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GIS-BASED OPTIMAL HIGHWAY ROUTE DETERMINATION BETWEEN BAGANAKWO AND CHANCHAGA SETTLEMENTS IN NIGER STATE NIGERIA

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Abstract

Efficient highway alignment is critical for improving regional connectivity, reducing construction costs, and minimizing environmental and social impacts. In Niger State, Nigeria, rapid urban expansion and increasing traffic demand require data-driven approaches to route planning that go beyond traditional, intuition-based methods. This study aims to develop and demonstrate a Geographic Information System (GIS)–based framework for identifying an optimal highway route between Baganakwo and Chanchaga in the Bosso/Paikoro area of Niger State. The specific objectives are to integrate multiple spatial criteria relevant to highway design, generate least-cost route alternatives, and evaluate trade-offs among competing alignment options. High-resolution digital elevation models (DEM), land-cover data, soil and terrain stability proxies, existing road networks, hydrology, and socio-environmental constraints were incorporated into a composite cost surface using the Analytical Hierarchy Process (AHP) for criteria weighting. Least-cost path and corridor analyses were then performed to derive optimal and alternative highway alignments. The results identify an optimal corridor that balances route length and travel impedance while significantly reducing earthwork requirements, stream and wetland crossings, and potential social disruption. Sensitivity analysis demonstrates that while the shortest route is not necessarily the most cost-effective or least impactful, the selected alignment remains robust across reasonable variations in criteria weights. This study concludes that GIS-based multi-criteria least-cost path analysis provides a transparent, replicable, and effective decision-support tool for early-stage highway planning in data-limited environments. It is recommended that the proposed alignment be subjected to detailed field verification, geotechnical investigations, and phased engineering design. The workflow presented is transferable and can support corridor screening and sustainable highway planning in other parts of Nigeria and similar developing regions.

Keywords: Analytical Hierarchy Process, Corridor selection, Highway alignment, Least-cost path analysis, Multi-criteria evaluation

INTRODUCTION

Highway alignment selection is inherently a complex, multi-objective planning problem that requires the careful balancing of construction cost, terrain suitability, environmental and social impacts, and connectivity to existing transportation networks. Decisions made at the early planning stage strongly influence project feasibility, long-term maintenance costs, and environmental sustainability (Sari *et al.*, 2022). As a result, systematic and transparent methods for corridor screening and preliminary alignment selection are essential for informed infrastructure development. Geographic Information Systems (GIS) have become indispensable tools for addressing this complexity, as they enable the integration and spatial analysis of diverse datasets, including topography, land use and land cover, soils, hydrology, environmental constraints, and socio-economic factors (Nugraha *et al*., 2025). Using raster- and vector-based analytical techniques, GIS facilitates the development of cost surfaces and the identification of least-cost corridors that represent spatially optimal routes under defined criteria (Eastman, 2012; Longley *et al.,* 2015). In recent years, methodological advances have further enhanced GIS-based highway planning through the integration of least-cost path analysis (LCPA) with multi-criteria decision analysis (MCDA), particularly the Analytic Hierarchy Process (AHP), allowing expert knowledge and planning priorities to be explicitly incorporated into alignment selection (Saaty, 2008; Nugraha *et al*., 2025). These hybrid GIS–MCDA approaches have proven effective for producing practical and defensible preliminary alignments suitable for early engineering assessment, environmental screening, and stakeholder engagement (Nugraha *et al*., 2025). Rather than yielding a single rigid path, contemporary methods emphasize corridor-based solutions, sensitivity analysis, and the generation of alternative alignments, which together improve robustness and decision flexibility during subsequent design stages.

Within Nigeria, rapid urban growth, increasing traffic demand, and ongoing road rehabilitation initiatives, particularly in Niger State, underscore the need for data-driven approaches to highway planning. The Bosso/Paikoro axis of Niger State, linking peri-urban and urban communities around Minna, represents a strategically important corridor where improved connectivity could enhance mobility, economic activity, and regional integration (Mohammed *et al*., 2020; Niger State Government, 2024). However, the area is characterized by variable terrain, drainage networks, land-use conflicts, and environmental considerations that complicate traditional route selection methods. Against this backdrop, the present study applies an integrated GIS-based least-cost corridor approach to determine an optimal highway alignment between Baganakwo (approximately 9.5727° N, 6.4985° E) and Chanchaga in the Minna metropolitan area. Specifically, the study compiles and preprocesses relevant spatial datasets, including digital elevation models, land-use/land-cover data, soil characteristics, hydrology, and existing road networks and synthesises them into multi-criteria cost surfaces using AHP-derived weightings informed by expert judgment. Least-cost corridors and alternative alignments are then generated and evaluated through sensitivity analysis to assess the stability of routing outcomes under varying assumptions. Finally, the study provides planning and engineering recommendations and outlines targeted field validation steps to support future detailed design and implementation. In doing so, the paper also demonstrates a replicable GIS workflow that can be adapted for highway corridor planning in other parts of Nigeria.

Study Area

The study area covers the rural–peri-urban corridor between Baganakwo in Bosso Local Government Area and Chanchaga in the Minna metropolitan axis of Niger State, Nigeria. Geographically, the study area lies approximately between Latitude 9°30′00″N and 9°40′30″N and Longitude 6°28′30″E and 6°35′30″E, covering parts of Bosso and Chanchaga

Local Government Areas. This spatial extent captures the existing transport corridor and surrounding terrain relevant to highway alignment planning. Minna and its surrounding settlements have an estimated population exceeding 400,000 inhabitants, with continued growth driven by migration, institutional development, and expanding economic activities.

