiveness through reduced construction work, and minimized environmental impact by preserving the natural terrain. The reclassified table for the technical theme factor is presented below. See table 5.

Table 5: Reclassified technical theme factor

Criteria maps	Class	Suitability	Cost
Slope	0-2 (Flat)	Suitable	1
	3-14 (Rolling)	Moderately suitable	3
	15-37 (Mountainous)	Less suitable	5
	>37 (Escarpment)	Unsuitable	7
Rock types	Pre-Cambrian Metamorphic	Suitable	1
	Tertiary Volcanics	Moderately suitable	2
	Quaternary volcanics	Less suitable	5
	Quaternary Alluvium	Unsuitable	7
Dominant soil	Vertic Cambisol	Suitable	1
	Bathurst	Moderately suitable	2
	Anthrosol	Less suitable	3
	Bedrock	Moderately unsuitable	5
	Neosol	Unsuitable	7
Elevation	403 - 843	Moderately suitable	3
	844 - 1,283	Suitable	1
	1,284 - 1,589	Less suitable	5
	1,590 – 1,901	Moderately unsuitable	7
	1,902 – 3,258	Unsuitable	9

The reclassified table of the technical theme factors offers a clear overview of the conditions suitable for road alignment based on slope, geology suitability, soil suitability, and elevation. By assigning appropriate classifications to each factor, the table allows for the identification of areas that meet the necessary engineering requirements, ensuring safety and cost-effectiveness in the road construction process.

This information is vital for making decision to select the most suitable route alignment that minimizes engineering challenges and optimizes the overall technical feasibility of the road project.

Economical theme

The economic theme in route selection involves assessing the financial aspects of road construction. The factors like existing road, drainage order, geology, and land use land cover affect the economy of route selection (Poudel & Kumar, 2022). This includes compensating for agricultural land and settlements affected by the project, considering the cost of constructing bridges based on drainage order, evaluating the feasibility of upgrading existing roads to minimize expenses, and determining the economic efficiency of blasting rock during construction. By considering these economic factors, decision-makers can make informed choices that optimize resources, reduce costs, and maximize the economic benefits of the road project.

In economic suitability cost surface more attention was given to the existing road in the area (Tae-Ho et al., 2008) and drainage order. The drainage of the study area has been classified as per stream order to avoid bridge construction and the flood risk area. LULC is classified into five classes based on study area characteristics (forest, agriculture, waterbody, built-up, and bare land) to avoid high-cost land use land cover types (Wahdan et al., 2019). Likewise, in this team, the geology of the study area is classified based on economic efficiency of blasting hard rocks to reduce construction costs.

The existing road network, given the highest weight, is buffered by 15 meters, rasterized, resampled, and reclassified to identify suitable areas for road development. Similarly, the drainage order is buffered by 50 meters, and the same resampling and reclassification process is applied to both the buffered drainage order and the existing road network to determine suitable areas in relation to drainage patterns. Additionally, the classified image is reclassified based on the assumed compensation cost for land use changes, providing insights into the cost implications associated with different land cover classifications. The resulting reclassified map represents the economic theme factor, offering a comprehensive overview of the suitability of each grid cell, guiding the selection of areas that minimize construction costs and optimize route efficiency.

The reclassified map of the economic theme factor, based on their suitability, is presented in the table below showing the suitability and the cost assigned for each factor. See table 6 below.

Table 6: Reclassified economical theme factor

Criteria maps	Class	Suitability	Cost
Land cover	Bare-land	Highly suitable	1
	Forest	Moderately suitable	3
	Agriculture	Less suitable	5
	Built-up and water bodies	Unsuitable	7
Existing road type	Major road	Highly suitable	1
	Minor road	Suitable	3
	Track road	Moderately suitable	5
	No road	Less suitable	7
Rock types	Quaternary Alluvium	Highly suitable	1
	Tertiary Volcanics	Less suitable	5
	Pre-Cambrian Metamorphic	Unsuitable	7
	Quaternary Volcanics	Suitable	3
Drainage order (Mondal et al., 2021)	No drainage	Highly suitable	1
	First order	Suitable	2
	Second order	Moderately suitable	3
	Third order	Less suitable	5
	Fourth order	Unsuitable	7
	Fifth order and above	Highly unsuitable	9

The reclassified table of the economic theme factor, which combines all the mentioned criteria, offers a comprehensive overview of the suitability of each grid cell within the study area. This table facilitates the identification of areas that align with the economic objectives of minimizing construction costs and optimizing route efficiency.

By assigning cost values to each cell, the table highlights areas with lower costs, indicating their suitability for the economic criteria. This information can aid to identify the most cost-effective route alignment that maximizes economic benefits while minimizing expenses, and this information helps to know which class need high cost and low cost. The overall selection depends on this assigned cost.

Environmental theme

The environmental theme in route selection involves assessing the ecological and environmental aspects of road construction. Specific factors considered in this theme include the distance from settlements (built up areas), agricultural land, water bodies, and aspect in the study area. These factors play a crucial role in determining the most suitable route that balances transportation needs with environmental preservation. The distance from settlements is taken into account to minimize disruptions to populated areas and ensure community well-being.

Preserving agricultural land is important for maintaining productive land. Careful consideration of water body is necessary to prevent adverse impacts on aquatic habitats, water quality, and the overall hydrological balance. Additionally, the aspect of the terrain is considered to evaluate its influence on microclimates, solar exposure, and potential erosion or stability issues.

In this study, we combine different environmental factors when choosing routes. This helps decision-makers make smart decisions that support sustainable development, protect ecosystems, and preserve the natural beauty of the study area.

The distance from built-up areas, water bodies, and agricultural land is prioritized as important factors in the route selection process. We consider specific distance thresholds to determine the suitability of routes. For instance, distances less than 100 meters from built-up areas and water bodies are deemed unsuitable, while distances greater than 1500 meters and 500 meters, respectively, are considered suitable. Similarly, distances less than 100 meters from agricultural land are considered unsuitable, while distances greater than 300 meters are deemed suitable. This approach ensures optimal suitability in relation to these specific features.

To implement this methodology in ArcGIS, we begin by converting the classified land use/land cover (LULC) data to polygons using the Conversion Toolbox. From these polygons, we extract the agricultural land, water bodies, and built-up areas. Multi-buffering is then applied to create buffers around these features, using buffer distances of 100-1500 meters for built-up areas, 100-300 meters for agricultural land, and 100-500 meters for water bodies.

These buffered zones are subsequently rasterized, resampled, and reclassified, facilitating the creation of thematic maps. The value of reclassified map for all criteria is presented. See table 7 below.

Table 7: Reclassified environmental theme factor

Criteria maps	Class	Suitability	Cost
Proximity to Built-up area (Karna, 2014)	<100	Unsuitable	9
	100-300	Highly Suitable	2
	300-500	Suitable	5
	500-1000	Moderately suitable	7
	1000-1500	Less suitable	8
	>1500	Unsuitable	9
Proximity to stream and water bodies (Poudel & Kumar, 2022)	0-100	Unsuitable	5
	100-200	Less suitable	4
	200-350	Moderately suitable	3
	350-500	Suitable	2
	>500	Highly suitable	1
Proximity to agricultural land (Wahdan et al., 2019)	<100	Less suitable	5
	100-200	Moderately suitable	3
	200-300	Suitable	2
	>300	Highly suitable	1
Aspect (Mondal et al., 2021)	North (337.5-360)	Highly suitable	1
	North west (292.5-337.5)	Moderate to high suitable	2
	West (247.5-292.5)	Suitable	3
	South West (202.5-247.5)	Moderately suitable	4
	South (157.5-202.5)	Less suitable	5
	South East (112.5-157.5)	Unsuitable	6
	East (67.5-112.5)	Moderately unsuitable	7
	North East (22.5-67.5)	Moderate to less suitable	8
	North (0-22.5)	Highly unsuitable	9

Low-cost values on the table indicate high suitability, while high-cost values indicate unsuitability. This classification approach enables identification of areas with varying levels of suitability and aids in route selection based on desired conditions and environmental factors.

CHAPTR IV: RESULT AND DISCUSSION

4.1. Spatial data analysis

In the context of spatial data analysis, the reclassified raster assigns the least value to the most desirable choice (least cost) and the highest value to the least desirable choice (highest cost). To determine the weightage for the criteria maps corresponding to their respective themes (engineering, economical, and technical), the AHP methodology is employed. This approach allows for a comprehensive analysis and comparison of different criteria, facilitating informed decision-making in spatial data analysis. Flowchart for carrying out AHP is as shown in below.

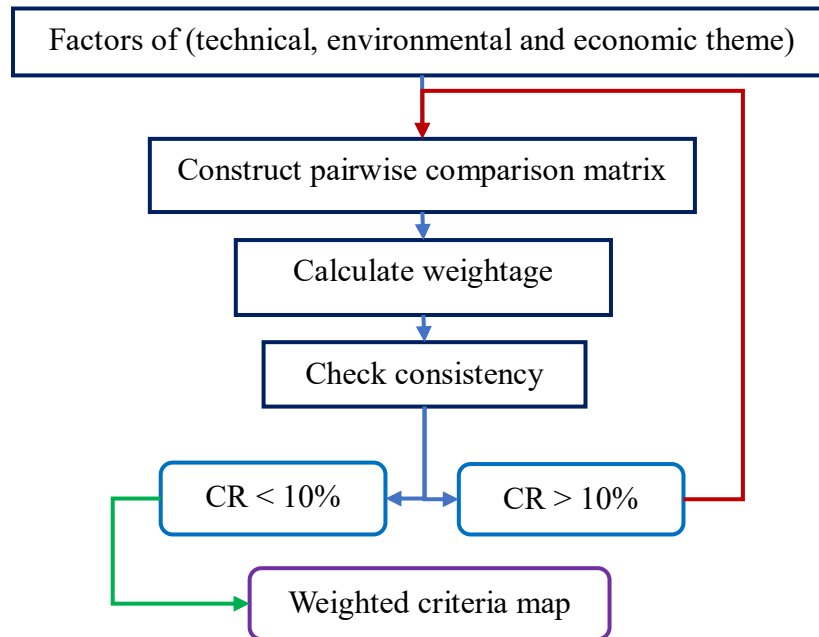


Figure 12: Weighted criteria map creation process

The weightage calculation using AHP was conducted using the IDRISI Selva software, specifically designed for spatial data analysis. This software enables efficient calculations and analysis of AHP, providing a comprehensive tool for decision-making processes. The weighted criteria map is only generated by accepting the value if the consistency ratio calculated is less than 10% unless the pairwise comparison matrix must be prepared again until it is less than 10%.

