

## Route Selection Using Geographical Information Systems, Remote Sensing and Analytical Hierarchical Process Techniques: Jos – Abuja Route

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### Abstract

*Route selection is an important aspect of road planning, engineering and construction. It highlights the sections of non-homogeneous space that should be considered for selection of least-cost route. Traditional methods that use paper topographic maps, and analog aerial photographs are manual and therefore tedious, laborious and inefficient, requiring long periods of time and consideration of only limited number of criteria at a time. Geographical Information System and Remote Sensing techniques, using Analytical Hierarchical Process (AHP), have the capabilities to transform the route planning and selection process considerably. They allow for the consideration of multiple criteria simultaneously and produce results that are significantly better than the manual methods, all within remarkably shorter periods of time. These techniques are greatly more efficient, reliable and productive. This paper demonstrates the efficacy of GIS and RS methods, coupled with AHP to select a new optimal (least-cost) route between the cities of Jos and Abuja, Nigeria.*

**Keywords:** Geographical Information System (GIS), Remote Sensing (RS), Analytical Hierarchical Process (AHP), Least-Cost Route, Optimal Route

### INTRODUCTION

The selection of a route for road construction is a complex and difficult task. The goal is generally to select the most cost-effective or least-cost route. This requires that many factors be accounted for, including environmental, sociocultural, political, economic and engineering factors. A tremendous amount of resources is expended to construct and maintain roads, and therefore represent a significant opportunity cost in terms of resources allocation. This cost extends to the use of the roadways, also in terms of pricing of the movement of people, goods and services along the road corridors. Some of the significant drawbacks of transportation such as congestion and air pollution, which incur large amounts of socioeconomic and environmental costs demand a time-effective movement process (Eliasson, 2021). Consequently, the quicker the movement process is completed, the less the drawbacks impede the development process. There is therefore a need for roads to be optimally routed to achieve cost effectiveness and time efficiency. In this regard, GIS and remote sensing have become important tools to accomplish the routing of roads for construction.

Traditional route selection is done on paper topographic maps and analog aerial photographs. It is usually manual in both cases hence multicriteria decision making is not adequately reflected in this approach because of limited capacity to efficiently accommodate many criteria all at once. However, in GIS geoprocessing and Remote Sensing techniques, different factors that play important roles in determining a highway alignment can be cumulatively evaluated simultaneously. Hence, this method can reduce the time required and efforts in the field. This approach also provides engineers, planners & decision makers with an opportunity to examine and evaluate various constraints cumulatively and interactively, thereby providing consistency, flexibility and accuracy of the route selection processes.

Transportation planning and highway engineering have therefore embraced GIS and Remote Sensing capabilities in the selection of an optimal route for road construction. These techniques have helped to reduce time of delineating routes, construction and operating costs, and several other negative environmental impacts associated with road construction (Farooq, Xie, Stoilova & Ahmad, 2019). Though it comes early in the

process, route selection using GIS and Remote Sensing methods is significant because it provides the foundation of road construction by choosing the least-cost path alternatives from which detailed analysis may be deployed. This has been made possible by the capability of GIS and Remote Sensing techniques to combine and transform both spatial criteria and subjective value judgments into a multi-criteria decision support system (MCDSS), which allows for the selection of an optimal or least-cost route for construction (Sameer, Abed & Sayl., 2023). The MCDSS offers engineers and planners formidable support throughout the entire process and ensures efficiency and effectiveness in decision making at all levels and through the entire project (Hamid-Mosaku et al. 2020).

The process involves the evaluation of a large number of criteria and stakeholders. Stakeholders also usually have different sets of preferred choices for the criteria, which leads to a large number of possible alternative routes to evaluate. Sorting through this multi-criteria ecosystem manually is difficult and not effective (Sameer et al., 2023). Geographical information systems (GIS and Remote Sensing (RS)) techniques are therefore employed because of their vast capacity and capability as spatial decision making systems (SDMS).

It must be acknowledged that GIS and Remote Sensing have been embraced and used in developed countries for quite a period of time. A tremendous amount of resources is expended to construct and maintain roads, which represent significant opportunity costs in terms of resources allocation. This cost extends to the use of the roadways in terms of pricing of the movement of people, goods and services along the road corridors. Added to these are congestion, and air pollution among other demands for a time-effective movement process (Eliasson, 2021). These negative impacts incur social and economic costs. Consequently, the quicker the movement process is completed, the less these drawbacks impede the development process. There is therefore a need for road constructions to be optimally routed to achieve cost effectiveness and time efficiency. In this regard, GIS and remote sensing have become important tools to accomplish the routing of roads for construction.

In developing countries such as Nigeria, not many agencies of government or even the private

sector have integrated GIS and Remote Sensing techniques in many of the areas for which they can effectively help with. In some cases, the dearth of necessary data has been the barrier, while in others the insufficiency of skilled personnel and skepticism or insufficient knowledge and appreciation of the capabilities of GIS and Remote Sensing are the culprits. This paper demonstrates the capability of GIS and Remote Sensing for optimal route selection in Nigeria, from Jos to Abuja.

## **MATERIALS AND METHODS**

### **Study Area**

Jos is one of the gateway cities from Abuja, the national capital and many parts of Southeastern Nigeria to most of the Northeastern states of Nigeria, which include Bauchi, Gombe, Adamawa, Borno and Taraba states, and vice versa. Most journeys to these places pass through the Plateau state capital, Jos. The Jos-Abuja road therefore experiences large volume of through-traffic flow on a daily basis in both directions. Currently, the road from Jos to Abuja has three streams of routes. All these three routes pass through many villages and towns with the noble and well-intentioned need to serve and open them up to traffic and catalyze their social and economic developments as roads are bound to produce. Consequently, the routes are long and tortuous, aimed to include as many places along its courses as may be possible. At the many villages and towns along the routes, traffic speed is slowed down either by the many economic activities that are directly on the roadways or by speed bumps constructed to minimize road traffic crashes. Travel time, costs, and air pollution are therefore increased, which renders the movement process less efficient. There is hardly a doubt that movement between the two cities requires substantial improvement.

There are two basic improvement thrusts that can be immediately suggested. The first is improvements in current routes through better traffic management strategies especially at the villages and towns along their course, including the addition of more lanes to cater for greater volume of traffic. This suggestion may improve time efficiency. The second suggestion is the construction of a new route. This has its benefits and drawbacks as well. One of the major benefits is that it will be purpose-built and therefore reduce many of the drawbacks such as congestion and improve time efficiency. This paper develops a multi-criteria model for a least-cost route

between Jos and Abuja using GIS and remote sensing techniques capabilities for effective and sustainable routing and transportation planning.

### Data

Least cost route generation is a technique for determining the least costly route from a source A to a destination B given the cost of travel from one cell to another in a given raster (Kiema, Dang'ana & Karanja, 2007). Several data types are therefore required and processed. A Geodatabase was created in ArcGIS 10.3 to house the GIS and remote sensing data used. All data were logically and consistently checked for errors, additions, emissions or gaps. For Remote sensing data, 30 m Shuttle Radar Topographic Mission (SRTM) satellite image was used. The GIS data were prepared in the Geodatabase giving rise to the various categories of Land Use Land Cover (LULC), slope, settlements/built up areas, proximity parameters from existing roads, rivers, and towns. Field values in the raster data were reclassified based on their valid statistics values to alternative scale values that can be used in computation. In the model environment, all factors were scaled between 1 and 10 appropriately (Table 3). Weights were derived for modeling the road route using Analytical Hierarchical Process (AHP). Weighted overlay analysis is done after reclassification and it brings together different factors with different level of significance expressed as weights. The reclassified elevation, slope, land use land cover, existing roads, settlement/built up, river and water body layers were overlaid (weighted overlay) to obtain best sites to construct a road at least cost. The resultant output was a cost raster.