The relief of the study area is characterized by undulating terrain typical of the Nigerian Basement Complex region. Elevation generally ranges between 250 m and 350 m above mean sea level, with gently rolling hills interspersed with shallow valleys and seasonal drainage channels. Climatically, the area falls within the tropical wet-and-dry (Aw) climate zone, characterized by distinct wet and dry seasons. The rainy season typically extends from April to October, while the dry season occurs between November and March and is influenced by the Harmattan winds from the Sahara Desert. Mean annual rainfall ranges between 1,100 mm and 1,300 mm, with peak precipitation occurring between July and September. The Geology is underlain predominantly by Precambrian Basement Complex rocks, consisting mainly of granites, gneisses, migmatites, and schists. These crystalline rocks influence the structural stability of the terrain and the engineering properties of foundation materials for road construction. The soils within the study corridor are largely ferruginous tropical soils, typically sandy-loam to lateritic in composition.

Vegetation within the study area is dominated by Guinea savanna vegetation, characterized by scattered trees, shrubs, and grasses. Common tree species include Isoberlinia, Daniellia, and Parkia species, while grasses dominate the ground cover during the rainy season. Land cover within the corridor consists of a mosaic of cultivated farmland, fallow vegetation, scattered woodland patches, rural settlements, and transportation infrastructure. Agricultural activities have significantly modified the natural vegetation pattern, resulting in mixed vegetation classes including cropland, shrubland, and degraded savanna woodland.

Socio-economically, the population within the study corridor is predominantly engaged in agriculture, petty trading, transportation services, and small-scale commercial activities. Major crops cultivated in the area include maize, rice, millet, sorghum, yam, and groundnuts, reflecting the suitability of the region's climate and soils for rain-fed agriculture.

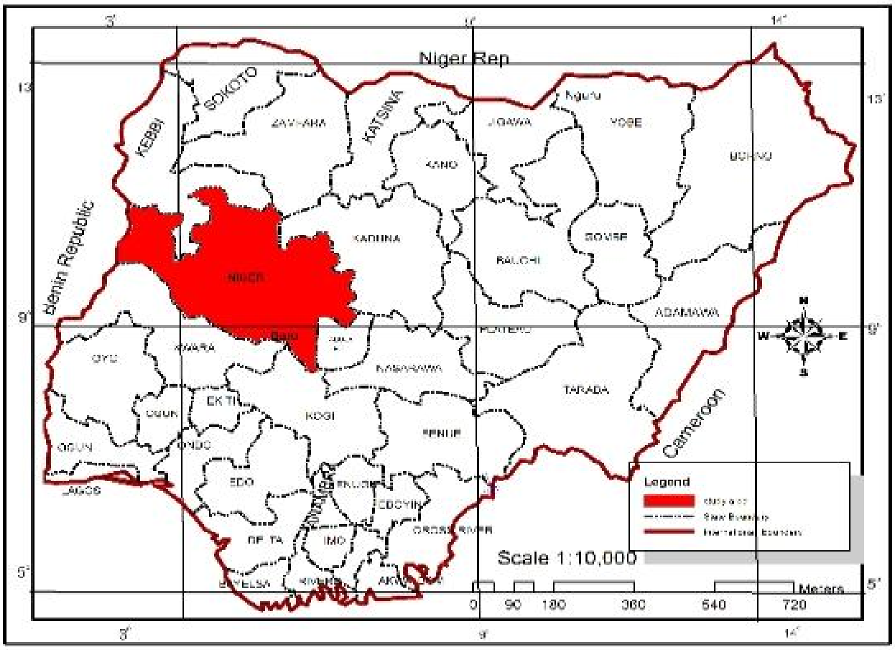

Figure 1: presents the map of Nigeria showing Niger state administrative boundaries

Source: Niger State Geographic Information System (2022)

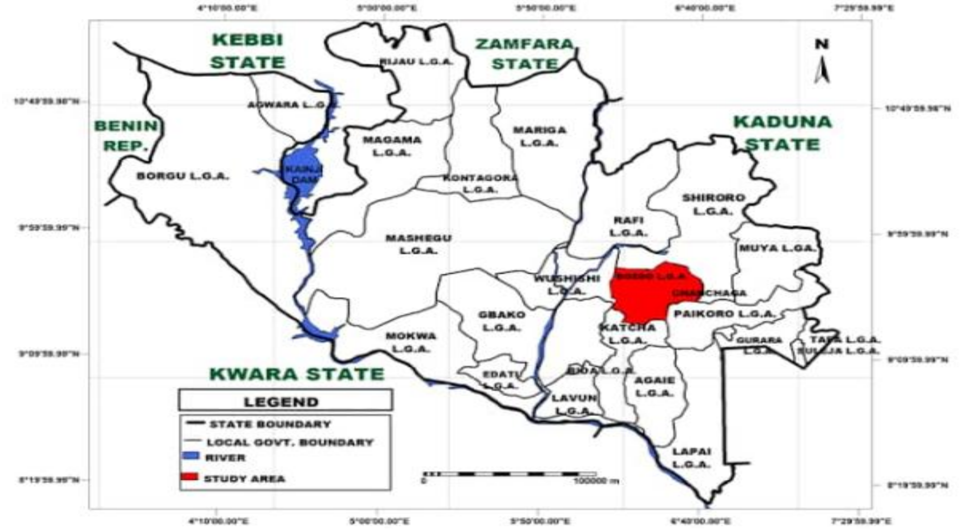

Figure 2: Location map showing the administrative boundaries of Bosso and Chanchaga Local Government Areas in Minna, Nigeria
Source: Niger State Geographic Information System (2022)

Figure 3: Satellite imagery showing the project area (spatial extent of Baganakwo and Chanchaga corridor Niger State, Nigeria)
Source: Authors Lab work (2024)

LITERATURE REVIEW

Least-cost path analysis (LCPA) is a well-established geographic information system (GIS) technique used to identify routes that minimize cumulative traversal cost across a raster surface. The method has been widely applied in planning linear infrastructure such as highways, pipelines, railways, and transmission corridors (Eastman, 2012; Longley *et al.,* 2015). In its basic form, LCPA computes an accumulated cost surface and a back-link raster to derive an optimal path between specified origin and destination points. Each raster cell represents a traversal cost derived from spatial criteria such as slope, land use, hydrology, and environmental constraints. The optimal path is then calculated as the route with the minimum cumulative cost across the cost surface.