4.1.1. Weightage Assignment

In the criteria mapping process, weights were assigned to factors to combine them in the raster calculator. For instance, if the study area had steep slopes, a higher weight was given to the slope

raster value to prioritize avoiding such slopes. To account for the diverse engineering, economic, and environmental parameters affecting road selection, three suitable surfaces were created to define the least cost routes. These criteria were determined through literature review, expert consultation, and the ERA design manual, ensuring a comprehensive approach. The consistency ratio of each theme was found to be within the 0.1 limit, satisfying the condition of AHP. The value from weight assignment is used as an input to generate weighted cost overlay map which further combined to create preferred theme map. This is all done to get the suitable surface in terms of cost, safety, accessibility and comfort.

Weight assigned for technical theme

To assess the technical aspects within the study area, factors relevant to the Technical Theme were evaluated and assigned weights. The pairwise comparison matrix, presented below, was utilized to determine the relative importance of each factor:

Table 8: Pairwise comparison matrix in technical theme

Pairwise comparison matrix				
Factor	Slope	Elevation	Soil	Geology
Slope	1	2	3	4
Elevation	1/2	1	2	3
Soil	1/3	1/2	1	2
Geology	1/4	1/3	1/2	1

The table 8 above illustrates the pairwise comparison of the criteria, enabling the assessment of their relative significance. The values in the table indicate the importance ratio between each pair of criteria. To ensure consistency throughout the matrix, reciprocal values are employed.

The pairwise comparison matrix provides a quantitative basis for assigning weights to the criteria and incorporating them into the decision-making process. These weights are crucial in combining the factors and generating a comprehensive theme map that highlights areas with higher and lower suitability based on the chosen criteria. This is done by inputting the reciprocal value in to IDRISI selva software to calculate the percentage influence of each criterion in respective theme.

Based on the pairwise comparison matrix, the weights for each factor were calculated. The resulting weights, displayed in the table below (see table 9), indicate the relative importance of each factor within the Technical Theme:

Table 9: Weightage of criteria under technical theme

Criteria	Weights	CR
Maximize construction through flat and gentle slope	46.73%	0.01
Minimize construction through unsuitable rocks	9.54%	
Maximize construction through favorable elevation conditions	27.72%	
Maximize construction through suitable soils	16.01%	

The weights indicate the relative importance of each factor within the technical theme. These weights are derived from the pairwise comparison matrix, where higher values indicate greater significance. The weights assigned to each factor are crucial in the subsequent analysis and decision-making processes, as they determine the contribution of each factor towards the overall assessment of road selection under the technical theme.

Weight assigned for environmental theme

To evaluate the environmental aspects within the study area, factors relevant to the Environmental Theme were assessed and assigned weights. The pairwise comparison matrix, shown below (see table 10), was utilized to determine the relative importance of each factor:

Table 10: Pairwise comparison matrix in environmental theme

Pairwise comparison matrix				
Factor	Prox. to residential	Prox. to water	Prox. to agriculture	Aspect
Prox. to residential	1	2	4	6
Prox. to water	1/2	1	3	5
Prox. to agriculture	1/4	1/3	1	2
Aspect	1/6	1/5	1/2	1

In the above matrix, the values represent the relative importance or preference of one factor over another in the context of the environmental impact on route selection. The diagonal elements are always 1, indicating that each factor is equally important to itself. The values below the

diagonal represent the reciprocal comparisons between factors, reflecting the relative significance of one factor compared to another in terms of environmental considerations during the route selection process.

Based on the pairwise comparison matrix, the weights for each factor within the Environmental Theme were calculated. The resulting weights, displayed in the table below, indicate the relative importance of each factor:

Table 11: Weightage of criteria under environmental theme

Criteria	Weights	CR
Minimize road crossing agricultural land	12.02%	0.04
Minimize Proximity to Stream and Water Bodies	31.29%	
Minimize proximity to residential areas.	49.90%	
Minimize north facing to avoid moist, cold and dampness	6.79%	

These weight values represent the relative importance of each feature in the analysis, with higher values indicating greater significance.

Weight assigned for economic theme

To evaluate the economic impact within the study area, factors relevant to the Economic Theme were assessed and assigned weights. The pairwise comparison matrix, shown below (see table 12), was used to determine the relative importance of each factor:

Table 12: Pairwise comparison matrix in economical theme

Pairwise comparison matrix				
Factor	Existing road	Drainage order	LULC	Geology
Existing road	1	2	3	5
Drainage order	1/2	1	3	4
LULC	1/3	1/3	1	2
Geology	1/5	1/4	1/2	1

The table presents the pairwise comparison matrix, which is used to assess the relative importance of the factors within the economic theme. Each cell in the table contains a value that represents the ratio of importance between the corresponding factors. To maintain consistency,

reciprocal values are used in the matrix. The weights for each factor within the Economic Theme were derived by calculating the values from the pairwise comparison matrix. The table presented below displays the resulting weights, which indicate the relative significance of each factor in relation to the Economic Theme.

Table 13: Weightage of criteria under economical theme

Criteria	Weights	CR
Maximize upgrading of already existing roads.	46.94%	0.02
Optimize alignment through areas with compatible LULC	13.71%	
Minimize road crossing higher drainage order	31.46%	
Minimize construction through hard and tough rocks	7.89%	

The weights are derived by normalizing the values obtained from the pairwise comparison matrix. These weights reflect the relative importance of each factor within the economic theme. They guide subsequent analyses and decision-making processes in the road selection process, ensuring a focus on factors that are essential in minimizing construction costs and optimizing route efficiency.

4.1.2. Weighted Cost Overlay

The Weighted Cost Overlay method was employed to generate a theme map by combining reclassified maps of criteria and their corresponding percentage influences. The criteria themes, representing specific factors of interest, were reclassified into different classes. Each criterion was assigned a percentage influence, indicating its relative importance.

The reclassified maps were multiplied by their respective weights to produce weighted maps. These weighted maps were then aggregated, resulting in a theme map that depicted the combined influence of all criteria. This approach facilitated the prioritization of factors and the identification of areas with higher suitability or preference based on the chosen criteria. The procedure for creating the weighted theme map is depicted in the accompanying flow chart.

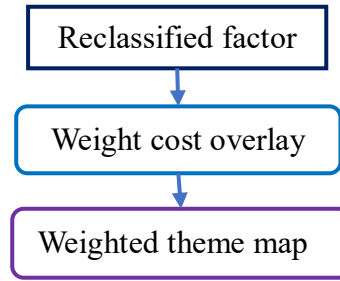


Figure 13: Procedure of weighted theme map creation

Technical Theme: For the Technical theme, the reclassified map is assigned the weightage obtained from the Analytic Hierarchy Process (AHP), reflecting the relative importance of the technical factors. Using the Weighted Overlay function, the reclassified map is overlaid with the assigned weightage. This process generates the technical theme map, which represents the combined influence of the technical factors. The resulting overlay map for the technical theme is displayed. See fig 14 below.

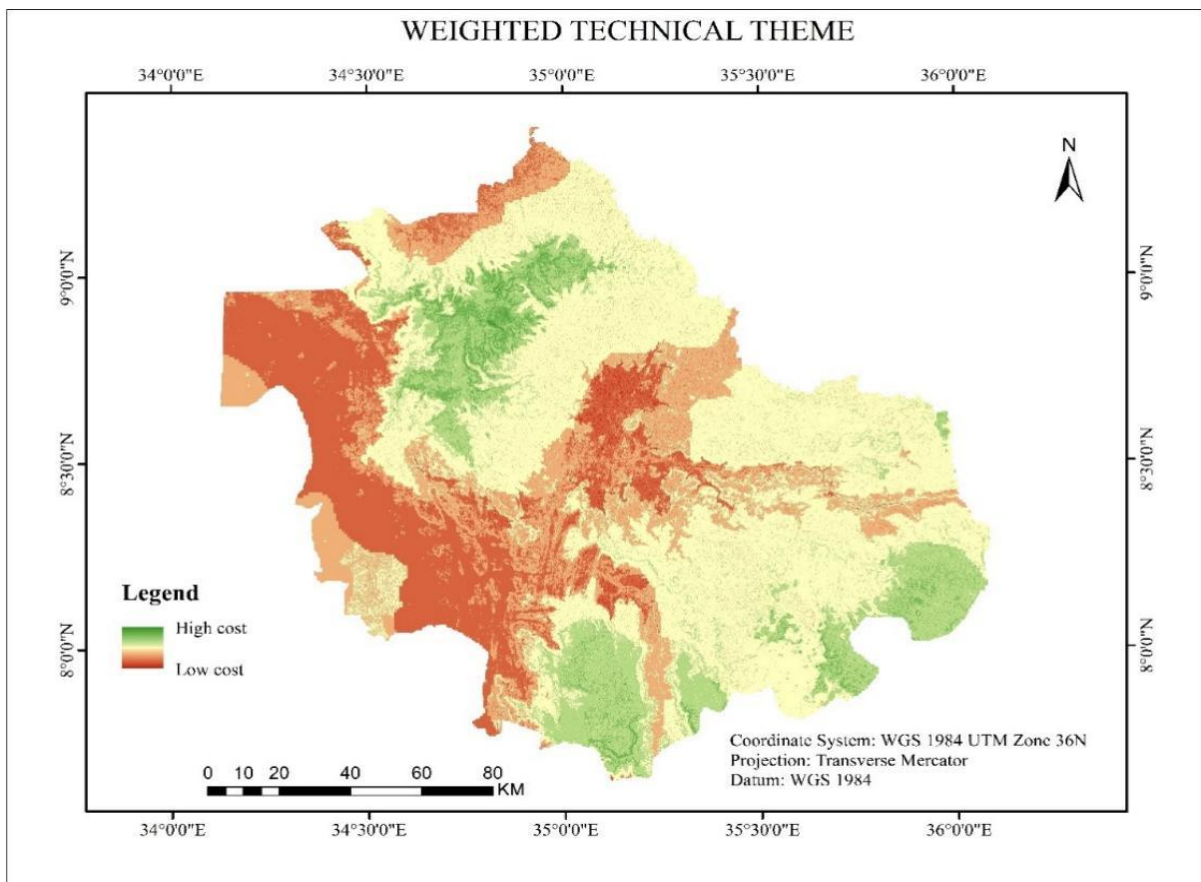


Figure 14: Technical overlaid theme map of the study area

The map utilizes a color ramp to depict the distribution of high and low-cost surfaces. This map provides an understanding of the technical considerations and their influence on the overall cost analysis.

Environmental Theme: Similarly, for the Environmental theme, the reclassified map is assigned the weightage derived from the Analytic Hierarchy Process (AHP) for the environmental factors. By applying the Weighted Overlay function, the reclassified map is combined with the assigned weightage. The resulting output is the Environmental theme map, which portrays the integrated impact of the environmental factors.

See fig 15 below which illustrates the overlay map generated for the Environmental theme. This map illustrates the combined influence of the reclassified maps and their assigned weightages, providing a visual depiction of the integrated environmental factors within the theme.