The cost distance analysis determined the shortest weighted distance (accumulated travel cost) from each cell to the nearest source location in costs not in geographic units, generated from the source data (Jos) and a cost raster. This operation gave the output for cost distance (distance) and cost back link (direction), both in raster formats.

Once the accumulative cost distance and backlink raster layers were created, least cost path route was derived from designated destination cells or zones. The cost path tool retraced the destination cells through the backlink raster to a source, i.e., it calculated the least cost path from the source (Jos) to the destination (Abuja). This analysis required the source (Jos) and destination data (Abuja), the cost

distance and cost back link layers to produce the least cost path, which was then converted from the raster to polyline. This process was executed in ModelBuilder GIS Environment that incorporated all the variables stored in the Geodatabase to produce an optimum route from Jos to Abuja.

### Analytical Hierarchical Process (AHP)

One of the most popular analytical techniques for complex decision-making problems is the Analytical Hierarchy Process (AHP). Analytical Hierarchical Process (AHP) is a Multi-Criteria Evaluation (MCE) method that uses hierarchical structures to represent a problem and then develop priorities for the alternatives based on the judgment of the user (Saaty, 1980). The AHP approach, which is the most popular MCE technique, focuses on capturing stakeholder views of the appropriate weights to give to each impact factor (Kiema et al., 2007). AHP consists of four steps: first, is the definition of the complex decision problem; second, pairwise comparison of the selection factors whereby the decision maker ranks the factors according to their relative importance to one another (Dedemen, 2013); third, weights are determined for the criteria in step 2, using the pairwise comparison matrix; and, lastly the consistency rate is computed. A consistency rate greater than 0.1 requires that the weighting process be revisited and redone (Sameer et al., 2023).

An AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation. AHP has the ability to handle decision situations involving subjective judgments and multiple decision makers and to provide measures of consistency of preference. It can also efficiently deal with tangible as well as non-tangible attributes, especially where the subjective judgments of different individuals constitute an important part of the decision process (Gayatri & Chetan, 2013). For the purpose of this research, weights for the different factors and criteria were derived for the road using Analytical Hierarchical Process (AHP).

### Procedure for Optimal Route Location in GIS Model Builder Environment

The general procedure for delineating the optimal route is presented in Figure 1.

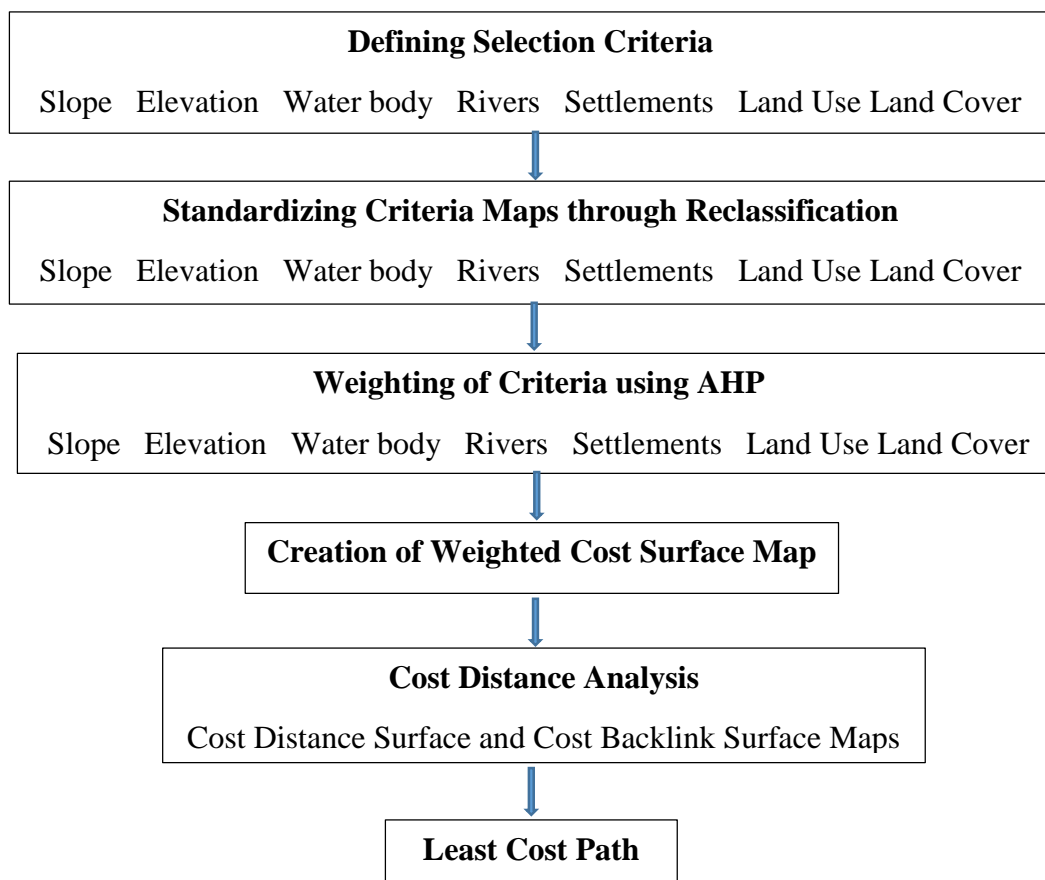


Figure 1: Procedure for Delineating the Optimal Route

The SRTM data are used to generate elevation and slope data of the study area. Then an analysis of distance (Euclidean Distance) is carried out on the shapefiles for settlement/built up, river and water body to obtain the proximity data for the shapefiles (settlement/built up, river and water body). All factor data used in the model are reclassified to a common scale (between 1 and 10). The factors were combined and overlaid in the model environment using the “weighted overlay” tool. Weights were then assigned to each of the factors based on percentage of perceived influence. An analytical hierarchy process (AHP) was undertaken to obtain suitable weights for the six criteria under consideration. For the purpose of this research all the criteria, except LULC were weighted equally and produced an average weight of 16% each (slope, elevation, proximity to settlement, water body and

rivers) (Table 3), while the land use land cover, had 20%, all adding up to a 100% (Table 4). Similarly, Sameer et al. (2023) weighted land use change greater than the other factors and noted that the close relationship between land uses and highways must be taken into consideration in the selection of a highway route. Rangzan, Mousavi, Saberi, & Darvishi (2019) also indicated that land use weigh heavily among several other factors considered for route selection. This is because highways have direct effects on and are significant tools to direct land uses in any given area (Sakar, Aydin & Akay, 2020). The AHP consistency ratio of 0.094886 was obtained and deemed adequate for this demonstration. Generally, a consistency ratio of less than 0.1 is deemed acceptable, indicating that the weighting of the criteria were consistent and could therefore be used (Saaty, 1980, 1990).