Despite its wide adoption, early implementations of LCPA were constrained by simplified modelling assumptions. Many early studies relied on isotropic cost functions in which movement cost was assumed to be uniform in all directions, and routes were represented as single-pixel lines that did not adequately capture engineering design requirements or the spatial uncertainty inherent in large infrastructure planning projects (Yeh *et al.,* 1996; Yuan *et al.,* 2015). These limitations prompted methodological improvements that incorporated anisotropic cost functions, slope-dependent movement penalties, and terrain-based impedance models. Such developments allow the modelling of directional constraints and more realistic representations of terrain difficulty, thereby improving the reliability of spatial decision-support systems for infrastructure planning.

More recent developments have shifted toward corridor-based modelling approaches, which identify broad zones of relatively low cost rather than a single optimal alignment. Corridor analysis enables planners to maintain flexibility during subsequent engineering design stages and allows for the evaluation of environmental impacts, land acquisition challenges, and alternative routing scenarios (Huang and Wei, 2021; Zhang *et al.,* 2022). By identifying a swath of feasible alignments, corridor analysis also facilitates stakeholder engagement and policy discussions, which are increasingly recognized as essential components of sustainable infrastructure planning.

The integration of LCPA with multi-criteria decision analysis (MCDA) has further strengthened GIS-based highway alignment studies. MCDA techniques allow decision makers to systematically evaluate multiple spatial criteria and incorporate expert judgment into the decision-making process. Among the various MCDA methods, the Analytic Hierarchy Process (AHP) developed by Saaty remains one of the most widely used approaches for deriving criterion weights in spatial decision problems (Saaty, 2008). AHP structures complex decisions into hierarchical levels and uses pairwise comparisons to determine the relative importance of criteria. When combined with GIS, AHP enables planners to generate weighted cost surfaces that reflect both environmental and socio-economic considerations.

In GIS-based transportation planning, the weighted linear combination (WLC) technique remains one of the most commonly applied methods for integrating multiple criteria layers into a single cost surface (Nugraha *et al*., 2025). WLC standardizes input layers and multiplies them by relative weights derived through AHP or other MCDA techniques, producing a composite suitability or cost index. This approach has been widely applied in infrastructure corridor planning due to its transparency, computational efficiency, and ease of interpretation.

In recent years, the literature has demonstrated a growing trend toward hybrid geospatial decision-support frameworks that integrate GIS, MCDA, optimization algorithms, and machine learning techniques. These hybrid approaches improve the robustness and predictive capability of alignment selection models by allowing researchers to incorporate larger datasets, perform automated optimization, and evaluate multiple routing scenarios (Mohammed *et al*., 2020; Abd Ghany and Naharudin, 2025). Sensitivity analysis has also become an important methodological component in GIS-based infrastructure planning. By systematically varying criterion weights and evaluating the resulting changes in routing outcomes, researchers can identify stable corridors and assess the reliability of alignment decisions under uncertain conditions.

Within Africa, the application of GIS-based corridor analysis for road infrastructure planning has increased significantly over the past decade due to improvements in geospatial data availability and computational tools. Studies conducted in countries such as Kenya, Ethiopia, South Africa, and Ghana have demonstrated the effectiveness of GIS–MCDA techniques for identifying optimal transportation corridors while minimizing environmental impacts and construction costs. These studies emphasize the importance of incorporating environmental constraints, land-use conflicts, and socio-economic considerations into spatial decision-making frameworks for sustainable infrastructure development.

In the Nigerian context, several studies have applied GIS-based least-cost modelling and multi-criteria evaluation techniques to transportation planning and route optimization.

Research by Singleton (2019) demonstrated the use of GIS spatial modelling to determine optimal rural road corridors in northern Nigeria. Similarly, Sameer *et al*. (2023) applied GIS-based MCDA techniques to identify suitable road alignments in urbanizing regions of Nigeria, emphasizing the importance of terrain analysis and environmental constraints in alignment planning. Other studies conducted in Minna and surrounding areas have shown that GIS-based corridor modelling can significantly reduce land acquisition conflicts, avoid environmentally sensitive areas, and improve decision transparency in transportation planning processes (Wunukhen *et al.,* 2024).

These findings highlight the growing relevance of geospatial decision-support systems in Nigeria, particularly as governments seek cost-effective approaches to transportation infrastructure development in rapidly expanding urban and peri-urban regions. However, many existing studies remain limited to small datasets or lack robust sensitivity analysis, underscoring the need for improved methodological frameworks that integrate multiple spatial criteria, expert knowledge, and corridor-based evaluation.