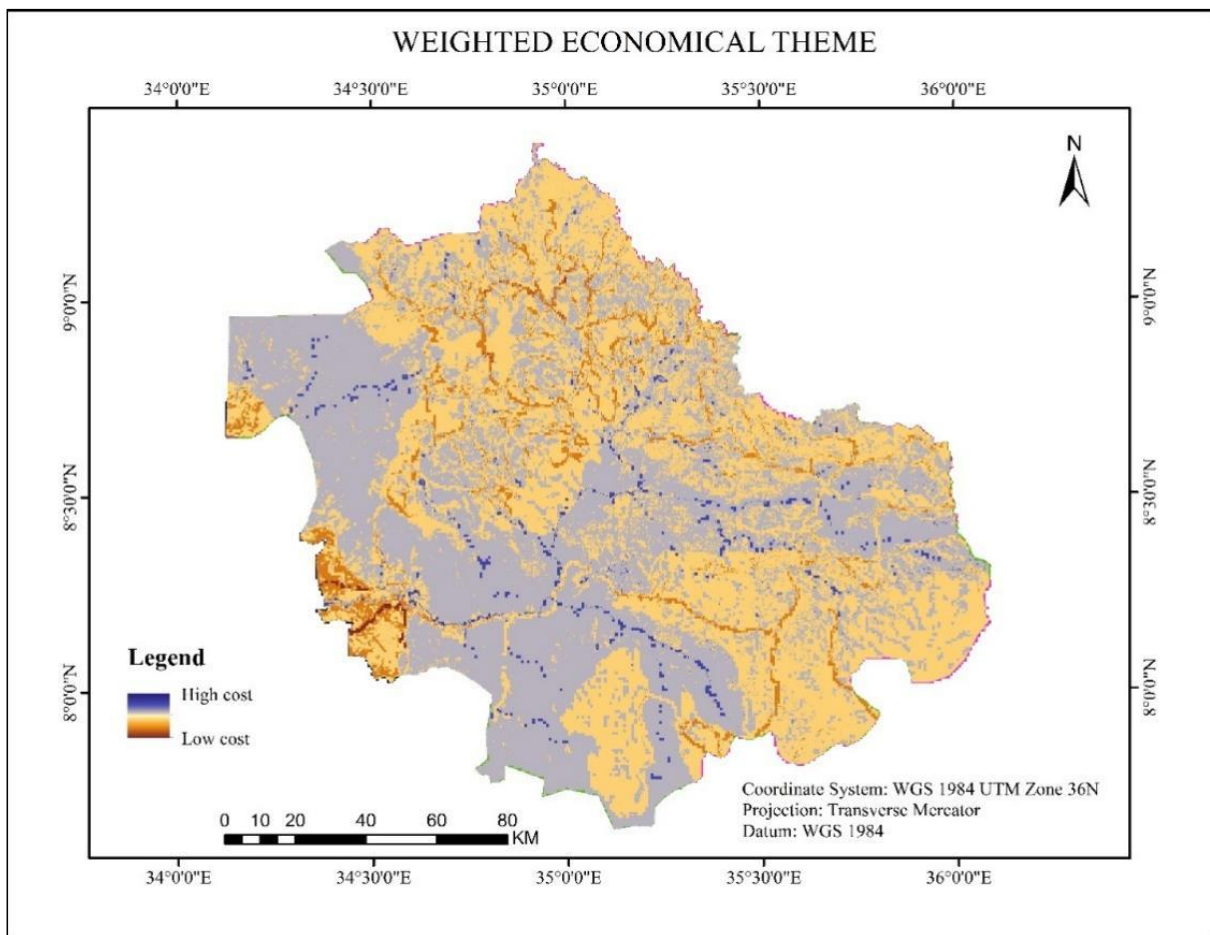


Figure 15: Economical overlaid theme map of the study area

The resulting map highlights areas with varying economic potential. Darker shades indicate regions with higher economic potential, while lighter shades represent areas with lower economic opportunities. This map aids in identifying economically favorable locations and making informed decisions based on economic considerations.

Economic Theme: In the case of the Economic theme, the reclassified map is allocated the weightage obtained from the AHP for the economic factors. Utilizing the Weighted Overlay function, the reclassified map is superimposed with the assigned weightage. This process yields the Economic theme map, which represents the collective influence of the economic factors.

See fig 16 which displays the overlay map for the Economic theme. This map exhibits the weighted overlay for the environmental theme. It demonstrates the amalgamation of different environmental factors.

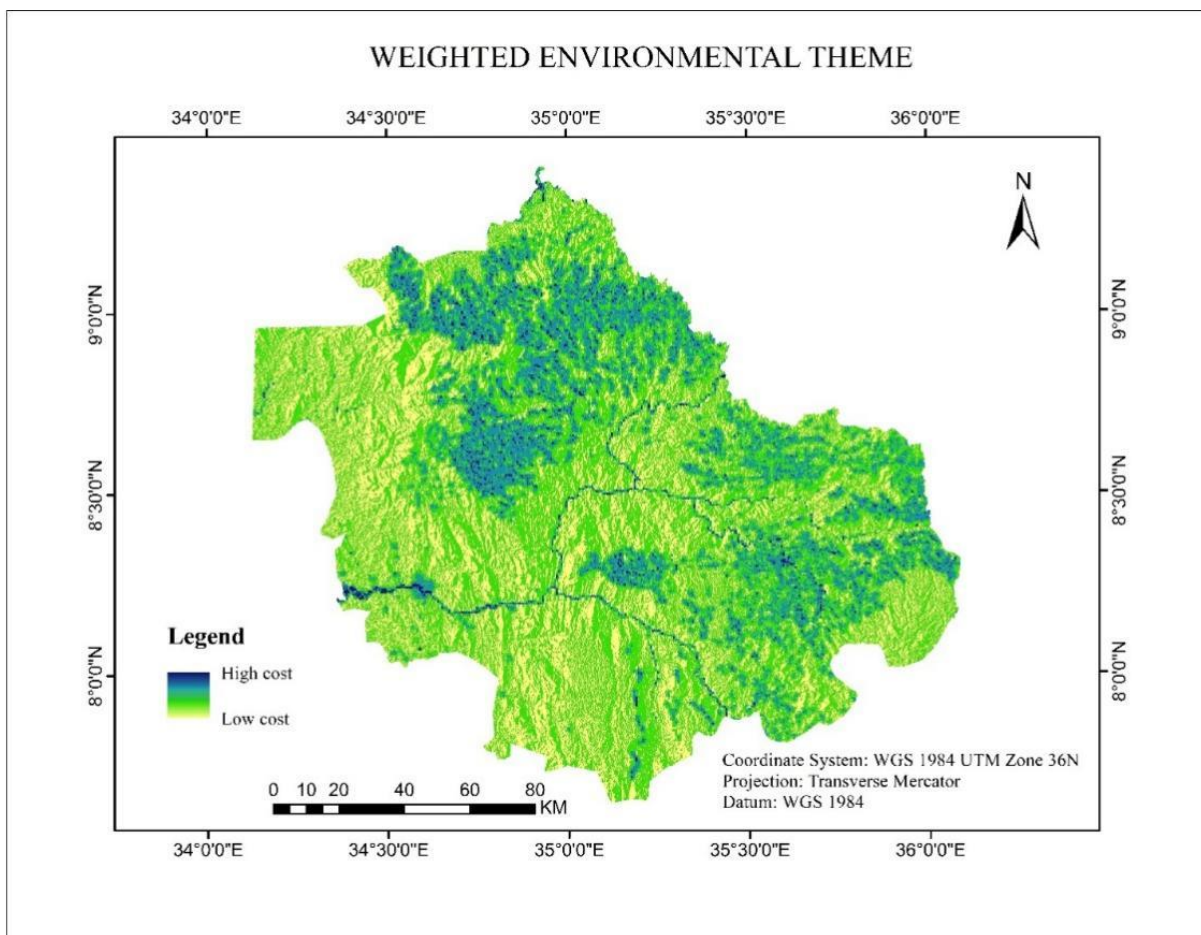


Figure 16: Environmental overlaid theme map of the study area

The resulting map provides an overview of the environmental characteristics and highlights areas with varying levels of environmental suitability. This map helps in understanding the environmental implications and assists in making environmentally conscious decisions.

4.1.3. Weighted Cost Overlay for Preferred Theme

The preferred theme map is assigned a weightage of 50%, while the remaining two themes each have a weightage of 25%. Using the weighted overlay tool in ArcGIS, these maps are combined to generate three maps: one for the preferred technical theme, another for the preferred economical theme, and the third for the preferred environmental theme.

The concept of the preferred theme in this context refers to a specific theme or category that has been given a higher weightage or priority in the analysis of selecting the least cost path. To determine the best route, these themes are transformed into preferred themes. The preferred theme is created through overlay analysis, where each theme is assigned weightages. In the case of the technical preferred theme, it is generated by assigning a weightage of 50% to the technical theme and 25% each to the other two themes. The same process is followed for generating the preferred themes for the economic and environmental aspects. The resulting preferred themes highlight areas or patterns that align with the prioritized criteria, aiding in the selection of the most favorable route based on the assigned weightages.

Cost distance map for preferred theme

The cost distance maps for the preferred technical, economical, and environmental themes provide a comprehensive representation of the analysis outcomes. They illustrate the relative costs associated with traversing different locations within the study area, with lower cost values indicating more favorable routes.

These cost distance maps are valuable tools for decision-making and planning purposes. They aid in identifying the most favorable routes or locations that align with the desired theme, whether it be technical feasibility, economic efficiency, or environmental compatibility. Stakeholders can leverage these maps to make informed decisions, optimize resource allocation, and prioritize interventions that align with the chosen preferred theme.

