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Optimal Route Selection of the Trans-ECOWAS Line Based on Ghana Railway Development – An Integrated Approach Using Entropy, TOPSIS and Least Cost Path Analysis

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INFORMATION

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ABSTRACT

In this study, an integrated approach of a GIS - based Least Cost Path Analysis (Dijsktra Algorithm) and Multi-criteria decision methods (MCDM) techniques comprising of ENTROPY and TOPSIS was employed for the selection of the optimal route from Aflao to Elubo based on calculation of the cost grid surface in the ArcGIS environment. Topographic data containing digital elevation models, forest reserves, drainage features, land use and settlement data were used for the study. The results showed a model of an optimal route with a length of 471.34 kilometers as against the 540.60 kilometer distance by road. Hence, saving a travel distance of 69.26 kilometers. Also, the proposed distance of the Trans-ECOWAS line was approximately 498 kilometers, which is about 26.66 kilometers further distance compared to the optimal route proposed by this studies. Hence, an economical route has been proposed in terms of time, travel and construction cost. The route passes through four (4) coastal regions. Towns located along the route in the Volta Region includes; Aflao, Tokpo, Mepe, Gefia and Weija, Ablekuma, Ofankor and Mobole are among the towns in the Greater Accra Region found along the stretch. In the Central Region; Efutu, Amissakrom, Ewuoyaa, Mankessim, Apaa and Gomoa Lome are located along the proposed route. Towns along the stretch in the Western Region includes Pataho, Ashiaem, Agege, Amoakwasuazo and completes at Elubo. The optimal route will achieve the lowest cost of railway construction based on calculation of the cost raster layers.

1. Introduction

On the basis of thorough studies of the current transport system and the proposed development plan of the Government of Ghana to expand and rehabilitate the existing railway infrastructures, a future outline has been drawn for the railway network system of the country (Akwetteh et al., 2021). The expansion is in conformity with the objective of the Economic Community of West African States (ECOWAS) to link all member states by rail. Also, it will facilitate the achievement of the broad objective of the Union of African Railways to link member countries by rail to enhance the existing trade potentials among African States and the rest of the world (Ghana Railways Master Plan, 2013).

In line with the Ghana Railway Master Plan, the Trans-ECOWAS railway line from Aflao to Elubo is to be developed. The development of the line will result in a direct rail connectivity with the neighboring States of Togo and Ivory Coast to boost trade and facilitate economic growth and development in the West African countries affected by the project (Akwetteh et al., 2021). Traffic congestion due to increasing human population have been an issue of concern in the country (Harrington and McConnell, 2003). Traffic congestion slows down economic activities by reducing working hours and productivity (Larbi et al., 2018). It retards economic development and raises the cost of living in a community. With the increasing market requirements more resource-efficient, and more intensive transportation services are required to achieve a rational division of labor and organic linkage of various modes of transportation, and to give full play to the overall efficiency and effectiveness of the integrated transportation system (Zhang et al., 2021).

Transport reorganization and reclassification is expedient for the Trans-ECOWAS network to hold properly and in effect reduce food price (Bayane Bouraima et al., 2020). Intermodal transport infrastructure is crucial for sustainable development (Bayane Bouraima et al., 2020; Sładkowski and Cieśla, 2015). Transport-GDP relationship is a massive economy booster (Troch et al., 2015). This shows how railway investment is a good opportunity with regards to intermodal linkage between countries and the environmental friendliness of rail-based intermodal freight movement (Akwetteh et al., 2021). According to studies by the Ghana Railway Development Authority freight traffic pressure is expected to hit 65.98 mil.tons/year in 2030 and 128.57 mil.tons/year in 2047 (Ghana Railways Master Plan, 2013). This has drawn the research focus of planners, engineers, geospatial professionals and other transport stakeholders to put measures in place to reduce traffic congestion and freight pressure.

The current transport system in Ghana depends mainly on the road network, made up of approximately 67,000 km of main and secondary roads, of which approximately 12,800 km are main arteries but of which only 3,800 km are paved (Akwetteh et al., 2021). The maneuvering of vehicles on road shoulders to avoid traffic congestion has been identified as one of the causes of road accidents, road damages and reduction of road width (Karuppanagounder and Venkatachalam, 2012).