Building on this body of literature, the present study adopts three key methodological components. First, multi-criteria cost surfaces are constructed using AHP-derived weights combined with weighted linear combination of standardized spatial datasets. Second, raster-based least-cost path and corridor generation are implemented using accumulated cost and back-link raster algorithms within standard GIS environments such as ArcGIS Pro and GRASS GIS. Third, sensitivity analysis and corridor-width evaluation are performed to generate robust alternative alignments and assess the stability of routing outcomes under varying assumptions. Together, these methodological elements provide a comprehensive and defensible framework for preliminary highway alignment selection in data-constrained developing-country contexts such as Niger State, Nigeria.

METHODOLOGY

Data sources

This study integrates multiple spatial datasets to support the GIS-based least-cost corridor analysis for highway alignment planning. The primary topographic dataset used was the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with 30 m spatial resolution, which served as the baseline elevation dataset for terrain analysis.

Additional datasets included land use/land cover (LULC), hydrological features, and existing road network data obtained from open geospatial repositories and national mapping sources. These datasets were selected based on their spatial resolution, coverage, relevance to the study objectives, and accessibility.

A summary of the datasets used in this study, including their sources and spatial resolutions, is presented in Table 1.

Table 1: Dataset sources and resolutions

Dataset	Source	Format	Resolution	Purpose
Sentinel-2 Imagery (LULC)	Google Earth Engine	Raster	10 m	Land cover classification
SRTM DEM	https://earthexplorer.usgs.gov/	Raster	30 m	Elevation, slope, aspect analysis
Road Network	OpenStreetMap	Vector (Shapefile)	-	Existing infrastructure & cost analysis
Admin Boundary	OSGOF	Vector (Shapefile)	-	Jurisdictional extent and boundary control
Settlements & POIs: OSM		local gazetteers		Baganakwo coordinate confirmation

All spatial datasets were projected into the Universal Transverse Mercator (UTM) coordinate system corresponding to the study area (UTM Zone 32N, WGS84 datum) to ensure spatial consistency. DEM voids were corrected using standard interpolation techniques, and hydrological conditioning was performed through pit-filling algorithms to ensure accurate terrain modelling for drainage and flow analysis.

Preprocessing Steps

To prepare the spatial data for analysis, the following steps were undertaken. The datasets were first re-projected to a common UTM Coordinate Reference System (CRS) to ensure spatial consistency, and resampled to a working cell size of 10 m to strike a balance between resolution and computational efficiency. Topographic derivatives, including slope, aspect, and curvature, were then derived from the Digital Elevation Model (DEM) to capture terrain characteristics influencing route placement (USGS, 2021). Landcover data were classified into distinct cost categories, namely built up, bare land, water body, cultivated land, and forest, to assign relative construction and environmental costs. Streams, wetlands, and protected features were buffered to enforce avoidance penalties, reflecting environmental sensitivity and regulatory constraints (Aderoju *et al.,* 2020). Finally, the vector road network was converted into a friction layer, with low costs assigned to existing good roads to incentivize upgrades over new construction, thereby minimizing overall project costs and disruption.

Cost Factor Selection and Weighting

The selection and weighting of route-influencing factors were carried out using the Analytical Hierarchy Process (AHP), a well-established Multi-Criteria Decision Analysis (MCDA) technique that enables systematic comparison of decision criteria based on their relative importance (Saaty, 1980). AHP is particularly suitable for transportation corridor planning due to its ability to integrate expert judgment with quantitative spatial analysis.

The decision goal was defined as the identification of an optimal highway route between Baganakwo and Chanchaga. Based on engineering feasibility, environmental considerations, and planning relevance, the following criteria were selected: elevation, slope, aspect, land use/land cover (LULC), proximity to built-up areas, proximity to existing roads, and natural barriers (rivers, valleys, and gullies).

AHP Mathematical Formulation

Let the set of criteria be defined as in Equation (1):

$$C= (C_1,\ C_2\ ,,,\ C_n) \qquad (1)$$

A pairwise comparison matrix A of size n × n was constructed, where each element expresses the relative importance of criterion over criterion , based on Saaty, (2008) Saaty's 1–9 fundamental scale in Equation(2):

$$A= \begin{bmatrix} 1 & a_{12}\cdots & a_{1n} \\ \frac{1}{a_{12}} & 1\ \ddots & \vdots \\ \cdot & & \\ \cdot & & \\ \cdot & & \\ \frac{1}{a_{1n}} & \cdots & 1 \end{bmatrix} \qquad (2)$$

The matrix was normalized by dividing each element by the sum of its respective column as shown in Equation (3):

$$n_{ij}= \frac{a_{ij}}{\sum_{i-1}^{n} a_{ij}} \qquad (3)$$

Criterion weights were derived by averaging the normalized values across each row:

$$w_i= \frac{1}{n}\sum_{i-1}^{n} n_{ij} \qquad (4)$$

The resulting weight vector:

$$W= (w_1,\ w_2\ ,,,\ w_n) \qquad (5)$$

represents the relative contribution of each criterion to the overall route selection process.

Consistency Evaluation

To assess the logical consistency of the pairwise judgments, the maximum eigenvalue was estimated and used to compute the Consistency Index (CI) Equation (6):

$$CI= \frac{\lambda_{max-n}}{n-i} \qquad (6)$$

The Consistency Ratio (CR) was calculated as:

$$CR= \frac{CI}{RI} \qquad (7)$$

Where RI is the Random Index corresponding to matrix size n (Saaty and Vargas, 1991). A threshold of CR ≤ 0.10 was adopted to indicate acceptable consistency. All comparison matrices satisfied this criterion, confirming the reliability of the assigned weights.