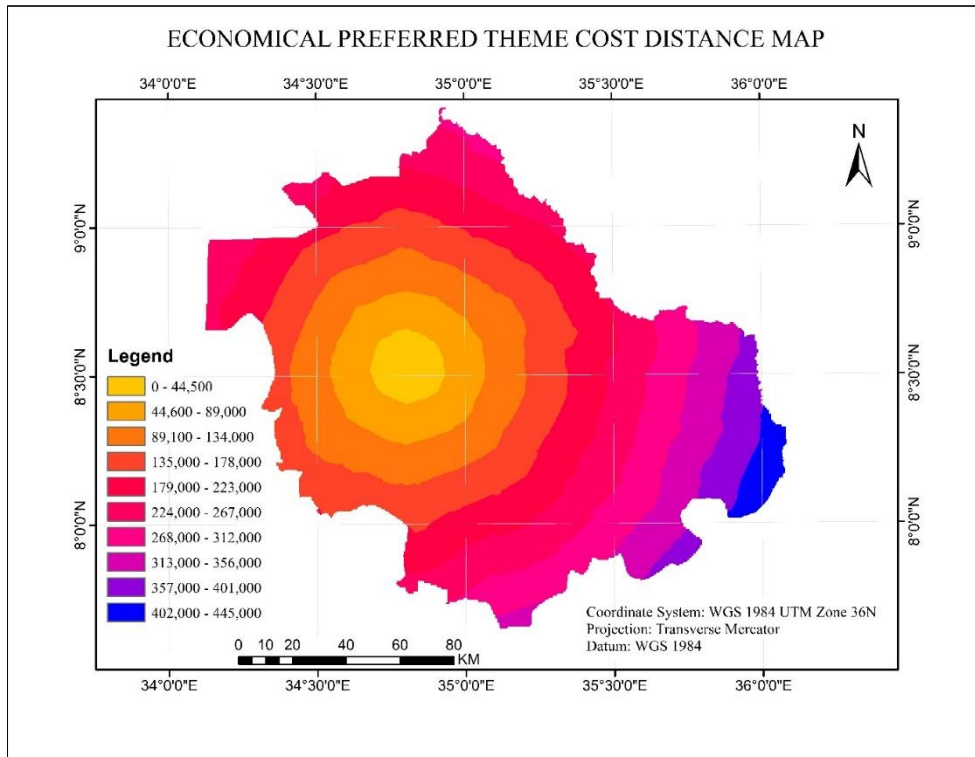


Figure 17: Cost distance map of economic preferred theme

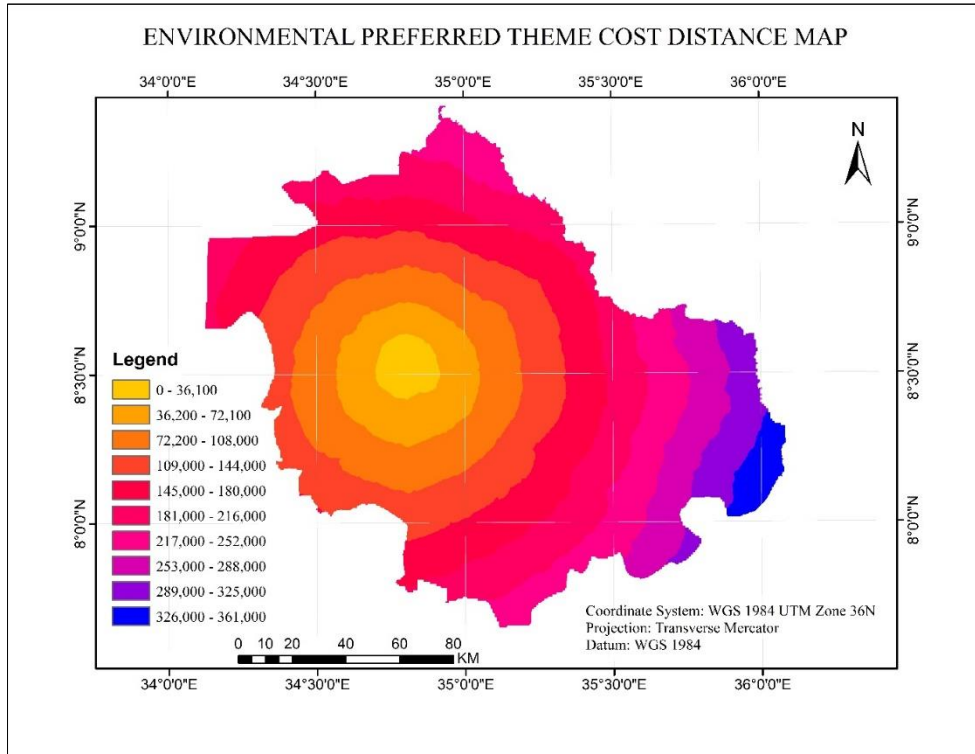


Figure 18: Cost distance map of environmental preferred theme

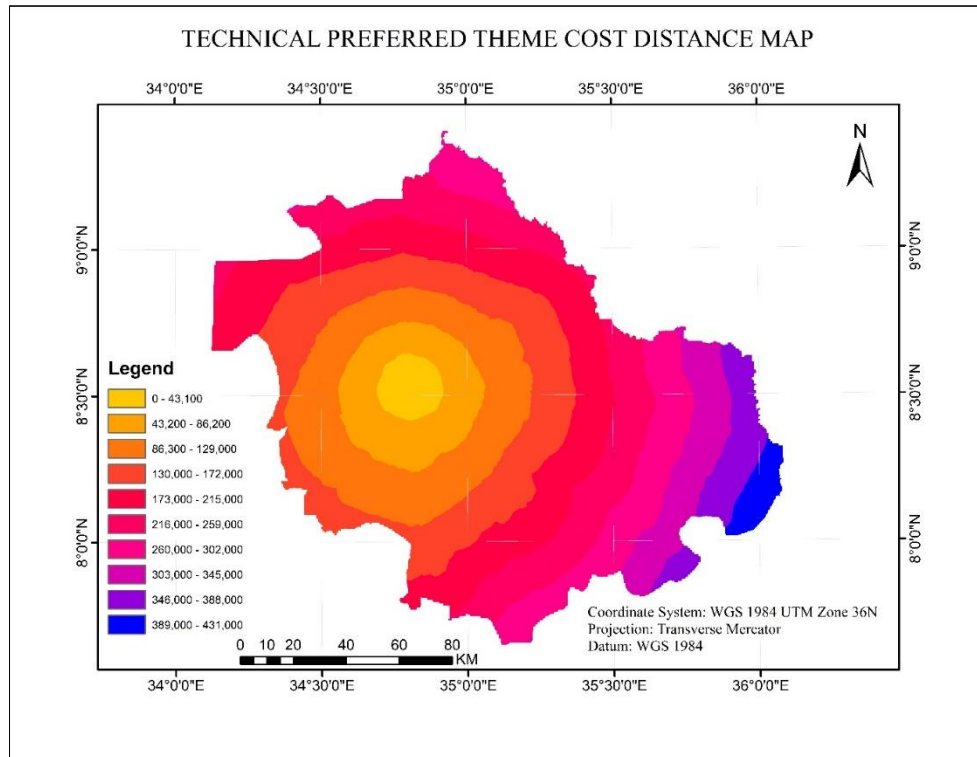


Figure 19: Cost distance map of technical preferred theme

These maps provide a comprehensive visual representation of the relative costs associated with traversing different locations within the study area. Lower cost values on the maps indicate more favorable routes or locations aligned with the respective preferred themes.

The cost distance map reveals areas with lower costs, indicating economic efficiency and cost-effectiveness, thus aiding in allocation of least cost path.

Cost backlink map for preferred theme

The cost backlink map for the preferred theme is a crucial component of the analysis, as it identifies the optimal paths or links within the study area based on the assigned weightages for each preferred theme (technical, economical, and environmental).

Using the weighted overlay analysis in ArcGIS, the individual theme maps are combined to generate the cost backlink maps for each preferred theme. These maps indicate the backlink or reverse direction from each cell or location to the adjacent cell or location that provides the optimal path within the study area, considering the assigned weightages.