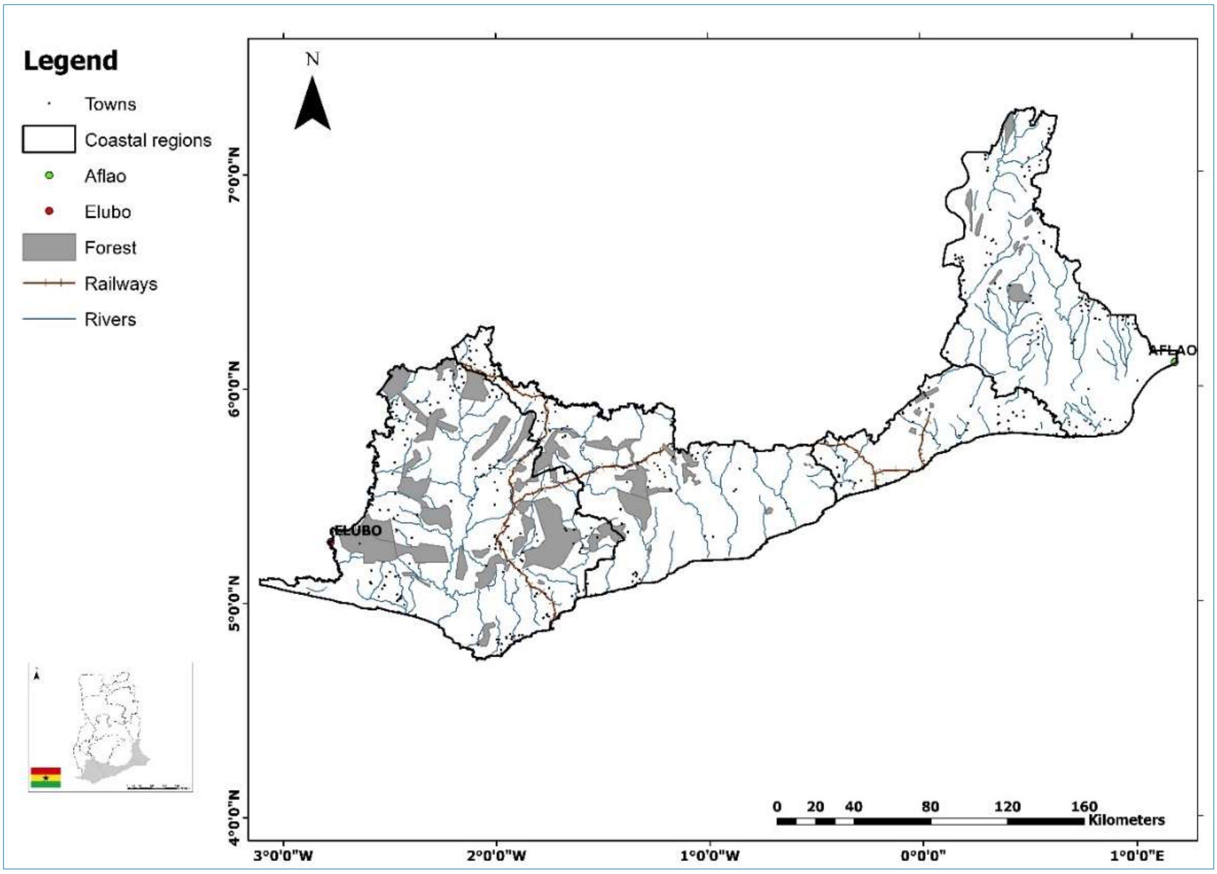

Fig. 1. Map of the study area

The reduction of road width is as a result of many big trucks found parking by the road side reducing the effective width of roads for other vehicles to use (Larbi et al., 2018). Ghana's development commenced with a vast ignorance in the aspect of railway architectural country development plan against a well-structured vehicle transport architecture (Ghana Railways Master Plan, 2013). The existing railway network is made up of three lines: Western, Eastern and Central together with some extended branch lines of approximately 940 km used for both freight and passenger traffic. Over the years this railway network has deteriorated, together with the rolling stock, due to lack of maintenance and is currently in a state of disrepair and is not able to guarantee reliable and safe transport (Akwetteh et al., 2021). This situation calls for the implementation of intermodal transport policy and enforcement of railway management regulations by government and the Ministry of Transport. These policies make it possible for railways to play a vital role in the integrated transportation system. So, it is urgent to study the cooperative operation theory and key technologies of the railway-based integrated transportation system (Zhang et al., 2021).