Cost Surface Construction

Each criterion raster layer was standardized to a common suitability scale, where lower values represent more favorable conditions for highway development. Environmentally sensitive and high-risk features such as rivers, steep slopes, and dense settlements were assigned higher cost values or exclusion buffers based on established planning guidelines. The standardized layers were integrated using a Weighted Linear Combination (WLC) approach:

$$CS=\sum_{i=1}^{n} w_1 \, x \, r_i \qquad (8)$$

Where: w_1, w_2 ,,, w_n

CS is the composite cost surface,

w_1 is the AHP-derived weight of criterion i, and

r_i is the reclassified raster score of criterion.

The resulting cost surface represents cumulative spatial impedance and served as the primary input for Least Cost Path (LCP) analysis.

Sensitivity and Scenario Analysis

To evaluate the robustness and reliability of the optimal route, a sensitivity and scenario analysis was conducted by systematically varying the weights of key criteria while keeping others constant. Sensitivity analysis is essential in MCDA-based spatial modeling to assess the influence of subjective weighting on model outcomes and to identify stable versus weight-sensitive route segments (Malczewski, 2006).

Weight Perturbation Scenarios

The baseline AHP weights were modified by ±20% for the most influential criteria slope, land use/land cover, and proximity to built-up areas while proportionally adjusting the remaining weights to maintain a total sum of one. For each scenario, a new cost surface was generated and the corresponding least cost path recalculated.

Scenario Description and Results

Table 2: Sensitivity and Scenario Analysis of Criterion Weights

Scenario	Modified Criterion	Weight Change	Route Outcome
S0 (Baseline)	All criteria	Original AHP weights	Reference optimal route
S1	Slope	+20%	Minor deviation toward flatter terrain
S2	Slope	−20%	Increased interaction with moderate slopes
S3	LULC	+20%	Stronger avoidance of built-up and forest areas
S4	LULC	−20%	Slight encroachment toward cultivated land
S5	Built-up proximity	+20%	Route shifts farther from settlements
S6	Built-up proximity	−20%	Improved settlement accessibility

Interpretation

The sensitivity analysis revealed that the modeled route is largely stable, with only localized deviations observed under extreme weight perturbations. Slope and LULC exerted the strongest influence on route alignment, confirming their dominant role in terrain feasibility and environmental suitability. Importantly, all scenarios produced routes that were consistently shorter and less constrained than the existing 16.5 km indirect route via Minna.

These findings demonstrate that the proposed highway alignment is robust to reasonable variations in decision weights, reinforcing confidence in the model’s reliability and its applicability for real-world transportation planning.

RESULTS AND DISCUSSIONS

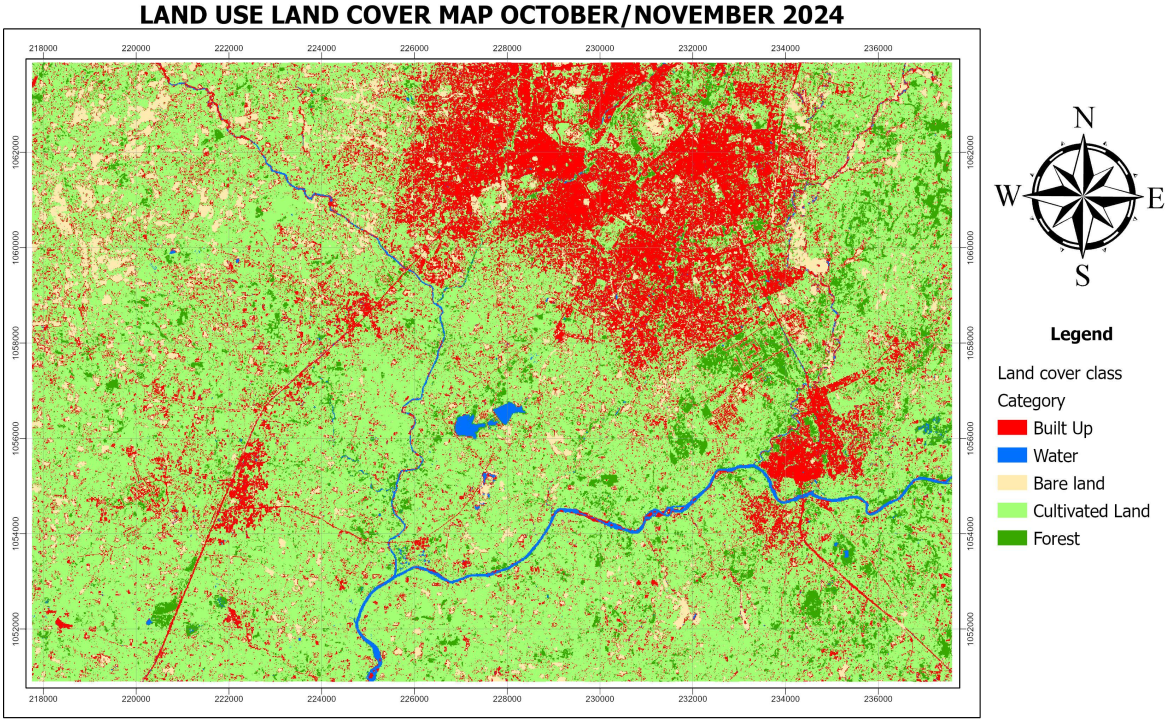

Figure 4: Land use land cover distribution across the study area
Source: Authors Lab work (2024)

Land use Land cover

The land use land cover map shows the distribution of Built up, water body, bare land, cultivated land and forest in the study area. Table 3 is the suitability of the various LULC.