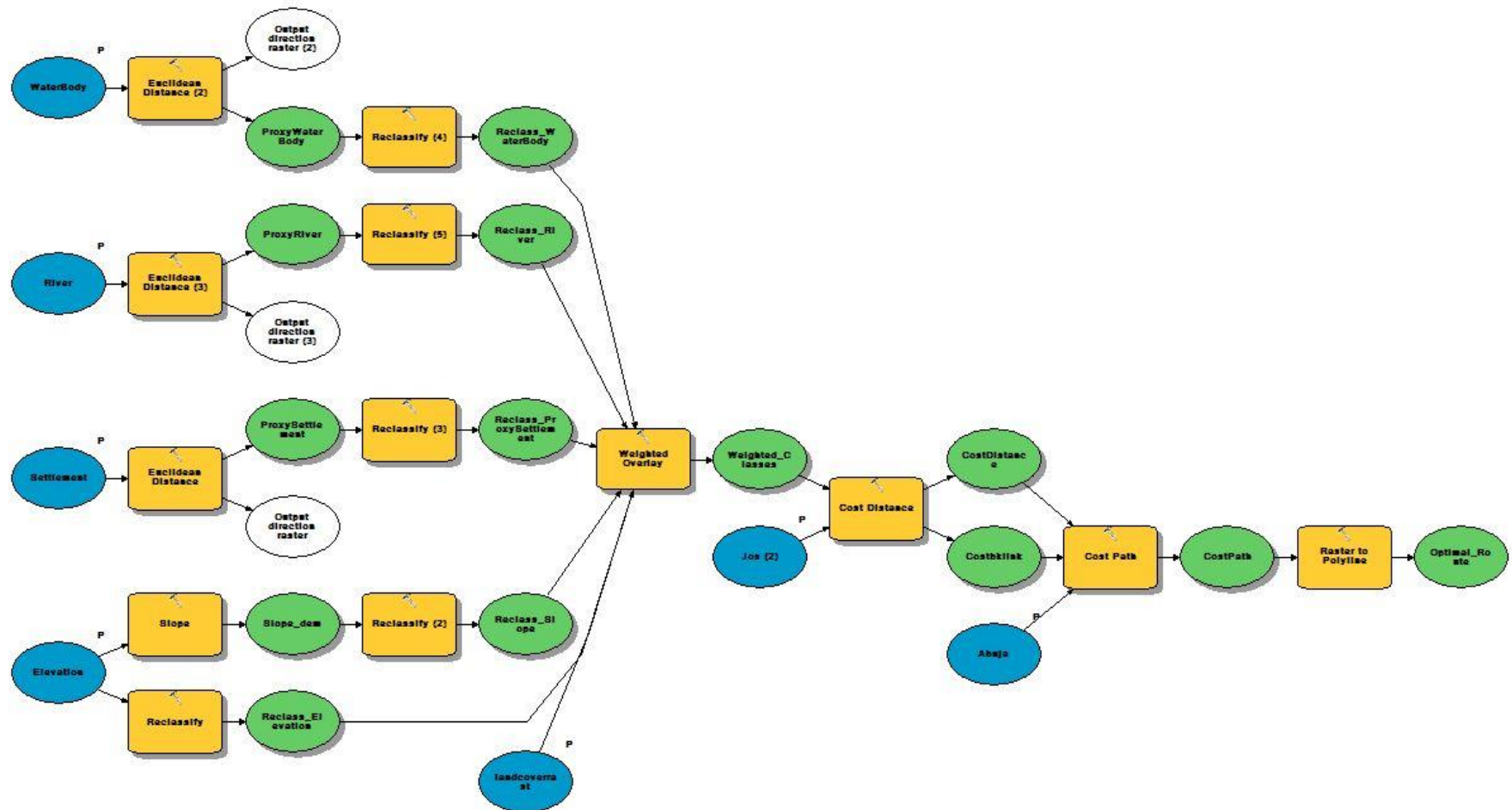


Fig. 2: Model for the Optimal Route

A cost distance analysis was then computed to calculate the least accumulative cost distance for each cell to the nearest source over a cost surface generated from the source data (Jos) to produce cost distance and cost back link layers. The cost path analysis requires the destination data (Abuja), the cost distance and cost back link to produce the least cost path to calculate the least cost path from a source to a destination. This task was achieved using the “cost path” tool in the Arc Toolbox. The least cost path generated is converted from raster to vector layer (Figure 2).

A new toolbox is created for the model, “Optimal Route”. The model environment is then set with all options required and the model builder was used to overlay the various data and parameters to generate an optimal route that is economical, logical, and meets the national standards for designing highways. Fig. 2 illustrates the model used for the possible best road path. The factors considered in the model were elevation, slope, land use land cover, existing roads, settlement/built up areas, river and water body.

## RESULTS AND DISCUSSION

### Results

#### Digital Elevation Model (DEM)

The elevation of the study area ranges from 0m to 1752m. This was categorized into five (5) classes. The lowest areas are within the southern part of the study area, while the highest areas are within the eastern part of the study area, where the Jos Plateau area is situated. Table 1 and Figure 3 present the classification of elevation.

#### Slope

Slope is the degree to which a surface (earth surface) tends upwards or downwards. Generally, in route location long, steep and unstable slopes are to be avoided to minimize geotechnical and related vertical alignments problems that might induce instability on slopes. It is therefore important to utilize natural terrain features such as stable benches, ridge tops and low gradient slopes to minimize the area of road disturbance. The output of the slope for the study area shows ranges from 0-86 degrees (°). These were classified into flat, gentle, moderate, high and very high slopes (Table 2).

Figure 4 presents slope distribution in the study area.

#### Land Use Land Cover

The Land Use Land Cover (LULC) classifies features within the study area. The land cover defined in the area include rain-fed cropland, sparse vegetation, bare areas, mosaic cropland/vegetation, mosaic forest/shrub land/grassland, mosaic vegetation/ cropland, close to open grassland, water body, close to open shrub land, open broadleaved deciduous forest, mosaic grassland/forest-shrub land, artificial areas including built up areas and close to open broadleaved evergreen. Water bodies and rain-fed cover areas were classified as restricted. Water bodies would probably increase costs of construction, and rain-fed agricultural areas are prime areas that would command large compensation rates. Figure 5 presents results of land use land cover classification.

#### Distance to Settlement

Distance range from 0 - 20,786m are closest to the settlement, while those from 187,078 - 207,863m are farthest distances to the settlements. The idea is to create a bypass path around settlements that minimizes congestion generated as a result of slow movement of traffic through settlement areas. Figure 6 shows the result of the distance to settlement analysis.

#### Distance to Rivers

The result for this analysis ranges from a distance of 0-201,672m. The closest distances range from 0 - 20,167m while the farthest distances range from 181,506 - 201,672m. Rivers are important considerations in road constructions because they affect the costs and time of construction. Bridges need to be constructed across river channels and these take time to accomplish. Figure 7 presents the network of rivers in the study area.

#### Distance to Water Body

Water bodies includes all other reservoirs like dams and lakes, which are not rivers. The closest distances range from 0-25,620m while the farthest distances range from 230,582 - 256,202m. Figure 8 displays result of distance to water bodies in the study area.