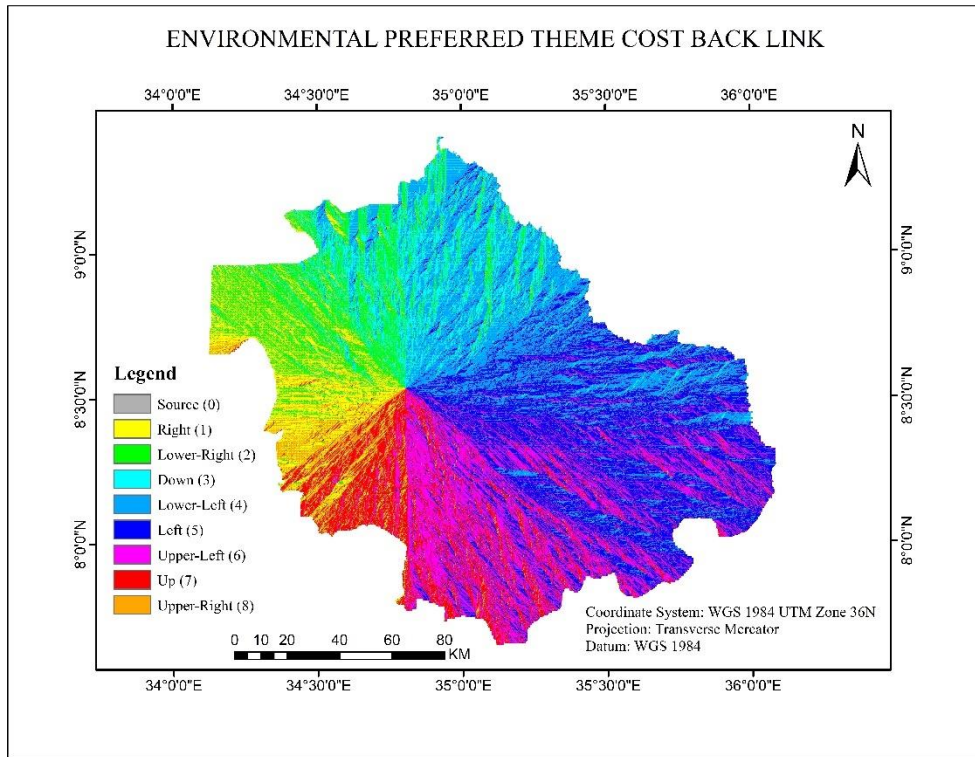


Figure 20: Cost backlink map of environmental preferred theme

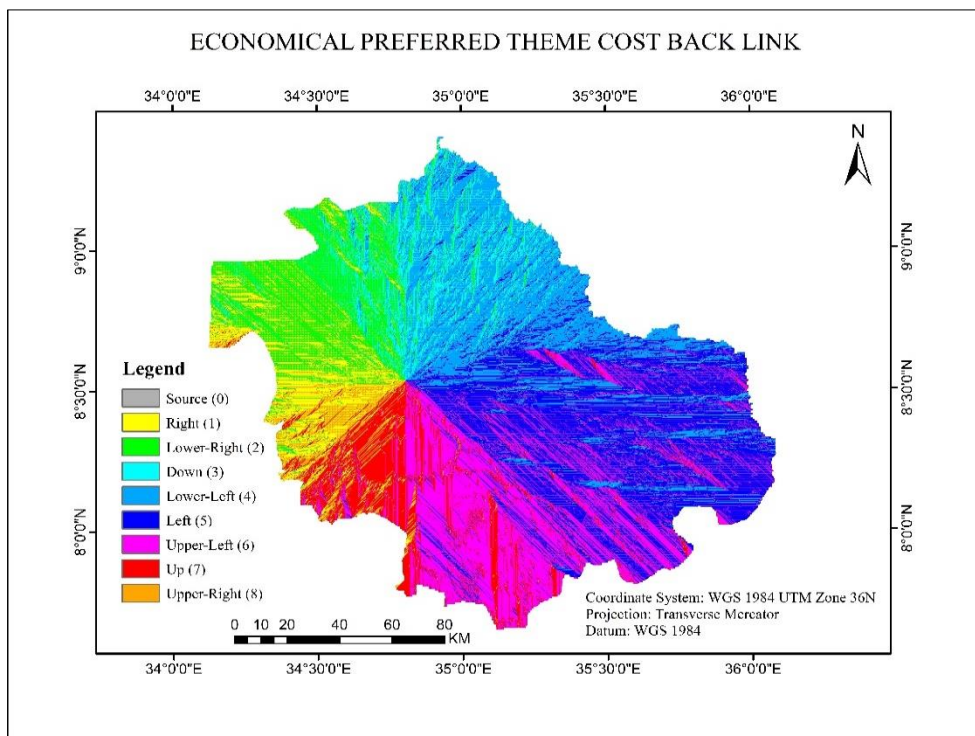


Figure 21: Cost backlink map of economic preferred theme

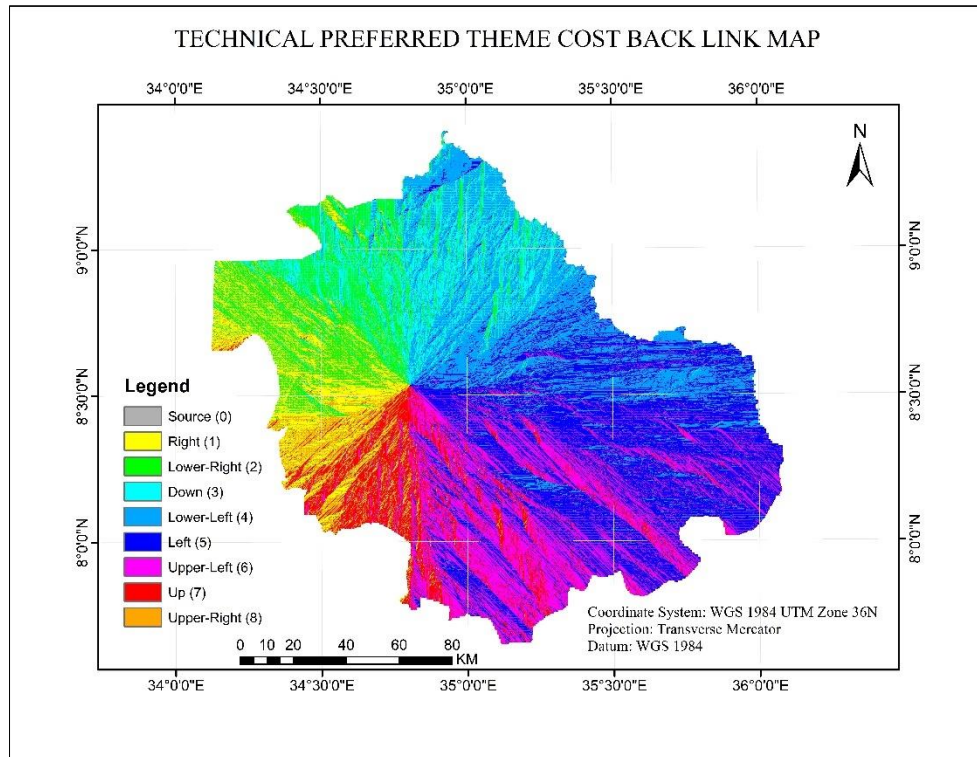


Figure 22: Cost backlink map of technical preferred theme

The cost backlink analysis was performed using the three preferred themes: Economic, Technical, and Environmental. Figure 20, 21, and 22 depict the cost backlink maps corresponding to each theme, respectively. These maps provide valuable information on the backward linkages from each grid cell to identify the most favorable routes based on the prioritized factors within each theme.

Generating cost path

To generate the alignment from the origin to the destination based on the preferred theme, the previously prepared cost distance maps and directional raster map were utilized. These cost distance maps represented the accumulated cost distances for each preferred theme, highlighting the least costly pathways across the study area. The directional raster map provided information on the preferred direction of movement for the alignment.

These cost distance maps, directional raster map, and the destination raster were used as inputs in the cost path analyst tool. This tool, available within spatial analysis software, takes into account the cost surfaces and directional preferences to determine the optimal route from the origin to the destination. Three alignments were derived as the least cost paths to determine the most optimal paths based on the respective preferred themes as shown. See fig 19 below. Each

alignment corresponded to a specific preferred theme, taking into account the associated factors and considerations.

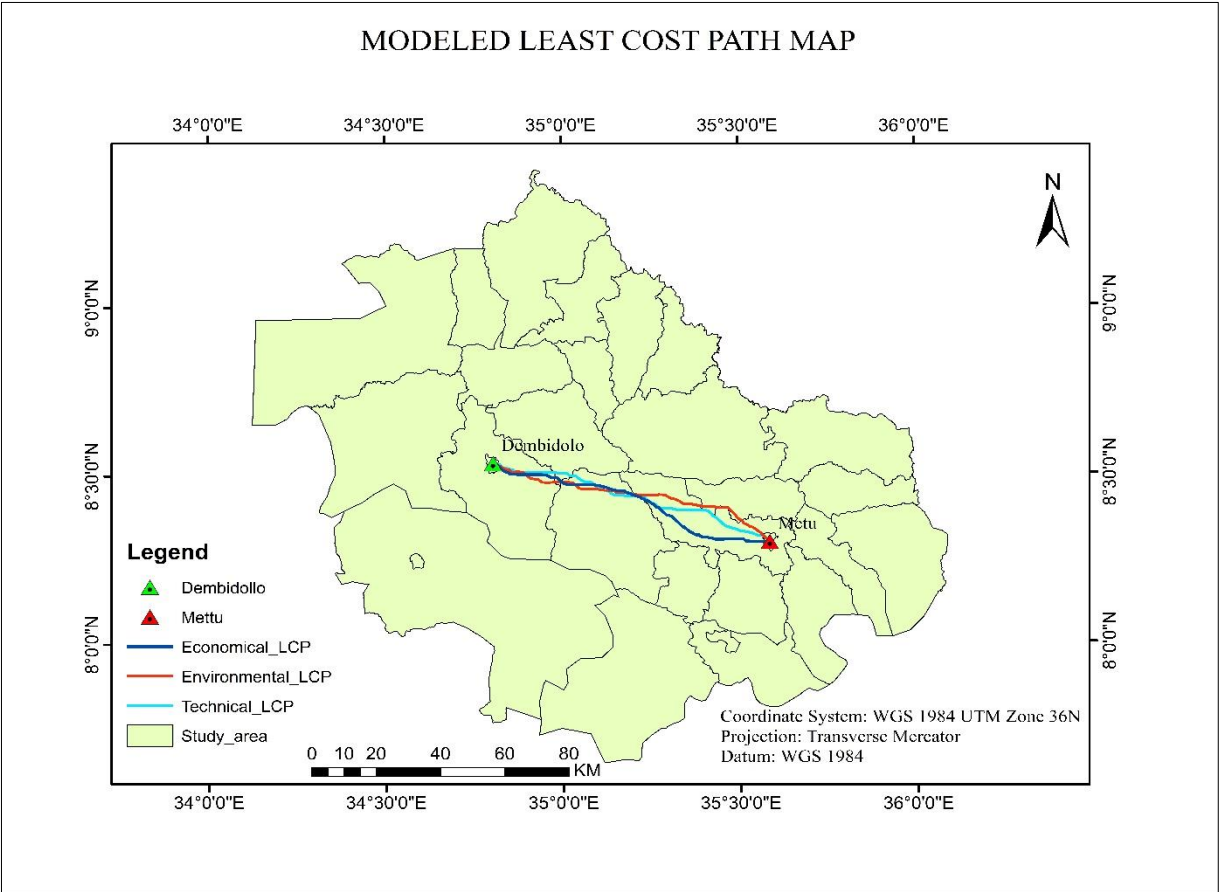


Figure 23: Modeled alternative least cost paths

4.2. Optimal route alignment Selection

The research adopts the multi-criteria evaluation methodology within the MCDA framework for the selection of the best alignment. MCE enables the assessment and comparison of alternative alignments using a predefined set of criteria. The criteria are weighted, alternatives are scored, and the scores are aggregated to derive a comprehensive evaluation and ranking.

In the selection process, a thorough analysis and comparison of the evaluated alternatives are conducted. Factors such as safety, ease of use, economic viability, and environmental impacts are carefully considered to determine the optimal route alignment. The ERA route alignment selection process aims to find a balance between these factors. A multi-criteria evaluation approach is employed, where the strengths and weaknesses of each alternative are weighed

against the established criteria. The goal is to identify the alignment that maximizes overall benefits while minimizing negative consequences. This selection process ensures that the chosen route alignment serves the interests of the community and achieves the desired objectives. Three alternatives were evaluated based on their impact factors. See table 14

Table 14: Evaluation results for three cost paths based on different criteria

Evaluation parameter		Units	Economic al LCP	Environment al LCP	Technical LCP
Number of Drainage crossed	Lower order	Number	43	31	35
	Higher order	Number	2	6	4
Length of road crossing built up areas		km	2.89	3.46	4.54
Road crossing 500m from water body		km	1.23	7.72	6.08
Area of agriculture within 15 Buffer		km ²	0.12	0.05	0.04
Length of the road		km	96.46	97.87	96.47
Road length crossing escarpment slope		km	0.372	0.605	0.341
Area of forest within 20 m buffer		Km ²	2.05	2.58	2.21
Area of bare land within 500m		Km ²	32.20	28.57	33.55
Length of the road crossing higher elevation		km	37.560	17.460	23.881
Number of Population within 5km buffer		Number	755988	677039	677039

4.2.1. The result of final route selection

The final route selection results, including the weight values assigned to each factor, are presented in the following comprehensive table. This table not only highlights the chosen route alignment but also provides valuable insights into the relative importance of each factor in the evaluation process. By including the weight values, it is easy to understand the significance and impact of each criterion in the final selection. This additional information enhances the transparency and robustness of the decision-making process, facilitating a more informed and confident implementation of the selected route alignment.

The result of the final route selection is presented showing the weight of each factor under the theme and the sum of the weight. See table 15.

Table 15: Weight of evaluated criteria

Evaluation parameter		Economical LCP weight	Environmenta l LCP weight	Technical LCP weight
Number of Drainage crossed	Lower order	2.8	3.8	3.4
	Higher order	5.5	1.8	2.7
Length of road passing through built up areas		4.0	3.4	2.6
Length of road passing 500m from water body		7.3	1.2	1.5
Area of agriculture within 15 Buffer		1.6	3.7	4.7
Total length of the road		3.4	3.3	3.3
Road length intersecting escarpment slope		3.7	2.3	4.0
Area of forest destroyed within 20 m buffer		2.9	2.3	2.7
Area of bare land within 500m		1.4	1.2	1.4
Length of the road passing higher elevation		2.1	4.6	3.3
Number of Population within 5km		2.9	2.6	2.6
Sum		37.5	30.2	32.3

After a comprehensive evaluation of the three alignments, it was found that the economical preferred least cost path received the highest weight of 37.5%, signifying its primary importance in the decision-making process. This outcome emphasizes the significance of considering economic factors in route selection. The technical preferred theme followed with a weight of 32.3%, underlining its relevance in determining the optimal route. Additionally, the environmental preferred theme closely obtained a weight of 30.2%, highlighting the crucial need to prioritize environmental considerations in the decision-making process.