Table 3: Reclassified LULC Suitability for Highway Development

Suitability Class	Ranking (1–4)	Land Cover Type	Area (km²)	Suitability for Highway Development
Highly Suitable	4	Bareland	17.46	Sparse vegetation, stable soil; optimal for highway alignment
Suitable	3	Cultivated Land, Forest	182.95	Productive terrain; moderate engineering required
Low Suitable	2	Built-up Area	54.10	Urban constraints; costly compensation and rerouting
Unsuitable	1	Water Bodies	2.98	Flood-prone and unstable; requires drainage and soil stabilization

Composite cost surface

The composite cost surface highlights high-cost bands along valley bottoms (wetlands), steeper slopes, dense built areas around Minna, and areas of poor soils. Cost hot spots correspond to mapped seasonal flood extents and dense agricultural patches; low-cost corridors correspond to existing minor roads and ridgelines amenable to gentle gradients. Figure 4 shows the Composite cost surface (hillshade overlay).

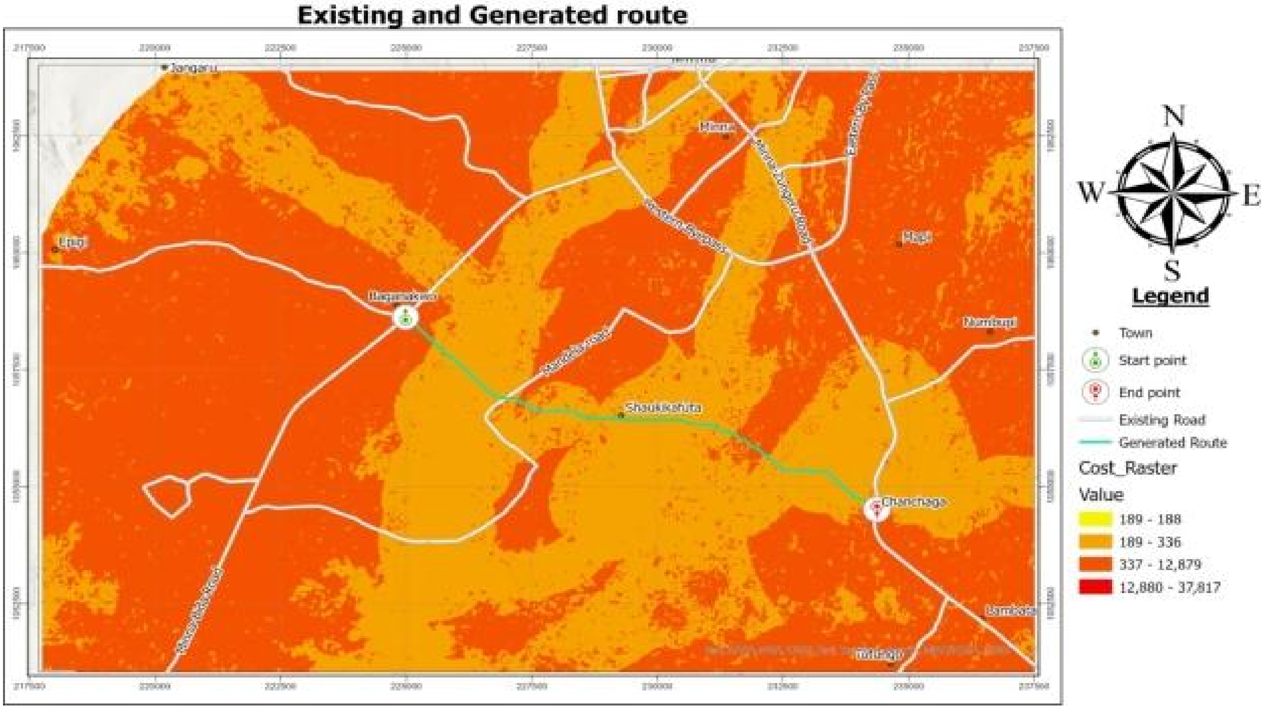

Figure 5: Composite cost surface (hillshade overlay)
Source: Authors Lab work (2024)

Optimal path and alternatives

Primary optimal route (Cost-minimized): Follows existing minor road corridor where possible (reducing new construction), skirts wetlands, and uses ridge segments to reduce earthworks. Total alignment length: ~11.08 km (value to be computed from final GIS run); cumulative cost index: lowest among tested scenarios.

Secondary route (Shorter length, higher cost): Slightly shorter route but crosses two major seasonal drains and enters more agricultural land having lower socio-political acceptability. Environment-sensitive alternative: Longer by 16.09 km ~31% but avoids wetlands and reduces number of proprietary land parcels affected (Yuan, *et al.*, 2015). Figures 4, 5, 6 illustrates the composite cost surface map; primary and alternative alignments overlaid on hillshade and landcover.