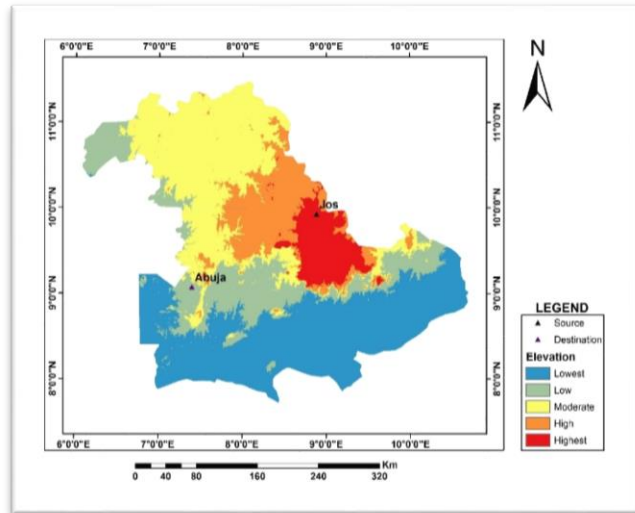


Figure 3: Digital Elevation Model

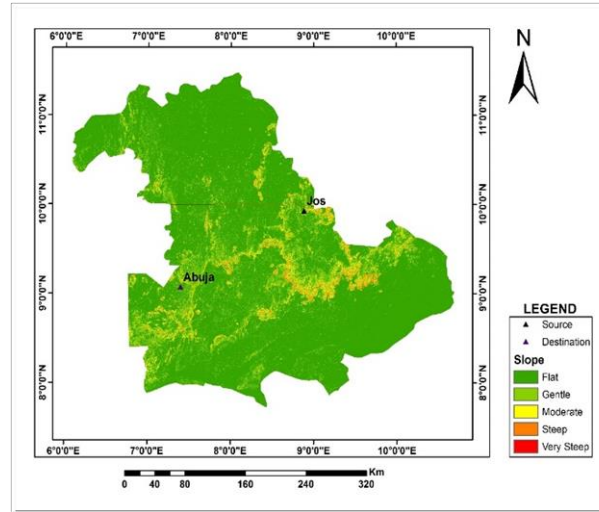


Figure 4: Slope

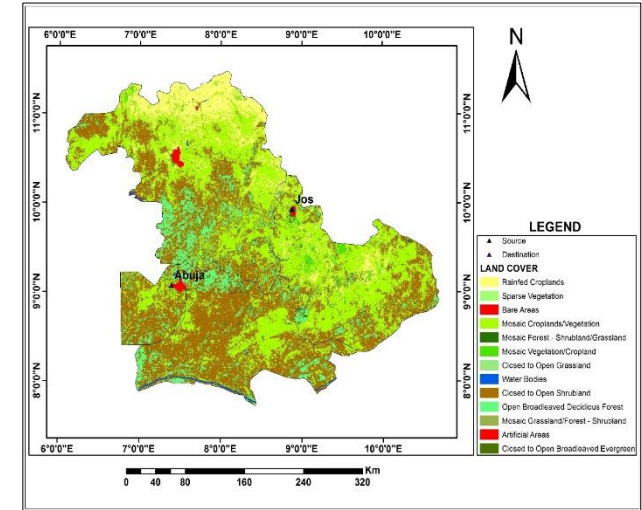


Figure 5: Land Use Land Cover

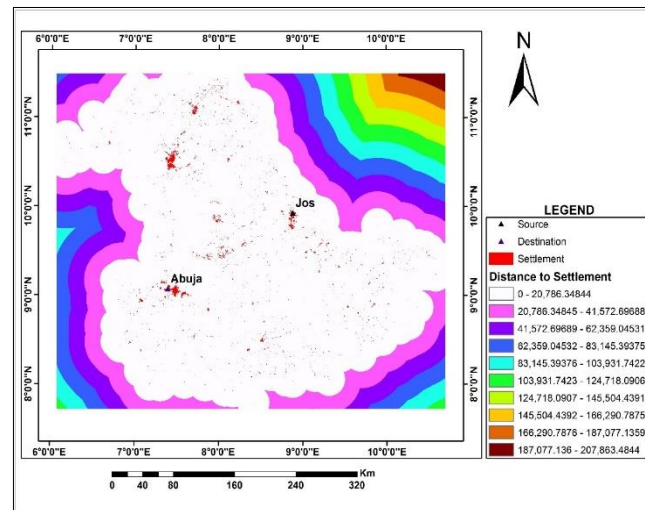


Figure 6: Distance to Settlements

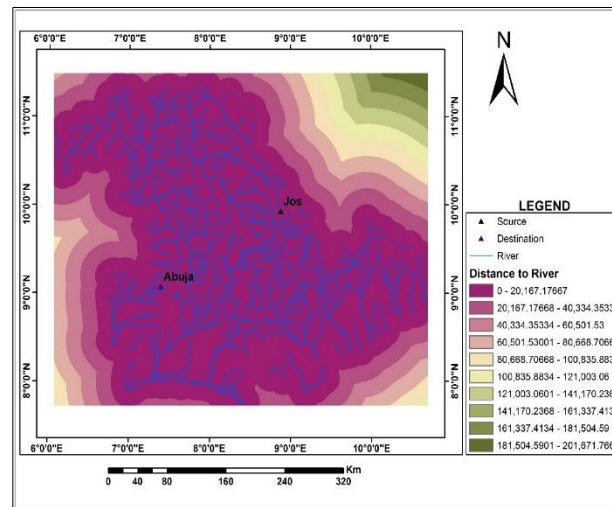


Figure 7: Distance to Rivers

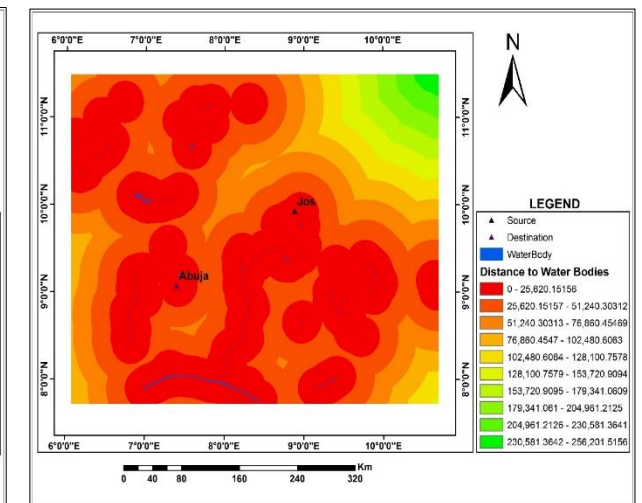


Figure 8: Distance to Water Bodies

**Table 1: Elevation Classes**

S/N	Elevation (m)	Rating
1	0 – 289	Lowest
2	290 – 515	Low
3	516 – 708	Moderate
4	709 – 996	High
5	997 – 1,752	Highest

**Table 2: Slope Classes**

S/N	Slope in degrees (°)	Rating
1	0 – 3	Flat
2	4 - 9	Gentle
3	10 -19	Moderate
4	20 -50	Steep
5	51- 86	Very Steep

**Table 3: Reclassification and Weighting of Factors of Influence**

S/N	Raster	% of Influence	Field Value	Scale Value
1	Reclassified Elevation (DEM)	16	1 – 10	1 - 10
2	Reclassified Slope	16	1 – 10	1 - 10
3	Reclassified Proximity to Settlement	16	1 – 10	1 - 10
4	Reclassified Proximity to Water Body	16	1 – 10	1 - 10
5	Reclassified Proximity to River	16	1 – 10	1 - 10

**Table 4: Reclassification and Weighting of Land Use Land Cover Factor of Influence**

S/N	Raster	% of Influence	Field Value	Scale Value
6	LULC	20	Rain-fed Croplands	Restricted
			Sparse Vegetation	9
			Bare Areas	10
			Mosaic Croplands/ Vegetation	8
			Mosaic Forest - Shrub land/ Grassland	9
			Mosaic Vegetation/Cropland	9
			Closed to Open Grassland	1
			Water Bodies	Restricted
			Closed to Open Shrub land	4
			Open Broadleaved Deciduous Forest	6
			Mosaic Grassland/Forest – Shrub land	6
			Artificial Areas	7
			Closed to Open Broadleaved Evergreen	6

### Reclassification of Factors of Route Determination

The factors of route determination (Digital Elevation Model (DEM), Slope, and Proximity to Settlement, River and Water Body) were reclassified to a common scale of 10, i.e., from 1-10. For all factors, sections classified as 10 are considered most appropriate for route construction. These include lower terrains and gentle slopes, and areas with close proximity to human settlements, and farthest away from rivers and water bodies. Areas reclassified with common scale values of 1 are least appropriate. These include areas of high terrain, steep slopes, farthest distances to settlements, and closest to rivers and water bodies.