The map presented below showcases the preferred least cost path, which represents the final result of the study. See fig 17 below. The path is overlaid with the existing major road network in the study area, serving as a crucial connection between the two locations. This visual representation offers valuable insights into how the preferred route aligns with the existing infrastructure, facilitating a comprehensive understanding of the proposed solution within the context of the study area. By overlaying the preferred path with the existing major road, it

becomes evident how the proposed route integrates with the established transportation network, ensuring a seamless and efficient connection between the specified locations.

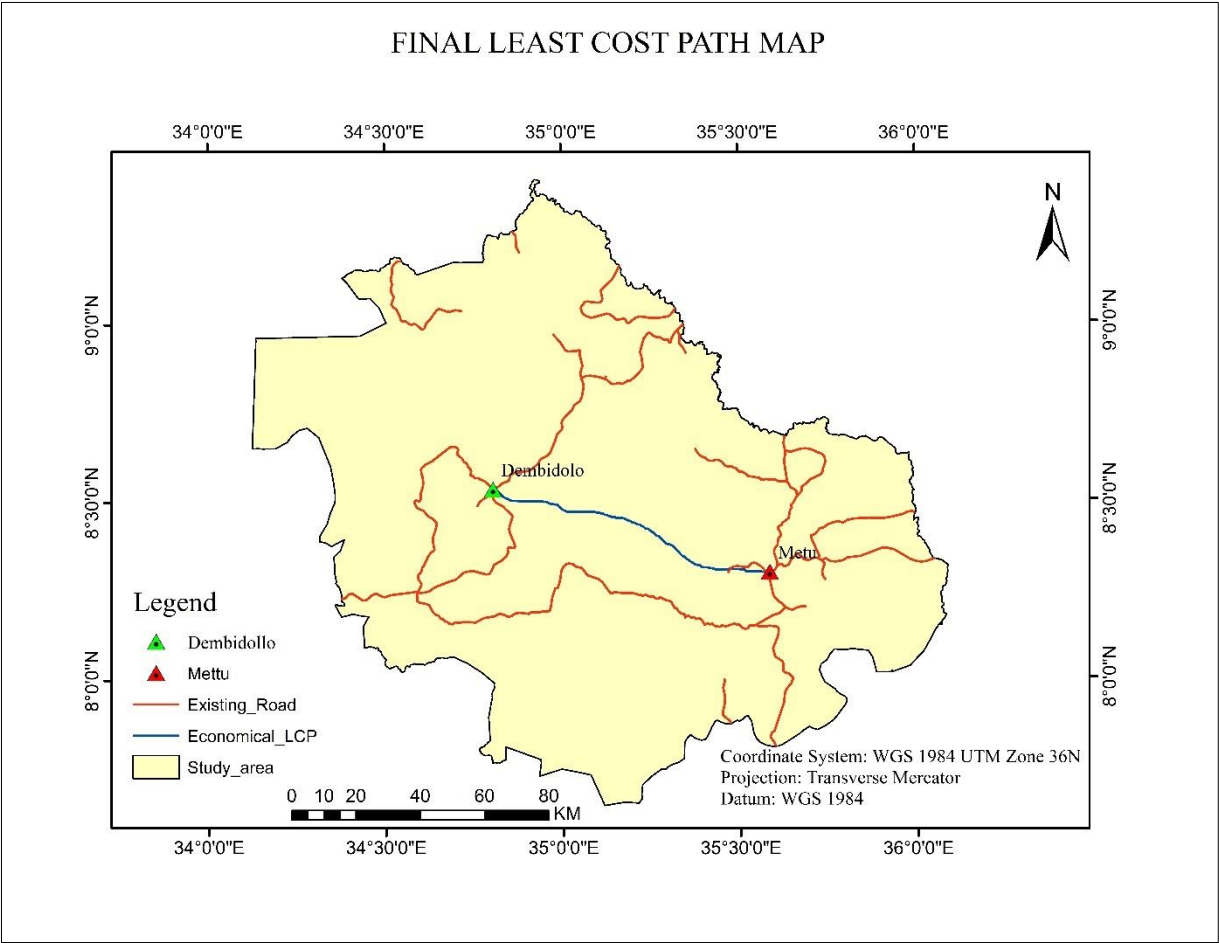


Figure 24: The chosen final least cost path

The existing road is quite long, covering a distance of 271 km. In contrast, the newly proposed route is much shorter, measuring only 96.46 km. This means that the proposed route is significantly shorter than the existing road. This difference brings several potential benefits. It can make travel more efficient, reduce the time it takes to get from one place to another, and potentially lower transportation costs. Moreover, the shorter length of the proposed route provides an opportunity to plan and use resources more effectively, which can lead to better overall transportation results. The considerable contrast in distance highlights the major improvement offered by the proposed route compared to the existing road.

4.3. Discussion

In the research on route alignment selection, the aim was to identify a preferable route that fulfills several important criteria. Safety considerations were given utmost priority to minimize potential hazards and risks, ensuring the safety of users. The chosen route was designed to be easily navigable and convenient for drivers, pedestrians, and public transportation users, while minimizing congestion and obstacles. Economic viability was also taken into account, ensuring the route was cost-effective, financially sustainable, and contributed positively to the economy. Additionally, the research emphasized the importance of minimizing the distance traveled to reduce travel times, lower transportation costs, and improve overall efficiency. Geospatial technologies played a crucial role in analyzing various factors and using advanced software tools to determine the least cost path that met these criteria effectively which is also used in (Mondal et al., 2021a; Poudel & Kumar, 2022; Sameer et al., 2021) and many other researches.

Route alignment selection in this study involved generating three main themes: technical, economic, and environmental. Geospatial analysis and parameter overlay were used to create these themes. To generate the technical theme, parameters such as slope, geology, elevation, and soil characteristics were overlaid and analyzed. By assigning appropriate weights to each parameter, the influence of factors like steep slopes, unfavorable geology, high elevation, and unsuitable soil conditions on route feasibility and cost was determined. Notably, slope was given the highest value in the technical theme generation process, as previous studies (Mondal et al., 2021; Sekulic et al., 2022) have indicated its significant impact on transportation efficiency and cost. For the economic theme, factors such as existing road infrastructure, drainage order, land use and land cover were taken into account. Existing road networks were given the highest value, reflecting the importance of utilizing and connecting to established transportation infrastructure. Additionally, drainage order and land use information were considered as they directly influence construction costs, accessibility, and potential disruptions during route alignment. The environmental theme focused on factors related to the surrounding natural environment. Proximity to water bodies, human settlements, agricultural land, and aspect (orientation towards the sun) were taken into consideration. Proximity to residential areas and streams and water bodies were assigned the largest value in the environmental theme generation process, considering the need to minimize potential impacts on local communities and ecological disruption. Preferred maps were generated for each theme, with a weight of 50% for

the preferred theme and 25% for each of the other two themes. (Poudel & Kumar, 2022; Sekulic et al., 2022) used this method to model the least cost path and get comparable result. This approach ensured a comprehensive evaluation of safety, ease of use, economic viability, and distance traveled in selecting the least cost path.

The analysis revealed that the Economic preferred cost path outperformed the Environmental and Technical paths in terms of various factors. These factors make it a favorable choice for infrastructure development, as it meets the needs of many while minimizing disruptions to urban areas and reducing the impact on forests.

Moreover, the study emphasized the importance of considering multiple criteria and utilizing a diverse range of software tools and technologies, including GIS, to determine the optimal route. Unlike previous research that primarily focused on distance, this study utilized a multicriteria approach, taking into account various factors for route selection. This highlights the significance of a comprehensive analysis in decision-making processes for infrastructure development.

The discussion highlighted the significant difference between the existing road (271 km) and the proposed route (96.46 km), emphasizing the major improvement offered by the shorter route in terms of travel efficiency, reduced travel time, and potential cost savings. The study showcased the advantages of the Economic preferred cost path and emphasized the importance of a multicriteria approach in route selection. Overall, the proposed route demonstrated substantial benefits compared to the existing road, highlighting its potential for improved transportation outcomes.

CHAPTER V: CONCLUSION AND RECOMMENDATION

This research aims to address several key questions related to road alignment selection between Dembidollo and Mettu towns. It investigates the influential factors, such as safety, economic viability, ease of use, and distance traveled. The study explores the utilization of geospatial technologies and software tools to develop and propose alternative road alignments considering technical, environmental, and economic criteria. It compares and evaluates these proposed alignments based on the defined criteria to determine the optimal route.

5.1. Conclusion

In conclusion, this research successfully utilized geospatial technologies for road alignment selection between Dembi Dollo and Mettu towns in Ethiopia. A comprehensive analysis of various factors, including safety, economic viability, ease of use, and distance traveled, was conducted to determine the optimal route alignment.

The integration of remote sensing and GIS proved to be highly efficient and cost-effective for imaging large areas. The use of ENVI software for image classification and Idrisi for criteria weighting in spatial multi-criteria evaluation yielded accurate and efficient results.

By incorporating multi-criteria evaluation, a balanced and comprehensive assessment of the proposed alternative road alignments was achieved. The technical, environmental, and economical themes considered various parameters, resulting in the identification of a recommended route spanning 96.46 km. The proposed route offered a cost-effective and safe solution, avoiding higher-order drainage and minimizing disruptions.

The research emphasized the significance of geospatial technologies in route selection, providing up-to-date information on terrain and land cover. The integration of the analytical hierarchy process and multi-criteria evaluation method enhanced decision-making by considering multiple parameters, resulting in a more efficient process.

The practicality and effectiveness of geospatial technologies in route selection for road infrastructure development were demonstrated. The findings contribute valuable insights for future studies, enhancing route planning and decision-making processes and facilitating the development of economically viable and sustainable transportation networks.

5.2. Recommendation

The finding of this research shows successful application of geospatial technologies contribution for the accurate analysis of factors influencing the route alignment. Following this;

1. It is recommended that researchers, road designers, and local government planners embrace geospatial technologies such as remote sensing, GIS, and related tools. By utilizing these technologies, they can gather and analyze up-to-date spatial data on terrain, land cover, and other relevant factors, benefiting from enhanced efficiency and accuracy.
2. To facilitate effective decision-making in route selection, it is recommended that researchers and decision-makers adopt a multi-criteria evaluation approach. This approach involves considering various factors simultaneously and employing methodologies like the analytical hierarchy process. By doing so, factors such as safety, cost, and environmental impact can be appropriately assessed, ensuring a well-rounded evaluation for informed route selection.
3. It is advised to promote the wider use of geospatial technologies in transportation and infrastructure planning. Policymakers, transportation planners, and infrastructure developers should be encouraged to embrace these tools to assess safety, cost, and environmental impact more effectively.
4. Encourage researchers and academic institutions to conduct further research on geospatial technologies in route planning, aiming to improve and expand their application by considering additional parameters for more informed decision-making.
5. Further study is recommended to assess the potential advantages of integrating LiDAR and UAV technologies in route selection for improved terrain and land cover data accuracy. This research can provide valuable insights for enhancing the efficiency and effectiveness of infrastructure planning decisions.