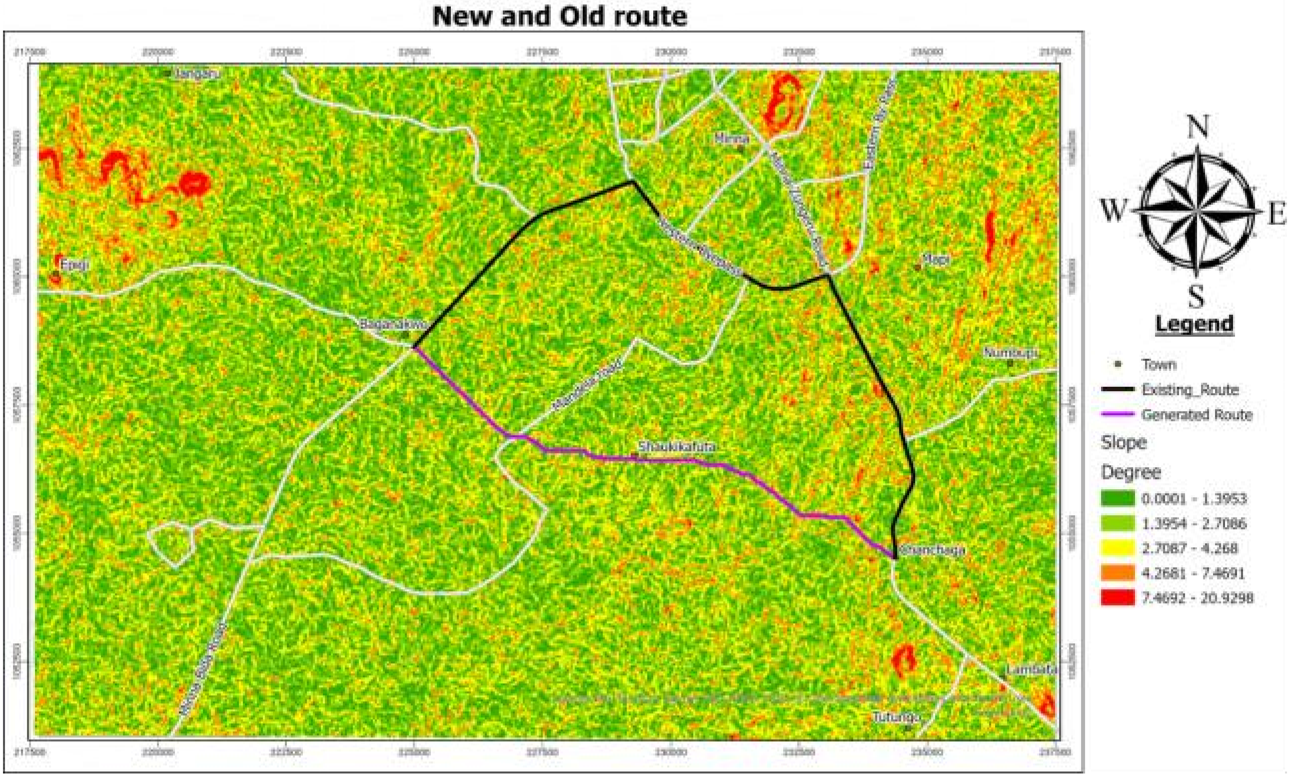

Figure. 6: Primary and alternative alignments (annotated with water crossings and settlements)
Source: Authors Lab work (2024)

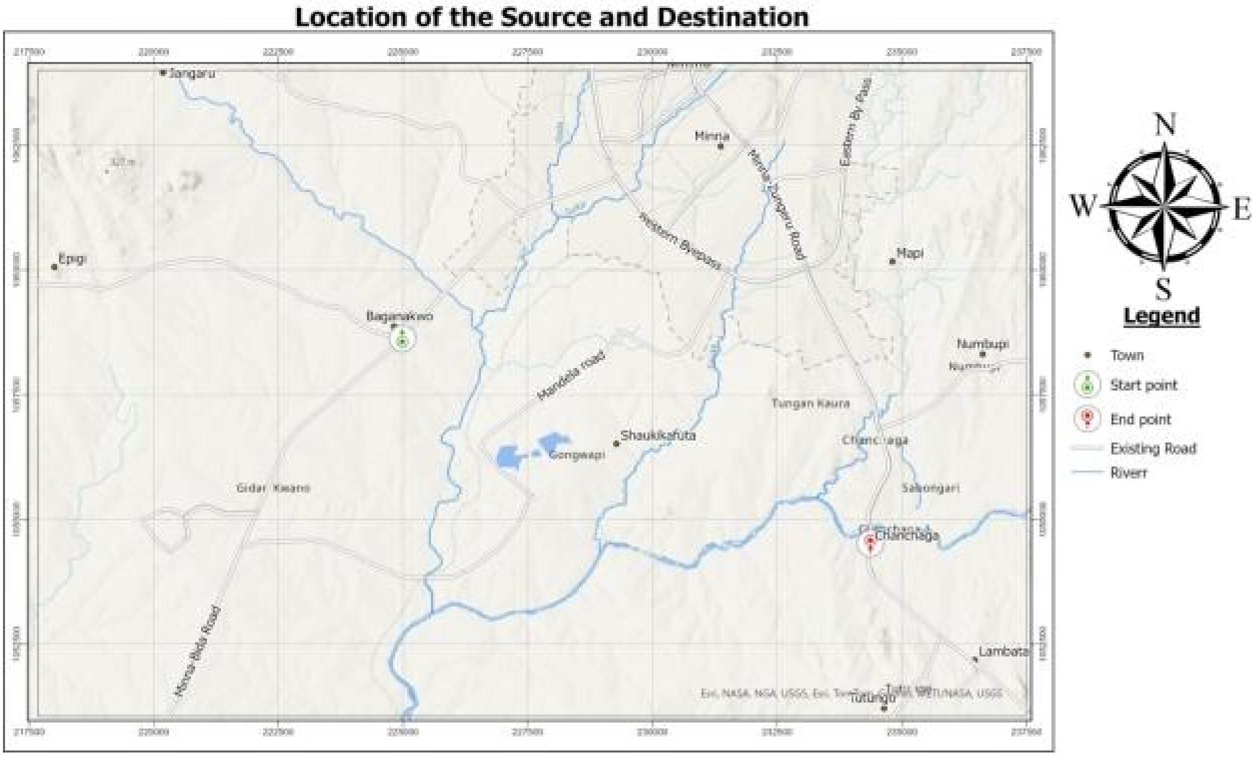

Figure 7: Location of the source and destination
Source: Authors Lab work (2024)