High terrain and steep slopes are inappropriate for obvious reasons. They add to construction costs, result in slow traffic movement, and pose more danger and risks for road crashes. Roads are also expected to service people and therefore proximity to settlements was considered desirable. Hence, distances farthest away from settlements are considered the least appropriate for constructing an optimal route. When roads cross over rivers and water bodies, bridges are expected to be constructed, which add costs to both construction and maintenance. There is an additional risk of possible flooding that could disrupt traffic flow and cause crashes. This makes it less attractive to construct routes close to rivers and water bodies.



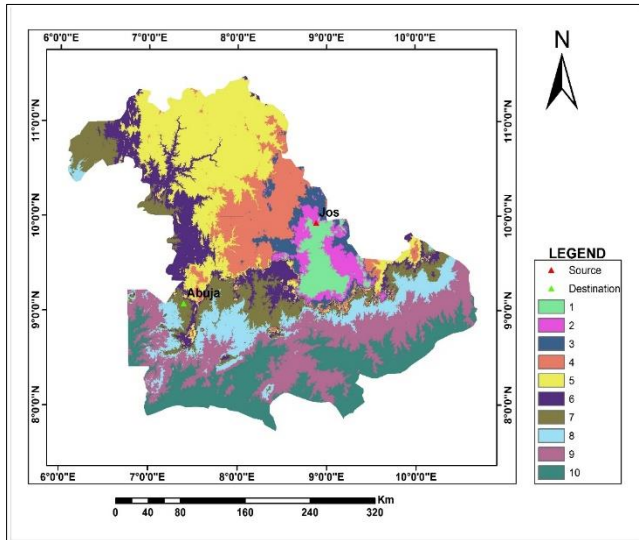


Figure 9: Reclassified Digital Elevation Model

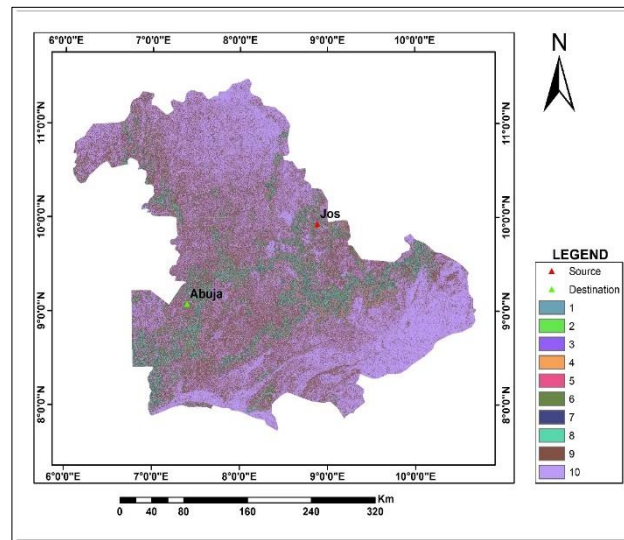


Figure 10: Reclassified Slope

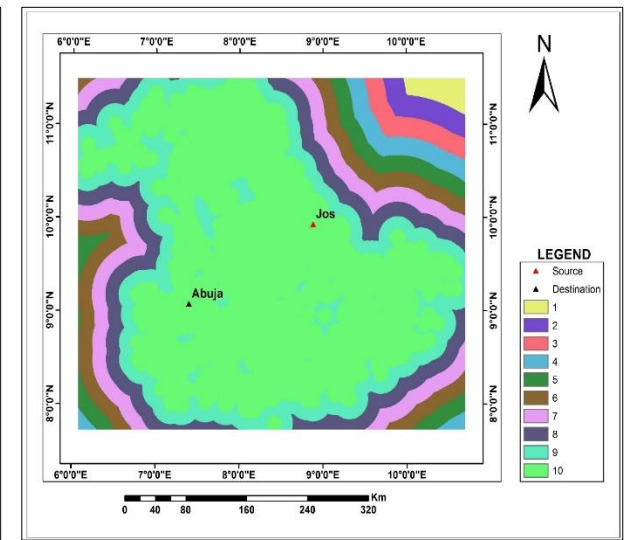


Figure 11: Reclassified Proximity to Settlements

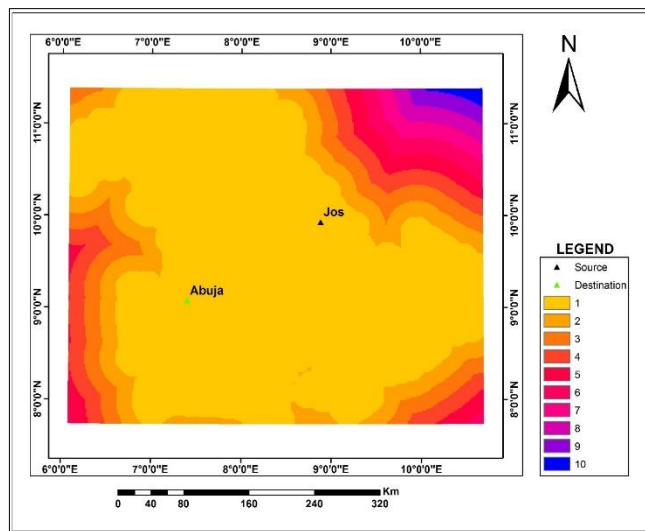


Figure 12: Reclassified Proximity to

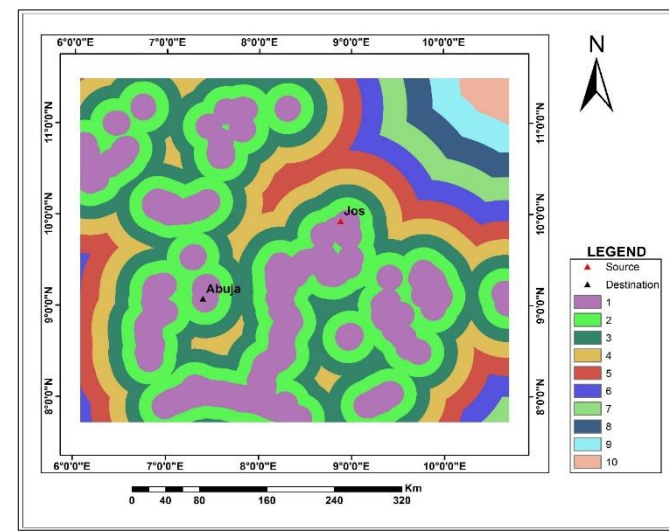


Figure 13: Reclassified Proximity to Water

### Weighted Overlay

The AHP method is a functional pairwise comparison method that is commonly used to assign weights to factors for overlay analysis. The method starts with a well-defined problem such as modeling of an optimal route, then compares factors in regard to their importance as determined by decision makers, and finally determines the weights for each factor. Though subjective, the method is flexible and allows for testing of different weight scenarios. For this study all factors except land use land cover (LULC) were considered to have uniform level of influence and were assigned weights that approximated 16% each (Table 3). Depending on nature of data collected on the study area, different factors may weigh greater than others. For example, for an area where rivers are few and far apart, proximity to rivers may weigh less than others. LULC was assigned a weight value that amounted to a percentage of influence of 20%. Unlike the other factors that are singular, LULC is a complex mix of land resources that need to be carefully considered. For example, fragile land areas, and prime agricultural lands may need to be preserved to ensure least damage to the ecosystem, and also reduce compensation rates.