Compared with other modes of transportation, railway transportation is more economical and environmentally friendly, and the advantages of transportation reliability and transportation security are more obvious. Moreover, railway transportation as a participant of multimodal transportation has good transportation conditions (Zhang et al., 2021). The successful completion of the rail project will increase employment, boost trade, industrial growth, rejuvenate old towns and a drastic reduction of road pressure. This helps to reduce travel times, minimize road accidents and more importantly control the movement of big trucks in busy environments such as mining communities (Raheem et al., 2015).

Also, considering the global low-carbon environmental protection, low-carbon transportation is highly sought by all countries (Wang et al., 2022). The basic route design problem is to find the most economical path connecting two or more end points based on topography, socioeconomic factors, and environmental impacts, while satisfying a set of designed criteria such as design speed, rail grade, rail width, design load, soil type and other operational constraints (Suleiman et al., 2015). Therefore, an effective methodology to evaluate multiple criteria decision analysis related to optimal route selection and to optimize the decision-making process should be developed taking into consideration the relative importance of the selection criteria (Choi et al., 2009). Traditional approaches of route selection such as cost-benefit analysis are mainly focused on monetary and technical factors (Tischler, 2017). Often faced by longer time period for project development: The preparation of detailed project documents, complex approval procedures, longsome negotiations with land owners, etc. are just a few reasons for increasing periods between the first project ideas and the commencement of construction (Tischler, 2017).

The most common methodology applied so far to the evaluation of transport systems has been the conventional such as Economic Analysis Technique (EAT). Classified into a class of single- objective models, it evaluates particular alternatives (alignments) on the basis of 'revenues' and 'costs'.