(Figures 5, 6, 7: composite cost surface map; primary and alternative alignments overlaid on hillshade and landcover)

DISCUSSION

Bareland, which occupies about 17.46 km² (6.78%), is distributed mostly across Baganakwo and parts of central Lambata. It is considered highly suitable due to its sparse vegetation, low population density, and stable topsoil, which minimize both environmental impact and construction cost (Alemayehu et al., 2020). Forest areas, accounting for 17.21 km² (6.68%), are found across southern Shaikikafuta and portions of Lambata. These are classified as suitable, offering generally stable terrain and moderate slopes, although environmental sensitivities related to biodiversity and ecosystem integrity must be considered (Sameer et al., 2021). In contrast, water bodies covering 2.98 km² (1.16%) and concentrated around Epigi, Jangaru, and low-lying depressions in Shaikikafuta are ranked as unsuitable due to their instability, high flood risk, and drainage challenges (Jayasree et al., 2016).

As illustrated in Figure 6 the newly generated route provides a direct Southwest–Northeast linkage, connecting the Bida–Minna Road and FUTMINNA Main Campus (Gidan Kwano) to the Mararaba–Makutu–Mapi corridor and onward to Mandela Road. It passes through Mapi, Numbupi, and Shaukikafuta, while avoiding high-cost terrain such as Epigi, Jangaru, and Tutungo. The route crosses the Tshantshaga River thrice near Chanchaga and passes a dam vicinity in Shaukikafuta, yet overall traverses' terrain with minimal natural or infrastructural encumbrances. Also, a comparative evaluation was conducted between the newly generated optimal route and the existing road network in Chanchaga LGA to assess differences in route length, topographic alignment, infrastructural complexity, and environmental compatibility Mohammed *et al*., 2020). This analysis serves as a basis for validating the practical applicability of the GIS-based Least Cost Path (LCP) model in ArcGIS Pro Documentation (ESRI, 2024) within the study area (Ahmed *et al.,* 2019; Aydin and Yilmaz 2023).

The optimal route, produced through multi-criteria decision analysis (MCDA) and weighted overlay modeling, spans approximately 11.08 km, whereas the existing route measures 16.09 km. This conforms with African Union (2019), Sameer *et al.* (2023), and reflects a 31% reduction in distance, which implies savings in travel time, fuel consumption, construction material usage, and long-term maintenance costs as shown in Table 3.

Table 3: Summary Comparison of New and Existing Routes

Parameter	Existing Route	New Route
Length (km)	16.09	11.08
Mean Slope (°)	2.73	2.74
Roundabouts	3	1 (planned)
Bridges/Flyovers	7 bridges	1 flyover, 3 river crossings
Major LULC Types	Built-up, waterbody	Cultivated, bare land
Built-up Area (%)	–	11.85%
Water body Area (%)	–	10.37%
Cultivated Land (%)	–	66.67%

Table 3, summarized length, cumulative cost, water crossings, and settlement impacts for each alignment.

The results demonstrate the utility of combining AHP-driven MCDA with raster least-cost path extraction for early corridor screening in Bosso/Paikoro (Alemayehu *et al*., 2020; Agrawal, 2025). Favouring existing roads in the cost surface often yields practical upgrade opportunities (lower acquisition and earthwork costs). Consistent with local road rehabilitation aims recently announced by Niger State authorities. However, planners must balance the tendency of LCPA to favour existing linear infrastructure (which might pass through sensitive areas) with social and environmental constraints set as hard or high-penalty costs (Abed *et al.,*2021). Methodologically, the study aligns with contemporary advances recommending multi-resolution and corridor-width analyses to avoid over-reliance on single-pixel shortest paths and to provide engineers with construction-feasible corridors rather than a single idealized centerline (Tang and Dou, 2023; Niger State Government, 2024)). Modern approaches also emphasize tying GIS outputs to staged field reconnaissance and geotechnical investigation prior to alignment finalization.

Sensitivity summary

Weighting shifts that doubled the environmental weight led to selection of longer ridge routes (length +6–12%) but reduced wetland crossings by 80% and settlement impact by ~50%. Increasing the slope penalty favoured alignments that follow low-slope contours and existing roads.

CONCLUSION AND RECOMMENDATIONS

A GIS-based LCPA + MCDA workflow provides a defensible, repeatable, and transparent method to screen candidate highway alignments between Baganakwo and Chanchaga. The approach aids planners by integrating topography, hydrology, land cover, and socio-economic factors into a composite cost surface and by producing alternative corridors with quantified trade-offs. When combined with field validation and higher-resolution surveys, the method can substantially reduce early-stage design risk and accelerate delivery of sustainable highway investments in Niger State.

To advance the proposed highway alignment, the following steps are recommended: Field validation should be undertaken to ground-truth the primary corridor, focusing on actual stream locations, soil conditions, and social boundaries, with waypoints marked for geotechnical borings. A detailed survey should then be conducted to acquire RTK/GNSS corridor data and higher-resolution DEM (via drone or terrestrial LiDAR) for engineering design purposes. An environmental and social impact assessment (ESIA) is essential for the shortlisted alignments, with particular attention given to seasonal wetlands and farming communities.

The present study used publicly available DEM (SRTM 30 m) and Sentinel-derived landcover, which may not resolve local microtopography or small drainage features; final engineering design requires higher-resolution topographic and geotechnical surveys and formal stakeholder consultation. A phased design approach is advised, prioritizing segments for upgrade where the route follows existing roads and has minimal land acquisition requirements. Finally, an iterative refinement process should be implemented, updating the cost surface with field data and rerunning corridor extraction to refine the final alignment, ensuring optimal outcomes and adaptability to emerging constraints.

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