By following these recommendations, researchers, road designers, and local government planners can make informed decisions in route selection processes, considering environmental, engineering, social, and economic factors. These recommendations aim to improve decision-making processes, enhance data availability, overcome challenges, promote collaboration, and foster continuous improvement in sustainable transportation infrastructure development.

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REFERENCES

- Bagli, S., Geneletti, D., & Orsi, F. (2011). Routeing of power lines through least-cost path analysis and multicriteria evaluation to minimise environmental impacts. *Environmental Impact Assessment Review*, 31(3), 234–239. <https://doi.org/10.1016/j.eiar.2010.10.003>
- Bongiorno, N., Bosurgi, G., Carbone, F., Pellegrino, O., & Sollazzo, G. (2019). Potentialities of a highway alignment optimization method in an i-bim environment. *Periodica Polytechnica Civil Engineering*, 63(2), 352–361. <https://doi.org/10.3311/PPci.12220>
- Brinkhoff, J., Vardanega, J., & Robson, A. J. (2020). *Land Cover Classification of Nine Perennial Crops Using Sentinel-1 and -2 Data*. 1–26. <https://doi.org/10.3390/rs12010096>
- Çalışkan, E., Bediroglu, & Yildirim, V. (2019). Determination forest road routes via gis-based spatial multi-criterion decision methods. *Applied Ecology and Environmental Research*, 17(1), 759–779. https://doi.org/10.15666/aeer/1701_759779
- Congalton, R. G. (2001). Accuracy assessment and validation of remotely sensed and other spatial information. *International Journal of Wildland Fire*, 10(3–4), 321–328. <https://doi.org/10.1071/wf01031>
- Eastman, J. R. (1999). *Multi-criteria evaluation and GIS*. 493–502.
- Effat, H. A., & Hassan, O. A. (2013). Designing and evaluation of three alternatives highway routes using the Analytical Hierarchy Process and the least-cost path analysis, application in Sinai Peninsula, Egypt. *Egyptian Journal of Remote Sensing and Space Science*, 16(2), 141–151. <https://doi.org/10.1016/j.ejrs.2013.08.001>
- ERA Manual. (2013). *Route selection manual route selection*.
- Gyabeng, B. A. (2020). Selection of Optimum Petroleum Pipeline Routes Using A Multi-Criteria Decision Analysis and GIS Least-Cost Path Approach. *International Journal of Scientific and Research Publications (IJSRP)*, 10(06), 572–579. <https://doi.org/10.29322/ijsrp.10.06.2020.p10270>
- Huang, I. B., Keisler, J., & Linkov, I. (2011). Science of the Total Environment Multi-criteria decision analysis in environmental sciences : Ten years of applications and trends. *Science of the Total Environment*, The, 409(19), 3578–3594.

<https://doi.org/10.1016/j.scitotenv.2011.06.022>

- Isah O. Anavberokhai. (2008). Introducing GIS and Multi-criteria analysis in road path planning process in Nigeria A case study of Lokoja, Kogi State. *Image (Rochester, N.Y.)*, August.
- Ivanová, E., & Masárová, J. (2013). Importance of Road Infrastructure in the Economic Development and Competitiveness. *Economics and Management*, 18(2), 263–274. <https://doi.org/10.5755/j01.em.18.2.4253>
- Jana, S. K., Sekac, T., & Pal, D. K. (2017a). *GIS and Remote Sensing Applications in Rural District Road Network Evaluation : The Case of Nebilyer in Western Highlands Province , Papua New GIS and Remote Sensing Applications in Rural District Road Network Evaluation : The Case of Nebilyer in Western . February 2020.*
- Jana, S. K., Sekac, T., & Pal, D. K. (2017b). *GIS and Remote Sensing Applications in Rural District Road Network Evaluation : The Case of Nebilyer in Western Highlands Province , Papua New GIS and Remote Sensing Applications in Rural District Road Network Evaluation : The Case of Nebilyer in Western . November.*
- Karna, B. K. (2014). *Road Network Planning for Sustainable Urban Development in Kirtipur Municipality , Nepal.* 34–40.
- Kazan-ankara, D. N. A. (2006). *Engineering Geology Assessment of the Quaternary Alluvium and Pliocene Deposits in North-western Ankara (Kazan-Ankara , Turkey).* September.
- Lai, D., Tang, K., Kong, H., Survey, G., Owen, R., & Sewell, R. J. (2010). *The Geological History of Hong Kong.* January. <https://doi.org/10.1080/10225706.2010.9684152>
- Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics*, 33(1), 159. <https://doi.org/10.2307/2529310>
- Macarringue, L. S., Bolfe, É. L., & Pereira, P. R. M. (2022). Developments in Land Use and Land Cover Classification Techniques in Remote Sensing: A Review. *Journal of Geographic Information System*, 14(01), 1–28. <https://doi.org/10.4236/jgis.2022.141001>
- Mahavar, V., & Pham, B. T. (2019). Development and Application of GIS Model in the Selection of Cost Effective Road Alignment. *International Journal of Applied Engineering*

Research, 14(15), 3413–3428. <http://www.ripublication.com>

Mck, P. (2010). *Soil Carbon Sequestration under Pasture in Southern Australia Prepared for Dairy Australia*. February, 0–42.

Mohanty, M., Sinha, N. K., Somasundaram, J., Mcdermid, S. S., Patra, A. K., Singh, M., Dwivedi, A. K., Reddy, K. S., Srinivas, C., Prabhakar, M., Hati, K. M., Jha, P., Singh, R. K., Chaudhary, R. S., Naresh, S., Tripathi, P., Dalal, R. C., Gaydon, D. S., & Chaudhari, S. K. (2020). Soil carbon sequestration potential in a Vertisol in central India- results from a 43-year long-term experiment and APSIM modeling. *Agricultural Systems*, 184(September 2019), 102906. <https://doi.org/10.1016/j.agsy.2020.102906>

Mondal, M. S., Garg, R. D., Pandey, V., & Kappas, M. (2021). Route alignment planning for a new highway between two cities using Geoinformatics techniques. *Egyptian Journal of Remote Sensing and Space Science*, 24(3P2), 595–607. <https://doi.org/10.1016/j.ejrs.2021.05.003>

Ouma, Y. O., Yabann, C., Kirichu, M., & Tateishi, R. (2014). *Optimization of Urban Highway Bypass Horizontal Alignment : A Methodological Overview of Intelligent Spatial MCDA Approach Using Fuzzy AHP and GIS*. 2014.

Piantanakulchai, M., & Saengkhaio, N. (2003). Evaluation of alternatives in transportation planning using multi- stakeholders multi-objectives AHP modeling. *Proceedings of the Eastern Asia Society for Transportation Studies*, January 2003, 1613–1628. https://www.researchgate.net/publication/228426663_

Poudel, A., & Kumar, P. (2022). *GIS Modelling for Optimal Alignment Selection : A Case Study of Karputar to Yamdi Section , Midhill Highway*. 8914, 100–108.

Reddy, G. P. O. (2018). *Geospatial Technologies in Land Resources Mapping , Monitoring , and Management : An Overview*. 1–18.

Sameer, Y. M., Abed, A. N., & Sayl, K. N. (2021). *Highway route selection using GIS and analytical hierarchy process case study Ramadi Heet rural highway*. <https://doi.org/10.1088/1742-6596/1973/1/012060>

Sarı, F., & Sen, M. (2017). Least Cost Path Algorithm Design for Highway Route Selection.

International Journal of Engineering and Geosciences, 2(1), 1–8.
<https://doi.org/10.26833/ijeg.285770>

Sekulic, M., Siljeg, A., Mansourian, A., Watson, L., & Cavric, B. I. (2022). Multi-criteria spatial-based modelling for optimal alignment of roadway by-passes in the Tlokweng planning area , Botswana. *Journal of Spatial Science*, 67(2), 237–254.
<https://doi.org/10.1080/14498596.2020.1755731>

Sherrod, B. D. R., & Smith, J. G. (1980). *Geologic map of upper eocene to holocene volcanic and related rocks of the cascade range , oregon.*

Soil, W., & Reports, R. (2015). *World reference base for soil resources 2014 International soil classification system.*

Stratigraphy, E., & Zone, M. (n.d.). *The Bedrock Geology of Massachusetts The Bedrock Geology of Massachusetts.*

Suleiman, S. A. N. I. S., Garwal, V. C. A., Al, D. E. L., & Unusi, A. M. S. (2015). *Optimal Route Location by Least Cost Path (LCP) Analysis using (GIS), A Case Study.* 04(44), 9621–9626.

Sunusi, A., Agrawal, V. C., Lal, D., & Suleiman, S. (2015). Selection of Road Alignment Location in Kano-Nigeria using GIS and Analytical Hierarchy Process (AHP) Model. *International Journal of Scientific Engineering and Technology Research*, 04(43), 9449–9455. www.ijsetr.com

Tae-Ho, R., Jong-Chool, L., Hee-Gyoo, K., Jong-ju, K., & Yeoung-Hwa, J. (2008). Construction on Decision Support System for Route Location. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 555–566.

Taylor, P., Ivanov, A. Y., & Zatyagalova, V. V. (2008). *International Journal of Remote A GIS approach to mapping oil spills in a marine environment.* October 2014, 37–41.
<https://doi.org/10.1080/01431160802175587>

Usikov, V. I., & Ozaryan, Y. A. (2021). Information and computational GIS for monitoring the natural and technical systems of placer gold deposits. *IOP Conference Series: Earth and Environmental Science*, 895(1). <https://doi.org/10.1088/1755-1315/895/1/012036>

- Vaidya, O. S., & Kumar, S. (2006). *Analytic hierarchy process : An overview of applications*. 169, 1–29. <https://doi.org/10.1016/j.ejor.2004.04.028>
- Veneziano, D., Hallmark, S., & Souleyrette, R. (2004). Accuracy of light detection and ranging derived terrain data for highway location. *Computer-Aided Civil and Infrastructure Engineering*, 19(2), 130–143. <https://doi.org/10.1111/j.1467-8667.2004.00343.x>
- Wahdan, A., Effat, H., Abdallah, N., & Elwan, K. (2019). Design an Optimum Highway Route using Remote Sensing Data and GIS-Based Least Cost Path Model, Case of Minya-Ras Ghareb and Minya-Wahat-Bawiti Highway Routes, Egypt. *Technology, and Sciences (ASRJETS) American Scientific Research Journal for Engineering*, 56(1), 157–181. <http://asrjetsjournal.org/>
- Yakar, F., & Celik, F. (2014). *A Highway Alignment Determination Model Incorporating GIS and Multi-Criteria Decision Making*. 00(0000), 1–11. <https://doi.org/10.1007/s12205-014-0130-1>
- Yildirim, V., Nisanci, R., & Reis, S. (2006). A GIS Based Route Determination in Linear Engineering Structures Information Management (LESIM). *October*, 1–8.
- Zhao, L., Liu, Z., & Mbachu, J. (2019). *Highway Alignment Optimization : An Integrated BIM and GIS Approach*. <https://doi.org/10.3390/ijgi8040172>