### Cost Distance and Cost Back Link Surfaces

A cost surface map is part of the least path analysis and it represents a cost map of movement from a source (starting point) to a destination point (Aldenderfer, 2008). The concept of cost can be measured in distance, monetary terms or time, from a source point to a destination point. The cost distance therefore is an indication of how far the source is from the destination in terms of cost. The cost back link is primarily about direction, indicating how to get to destination from a source. Hence, the cost back link functions as a guide on how to get to a particular destination. The cost surface is a product of the weighted overlay operation and used to generate the new route. From these weighted layer, the cost surfaces which included the cost distance and the cost backlink were generated in order to specify the least cost path which is in raster format. The cost distance raster is generated with the source cells and the weighted sum and calculates the shortest weighted distance between the cells. The back link raster defines the neighboring pixel to go back to the destination cell.

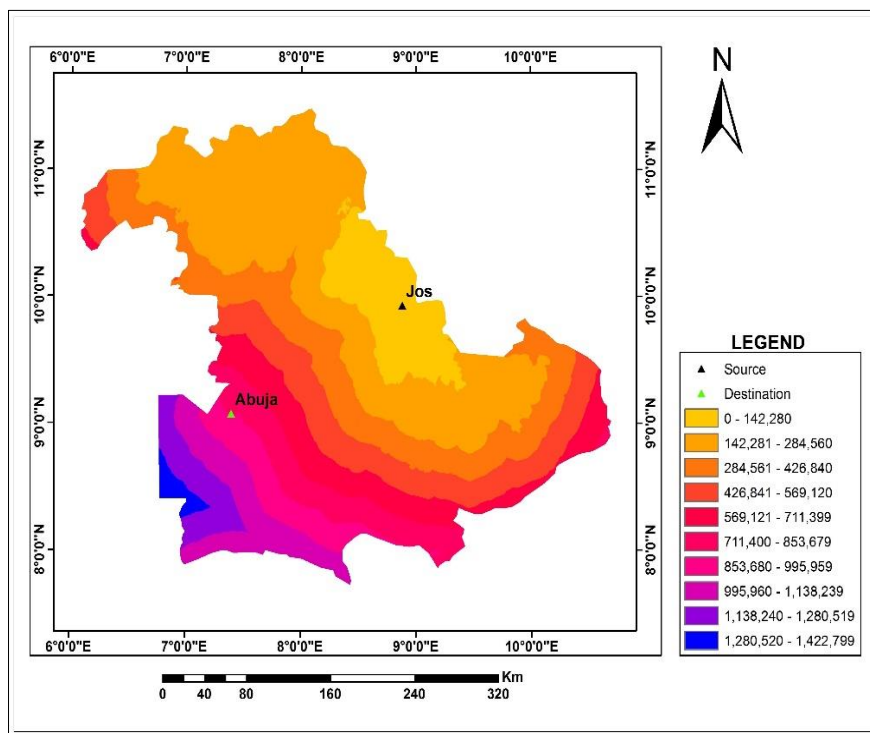


Figure 14: Cost Distance

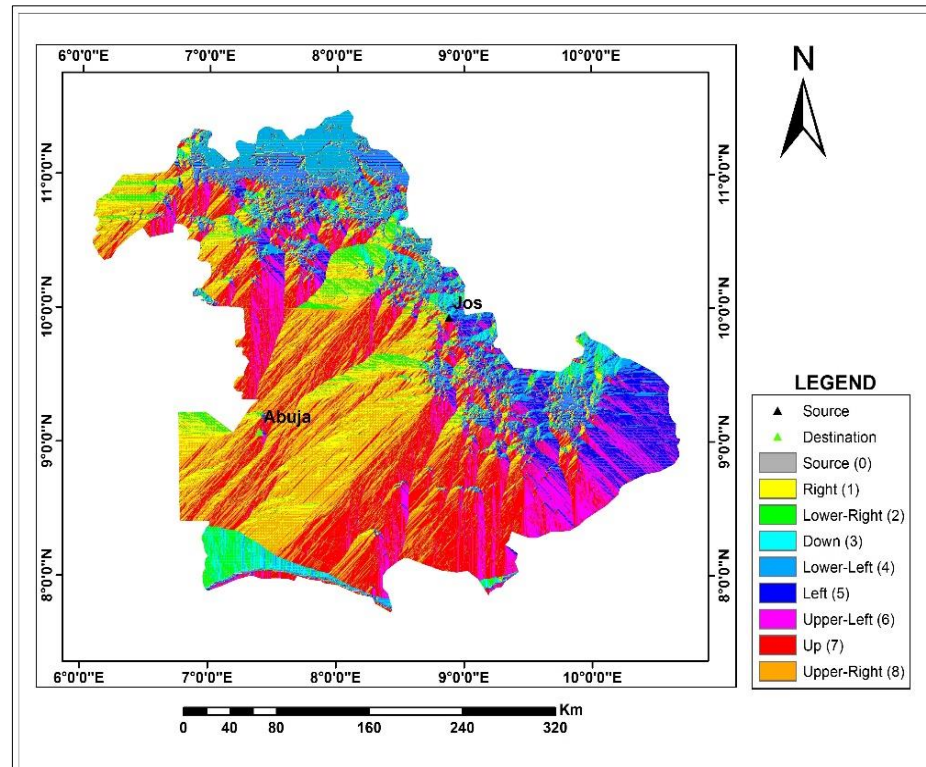


Figure 15: Cost Back Link

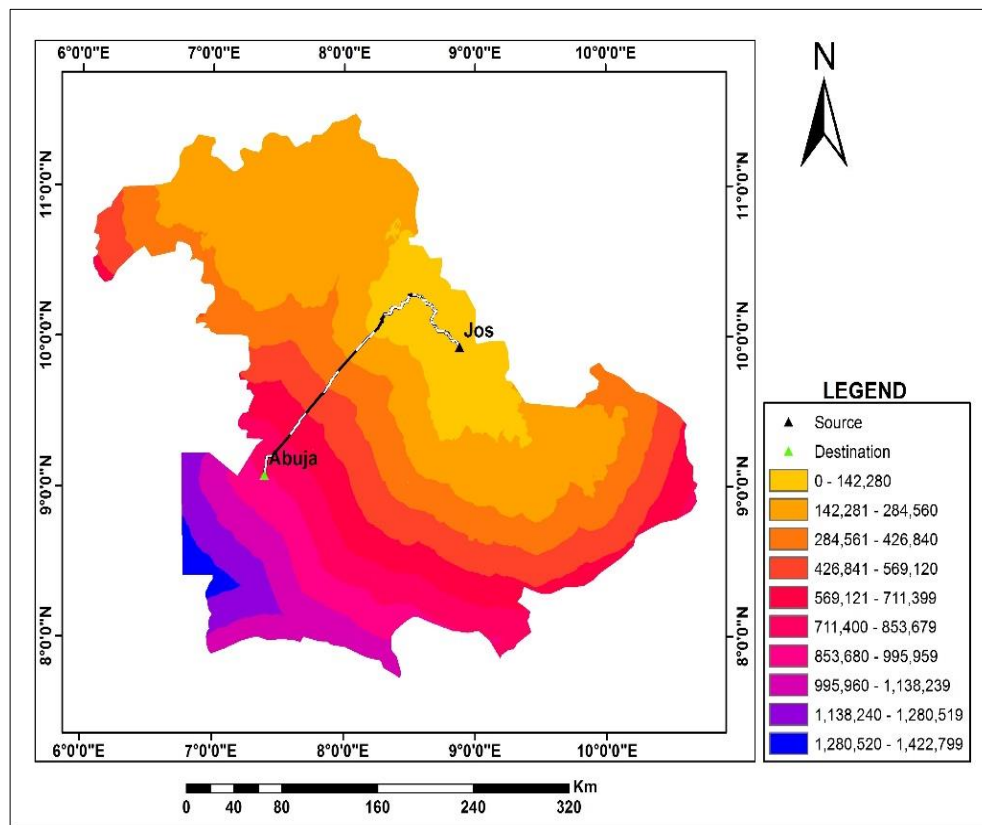


Figure 16: Cost Surface and Generated Route

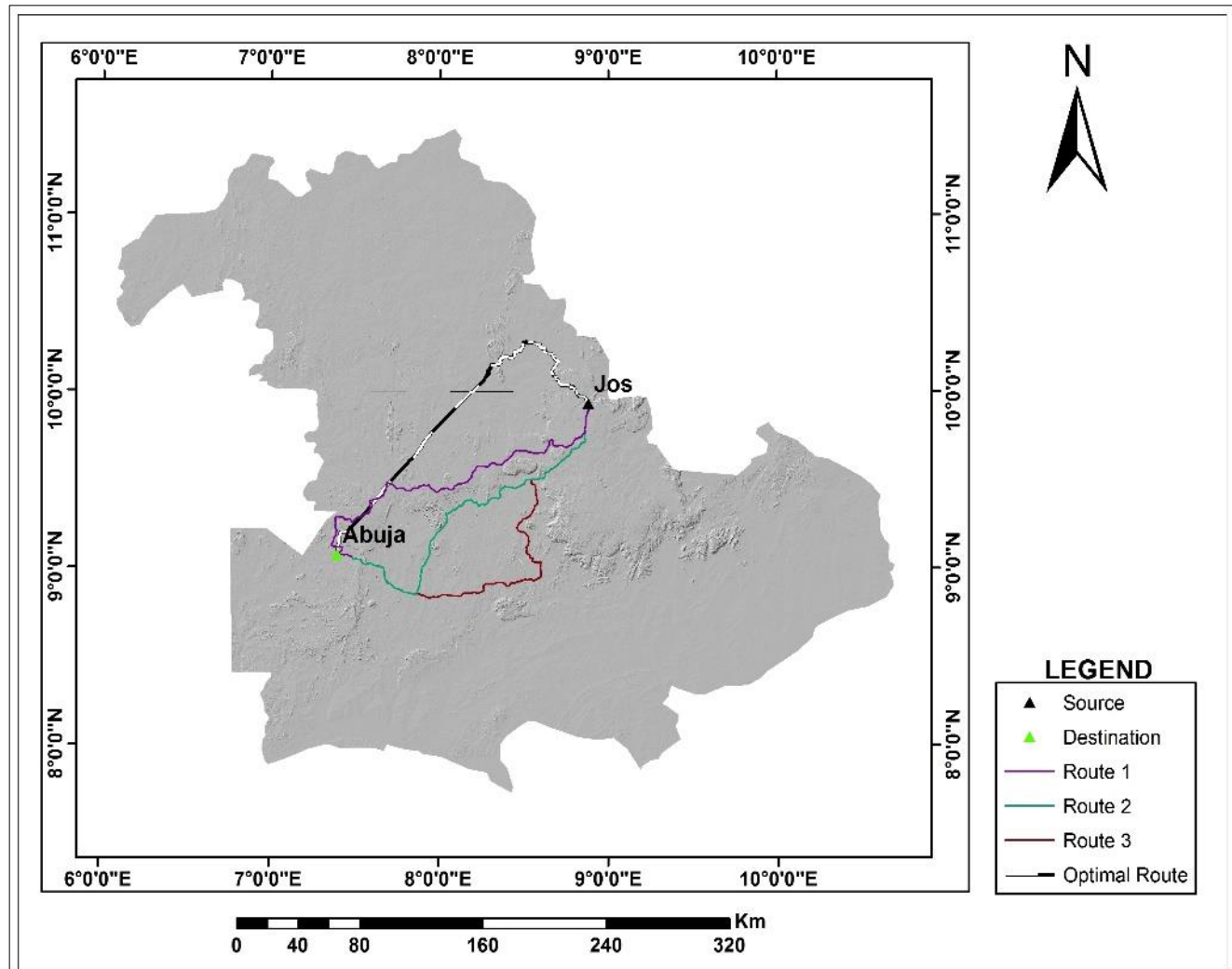


Figure 17: Generated and Existing Routes

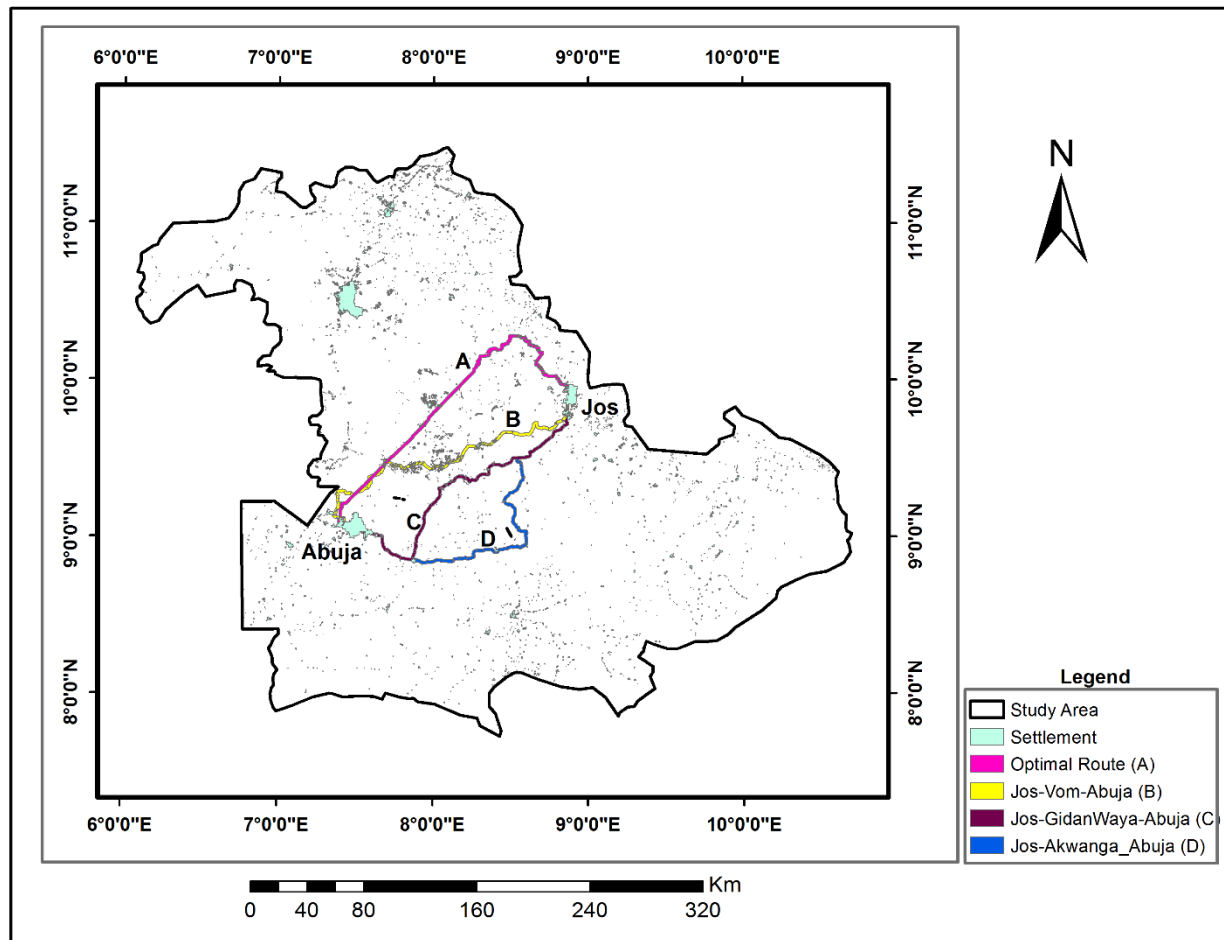
### Discussion

There are three existing stems of route between Jos and Abuja. These were identified and measured using geometric tools in ArcGIS to allow for comparison with the new generated route. Route 2, the Jos-Vom-Abuja road is about 278 km long, with a detour index of 0.66; Route 4, the Jos-Gidan Waya-Abuja route is about 259 km long and is the