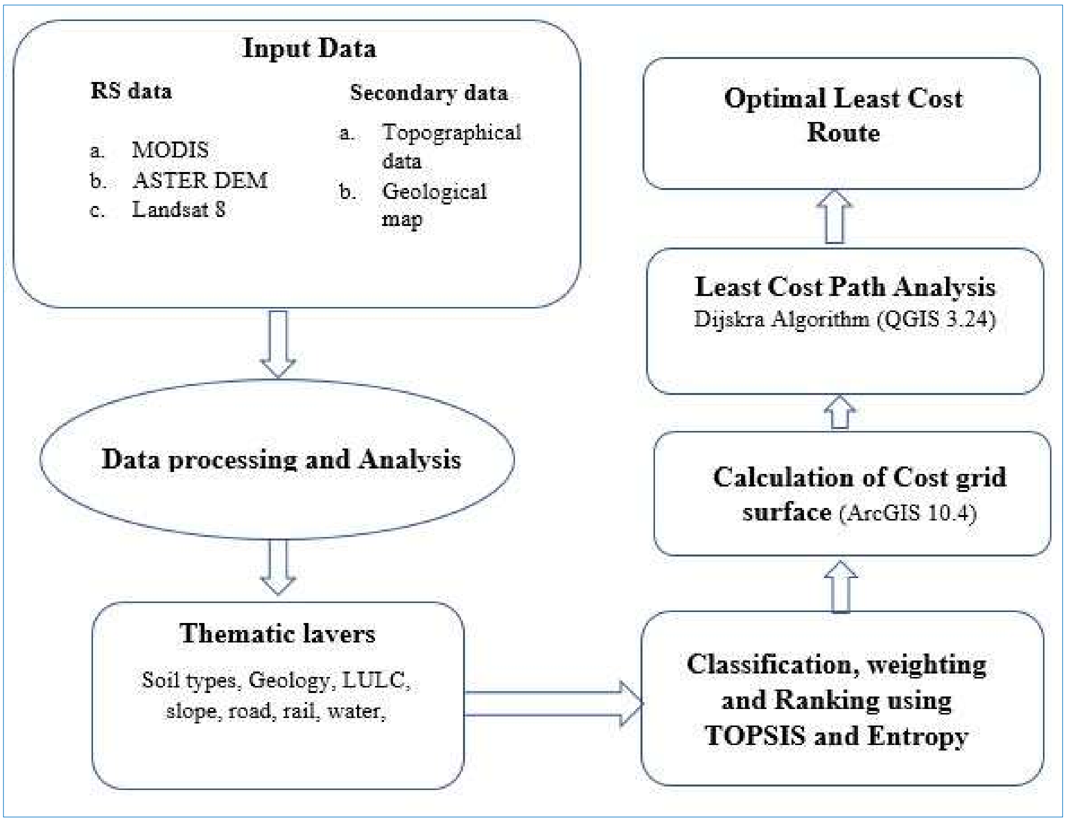

Fig. 2. Flow chat of methods

Traditionally, these decision support techniques have lacked the capability to take into account the physical constraints placed on the decision by the geographic characteristics of the study area (Tischler, 2017). Route planning algorithms are frequently used in modern navigation tools, including smartphones and help to find the most practical way between a departure and a destination point. The algorithms are based on the mathematical analysis of the existing road network taking into account different attributes of the road sections In a research study by Albert and Sárközy (2021), very popular route selection algorithms namely; Dijkstra Algorithm, Bellman-Ford Algorithm, Floyd-Warshall and Tobler's off-path function were compared on the basis of complexity and performance in terms of shortest path optimization.

The results show that Dijkstra Algorithm is best in terms of execution time and more efficient for solving the shortest path issue, but the Dijkstra Algorithm works with nonnegative edge weights. Tobler's off-path function works only with slope degrees, and does not take the land cover into account. At present, the research on multimodal transport does not consider the influence of natural factors such as weather, terrain, and some special human factors on the transport. In actual transportation, these factors may lead to the delay of transport time, and even the occurrence of dangerous accidents and damage of goods. At this time, the cost and time of the original optimal path will change, and the optimal path will be affected accordingly (Zhang et al., 2021). Modern approaches employed in route selection such as machine learning (ML) based methods; Random Forest (RF), Artificial Neural Networks (ANN), Logistic Regression (LR), Naïve Bayes Classifier, Support Vector Machines (SVM) and MCDM such as Analytical Hierarchy Process (AHP), Elimination and Choice Expressing Reality (ELECTRE), Technique for Order Preference by Similarity to Ideal solution (TOPSIS), Grey Relational Analysis (GRA), Vlsekriterijumsko KOmpromisno Rangiranje (VIKOR) and ENTROPY are gaining popularity over traditional methods (AbuSalim et al., 2020; Mugiyo et al., 2021).

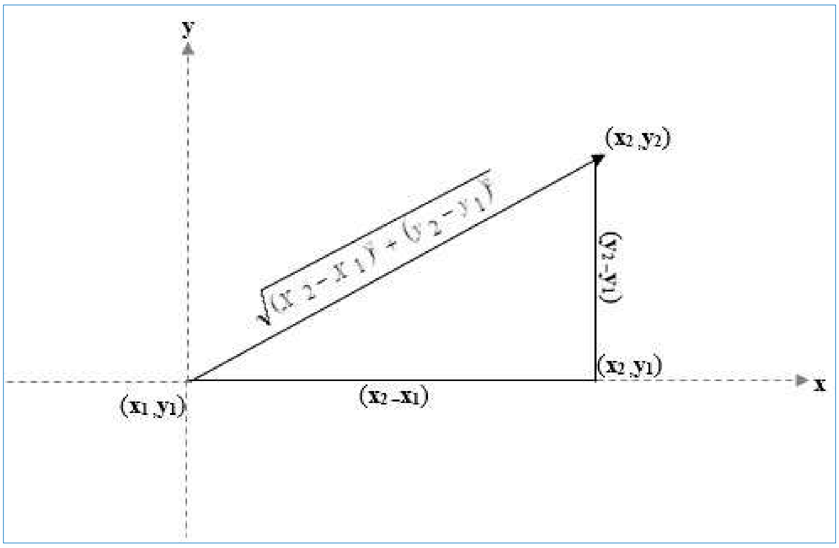

Fig. 3. Euclidean distance

Several methods in the past and recent decades have been developed for optimal route planning for roads, railways and other linear features utilizing Geographic Information System (GIS) (Chandio et al., 2012). The Least Cost Path Analysis (LCPA) is a GIS-based spatial optimization technique. The LCPA is based on the Dijkstra Algorithm used in finding the optimal path between the source and the destination (Kang and Lee, 2003). The Dijkstra Algorithm is not restricted to acyclical graphs. The raster map used for the analysis thus contains numerical values representing the "travel cost" of a given surface type, and is therefore called a "cost raster" (AbuSalim et al., 2020; Herzog, 2013).