APPENDIX

Appendix I: Multibuffered map of Built-up, agriculture and water body

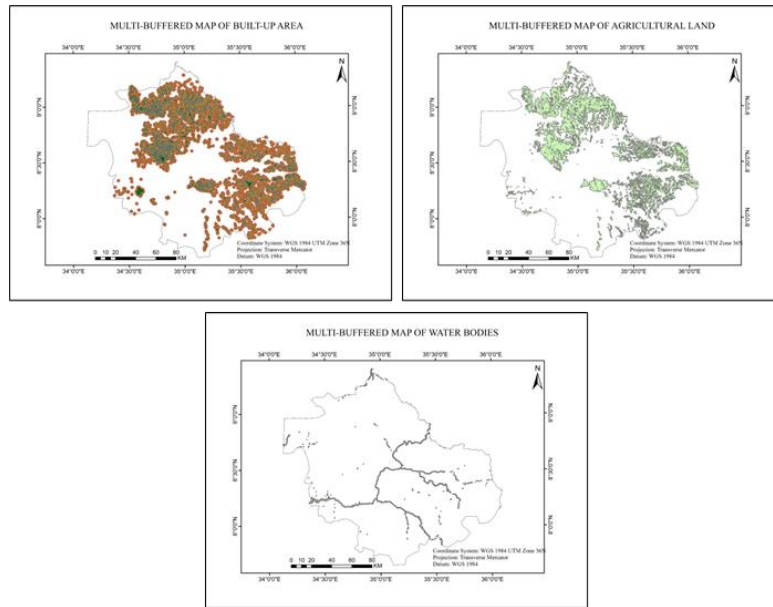


Figure 1: Multiring buffer map of Built-up, agriculture and Water bodies.

Appendix II: Reclassified map of slope, elevation, geology and soil.

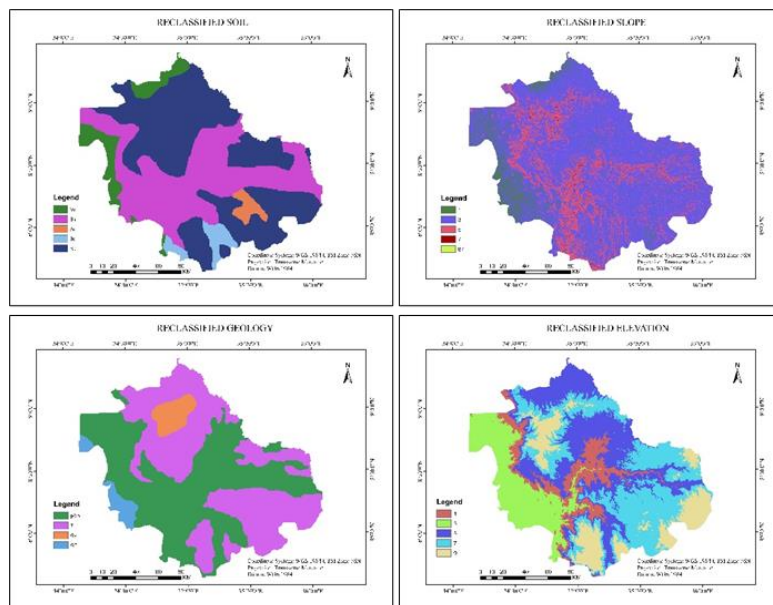


Figure 2: Reclassified technical theme parameters.

Appendix III: Reclassified map of proximity to agricultural, proximity to Built-up, proximity to water body and aspect.

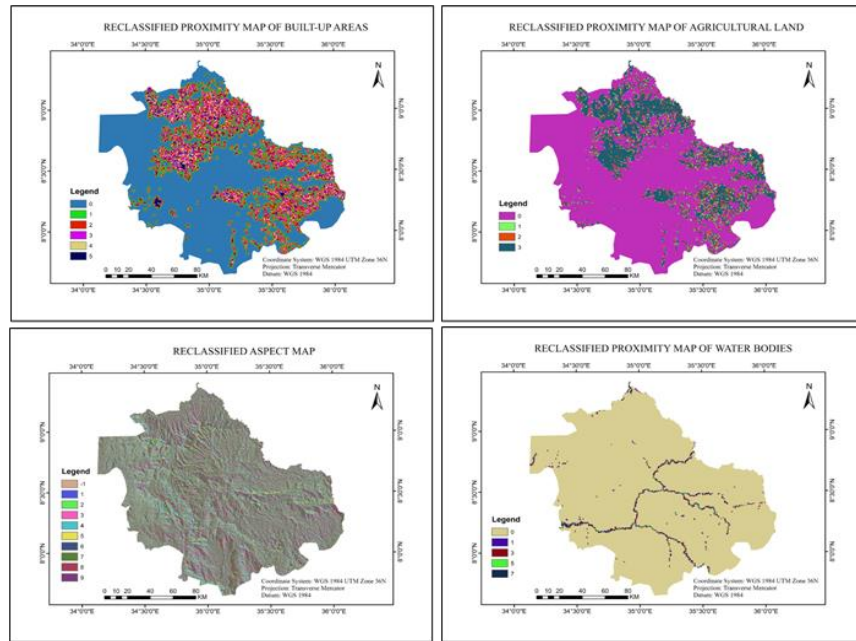


Figure 3: Reclassified environmental theme parameters.

Appendix IV: Reclassified map of drainage order, LULC, existing road and geology

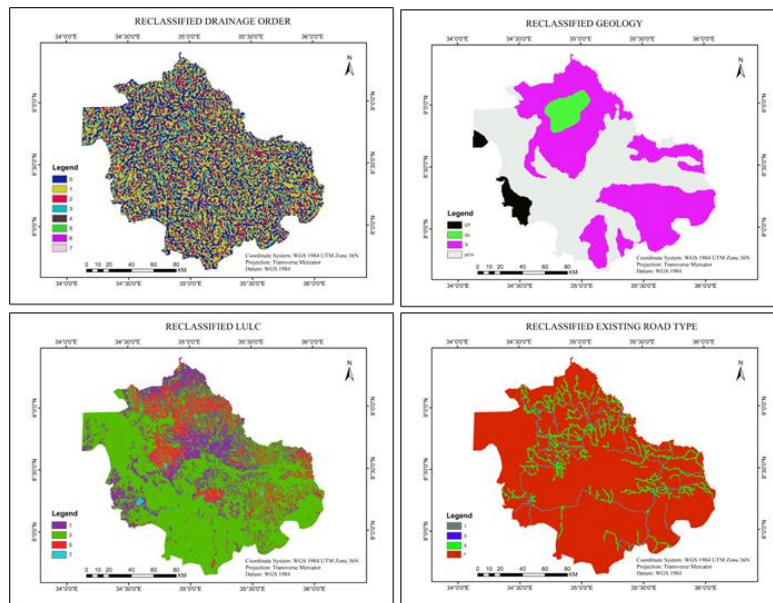


Figure 4: Reclassified economical theme parameters.

Appendix V: Weighted map of preferred economic, environmental and technical theme.

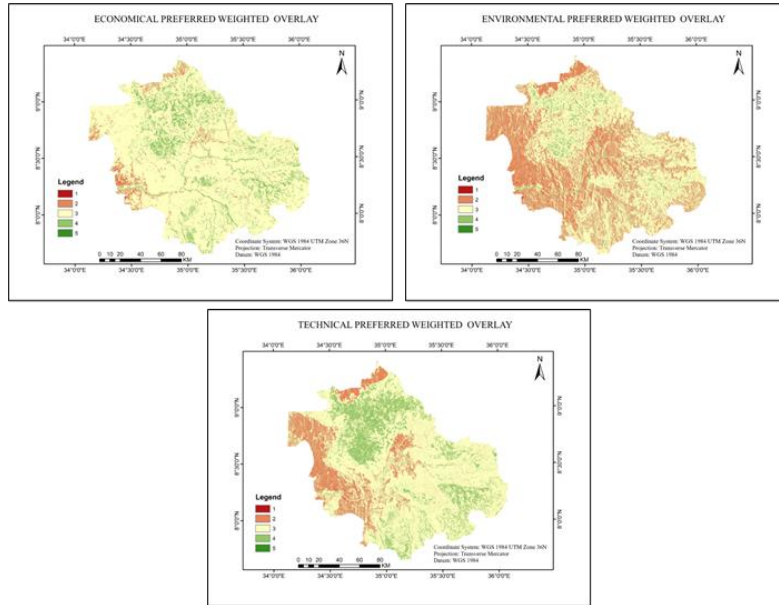


Figure 5: weighted map of preferred themes.

Appendix VI: Contour map of the study area

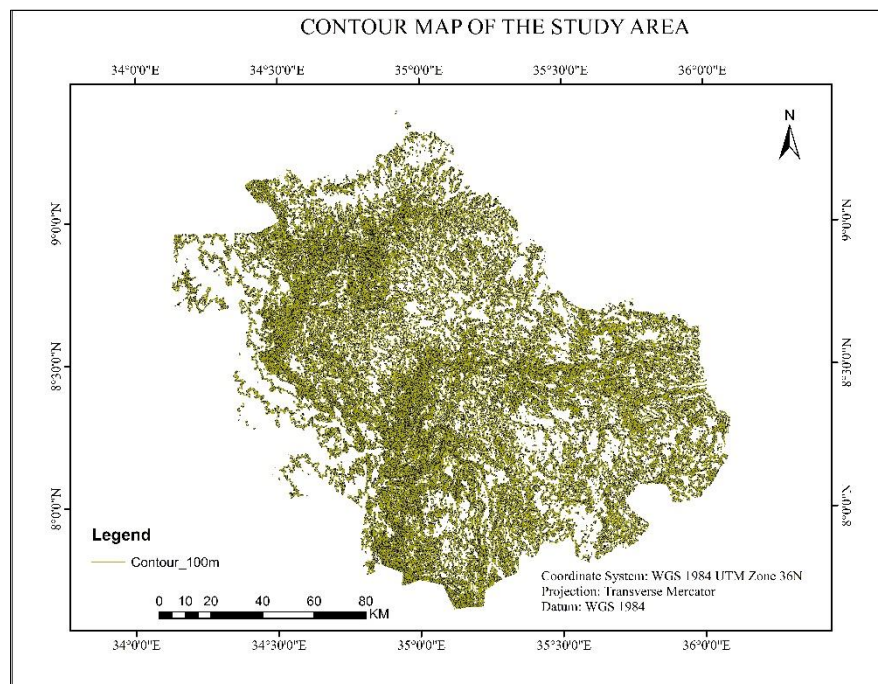


Figure 6: Contour map of the study area