shortest of them. It has a detour index of 0.70; while, Route 3, the Jos-Akwanga-Abuja road is measured at about 305 km long, the longest of the three, with a detour index of 0.60. It turned out that all three are shorter than the new generated route, which was measured at 310 km and has a detour index of 0.58. This has several implications.

Table 5: Characteristics of Routes

	Route	Length (Km)	Detour Index	Settlements within 1 km	Settlements on Route
A	Optimal Route	310.75	0.58	23	11
B	Jos-Vom-Abuja	277.98	0.66	77	63
C	Jos-Gidan Way-Abuja	258.88	0.70	44	33
D	Jos-Akwanga-Abuja	305.32	0.60	46	32



**Figure 18: Routes-Settlement Relationship**

First, the cost of construction and maintenance of the new optimal route may be significantly high. The new route is about 60 km longer than Route 3, the shortest; 33 km longer than Route 2; and, 5 km longer than route 3, the longest of the three. On face value therefore, the three existing routes would be preferable to the new route in terms of distance. Second, the three existing routes also have better detour index values than the optimal route. The detour index measures the sinuosity of a route. It compares the length of the road against a straight length route between the source and destination points. A route that is a straight line will have a value of 1 indicating the route and the straight line from source to destination are same. With the lowest detour value at 0.58, the optimal route has more bends to negotiate the existing routes. Interestingly, Route 4 has a better detour index (0.66) than Route 2 (0.60) even though it is nearly 30 km longer.

However, there may be some mitigating factors for the new route.

The length of the new route appears to have been increased by its apparent sinuosity in its first few kilometres from Jos, as its routing attempts to navigate the high and steep areas in search of low and gentle terrain of the Jos Plateau to meet the criteria set in the routing algorithm (Figures 16 and 17). This may explain why the new route heads northward in its first instance instead of the southern direction favoured by all three existing routes. Figures 3 and 8 show that the south of Jos has much higher and steeper elevations and slope terrains than the northern section, which the new route selected. The terrain (elevation) and gradient (slope) are guaranteed to be lower and gentler, which could be an advantage in terms of costs.

Furthermore, the long length of the new route may suggest a longer period of time to cover the



distance. This would be disadvantageous to a proposal to construct the route. However, this does not necessarily have to be the situation. The new route shows that most of its length is straighter than that of all the three existing routes, once the first quarter of the road, which is sinuous is successfully negotiated. This should allow for faster flow of traffic on the remaining longer section of the route. With a fast flowing traffic, travel time would be much reduced. This would save costs of transportation especially of good and services, and reduce environmental costs such as pollution as vehicles may take shorter period of time on the road.

A detailed analysis showed that the new route would pass through less number, and smaller-sized towns than are on the existing routes, with implications for less congestion and less bottlenecks as vehicles pass through towns. Through-traffic may therefore be better off patronizing the new routes than going through the existing routes. Table 5 shows that the optimal route would have about twice less the number of settlements within one kilometer of it than Routes C and D, and 3.5 times less than Route B. Significantly, the optimal route has only 11 settlements directly in its path, three times less than those of C and D and almost 6 times less than those on Route B. The implication for flow of traffic is obvious. There is no doubt that the presence of a new road would generate growth in existing settlements and probably catalyze the development of new settlements to provide essential services to travelers. This would be a welcome development. With proper planning and development control the growth in settlements will not pose a significant barrier to traffic flow as being experienced along the existing routes.

It must be admitted that there are many limitations in the routing. Generally, more factors would be considered and the weight of each factor is carefully computed than have been put forward in this paper. Environmental, sociocultural, economic, and engineering factors among many others must be carefully considered and weighted. Several stakeholders are expected to be involved in decision making. In the final analysis, the same or identical procedure presented in this paper will be followed to produce the desired route that accounts for all the criteria set forth by the decision makers. Beyond route selection, different sections of the route needs to be considered through series of analyses including soil, geologic and angular dimensions of

terrains. Further decision may be taken to provide a tunnel through a passage rather than deviate a route around a particular obstacle depending on actual conditions along the selected route. Route selection is therefore a first step but a clearly significant one.

## CONCLUSION

Route selection through the use of remote sensing and GIS geoprocessing is gaining grounds in engineering sectors in Nigeria. It is one of many applications of geospatial technologies that is only now gaining appreciation probably due to its relatively recent deployment in the country and the insufficiency in the number of trained and skilled professionals in the discipline. Using this method, several alternative routes may be derived using different combination of factors and weights to arrive at an optimally-considered route. All this can be achieved in minimal time. This paper has demonstrated that geographical information system (GIS) and remote sensing techniques are veritable tools to process and analyze multiple criteria for route selection and possess the capabilities and flexibility to include any detail necessary to actually delineate a road passage across space.

## REFERENCES

- Aldenderfer, M. (2008). Cost surface. In K. Kemp (Ed.), *Encyclopedia of geographic information science*. Thousand Oaks, CA: SAGE Publications. 55-57.
- Eliasson, J. (2021). Efficient transport pricing—why, what, and when? *Communications in Transportation Research*, 1 (December), 1-6
- Dedemen, Y. (2013): A Multi-Criteria Decision Analysis Approach to GIS-Based Route Selection for Overhead Power Transmission Lines. Unpublished M.S thesis submitted to Middle East Technical University <http://etd.lib.metu.edu.tr/upload/12615992/index.pdf>
- Farooq, A., Xie, M., Stoilova, S. and Ahmad, F. (2019). Multicriteria Evaluation of transport plan for high-speed rail: an application to Beijing-Xiongan. *Math Prob Eng* <https://doi.org/10.1155/2019/8319432>
- Gayatri, V., and Chetan, S. M. (2013). Comparative Study of different Multi-criteria Decision-making Methods,



- International Journal on Advanced Computer Theory and Engineering*, 2(4) 2319-2526.
- Hamid-Mosaku, I. A., Oguntade, O. F., Ifeanyi, V. I., Balogun, A-L. and Jimoh, O. A. (2020). Evolving a comprehensive geomatics multi-criteria evaluation index model for optimal pipeline route selection. *Struct Infrastruct Eng*, 16(10),1382–1396
- Rangzan, K., Mousavi, S. S., Saberi, A. & Darvishi, S. (2019) Optimum route selection for Pole Zal - Khorram Abad highway using GIS and environmental consideration, *Adv. Appl. Geol.*, 9(3), 284-299
- Saaty, T. L. (1980). *The Analytical Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill, New York.
- Saaty, T. L. (1990): *Decision Making for Leaders*. RWS Publications, Pittsburgh, USA.
- Sameer, Y. M., Abed, A. N. & Sayl, K. N. (2023) Geomatics-based approach for highway route selection. *Applied Geomatics* <https://doi.org/10.1007/s12518-023-00495-x>