However, little attention has been paid to the methods of assigning consistent weights to the various criteria for the generation of the cost surface in the LCPA. Hence, the LCPA requires a multi criteria evaluation technique to assign weights to the selected criteria (Atkinson et al., 2005). This study adopted an integrated approach using ENTROPY and TOPSIS as a multi-criteria decision tool for assigning weights to the selected criteria. The speed of travel is basically a non-linear function of terrain, transport network and land cover. Because of this, the easiest (ideal) route between the two points and its time cost can be calculated using the LCPA GIS method, which can be prepared to take into account these map feature categories. This method is based on the calculation of a cost surface, then the analysis of the ideal path from a given point to the destination (Albert and Sárközy, 2021). Multi-criteria Decision methods (MCDM) and GIS are very useful tools for solving problems in spatial context because various decision variables can be evaluated and weighted. (Peprah et al., 2018). The huge progress in digitalization and networking together with the development of GIS triggered the increased use of GIS-based methods for transport infrastructure development projects (Tischler, 2017).

The GIS, MCDM and LCPA methods have proven relevant in solving many multi- criteria decision, spatial and route planning problems. Notable among them are optimal technology in pipe rehabilitation (Aschilean et al., 2016), determining the best route for electric transmission line (Berry, 2007), suitable oil pipeline routing (Huseynli, 2015), highway route selection using intelligent optimization methods (Id et al., 2022), quantification of LCPA for forest road planning (Ismail, 2015), definition of CCS provinces (Carneiro and Mesquita, 2014), glacial archaeological potential site prediction (Rogers, 2015), optimal haulage routing in open pit mines (Choi et al., 2009), mapping of urban wind ventilation (Wong et al., 2010), identification of dispersal routes in landscape genetics (Vaissi and Sharifi, 2021).

The MCDM and GIS are very useful tools for solving problems in spatial context because various decision variables can be evaluated and weighted. Thus, to optimize the design of a route for rail transportation, various criteria should be simultaneously considered in the LCPA. Hence, MCDM and GIS techniques were adopted in the present study. The present study aims to employ an integrated approach of a GIS - based LCPA (Dijsktra Algorithm) and MCDM techniques comprising of ENTROPY and TOPSIS for the selection of the optimal route from Aflao to Elubo based on calculation of the cost grid surface. Also, the paper establishes a multimodal transport route selection model based on railway transportation, considers, time penalty cost and damage compensation cost, considering the transportation reliability and safety factors in the transportation process to build a path optimization model which is in line with reality (Zhang et al., 2021).

It is also necessary to reduce carbon emissions as much as possible in response to national calls. Feasibility studies are currently on-going towards the development of the line. Moreover, not much research has been carried out on the subject matter in existing literatures. It will thus serve as a guide for individuals, developers, the government and other stakeholders in railway development, road sector, urban planning and other related areas for further research and decision making.

2. Study Area

The study area, which is the coastal region, stretches from the south western to the south eastern part of Ghana, geographically located between latitudes 04˚42'N and 06˚35'N and longitudes 03˚03'W and 01˚12'E. It covers a total land mass of about 37,443.837 square kilometers. The study sites fall within the dry and wet equatorial climatic zones which have mean annual precipitation values ranging between 700-1500 mm coast (Keelson, 2015). The dry equatorial zone occurs along the middle to eastern coast of Ghana including the Greater Accra, Central regions and Volta Region. The wet equatorial zone covers the Western region extending from the coast to the inland areas (Keelson, 2015).

The climatic zones experience a double maxima rainfall regime (Kumi-Boateng et al., 2020). The interplay of heavy rainfall and soil types find expression in the vegetation cover characterized by the semi-deciduous forest and tropical evergreen forest (Larbi et al., 2018). This geographical area is drained by the Southwestern and Coastal Rivers Systems which comprises of the Pra, Tano, Bia, Ankobra, Densu, and Ayensu Rivers (Keelson, 2015). The average annual temperature is 26˚ with small daily temperature variations (Larbi et al., 2018). Relative humidity varies from 61 % in January to a maximum of 80 % in August and September (Peprah and Mensah, 2017). The main economic crops grown in the district are cocoa, rubber, oil palm, citrus and kola. It is endowed with natural resources such as Gold, Manganese and Bauxite which contributes significantly to the economic development of Ghana and perhaps of far greater economic significance, is the discovery and development of oil and gas within the Tano Basin off the coast of Jomoro District (Akyen et al., 2017).

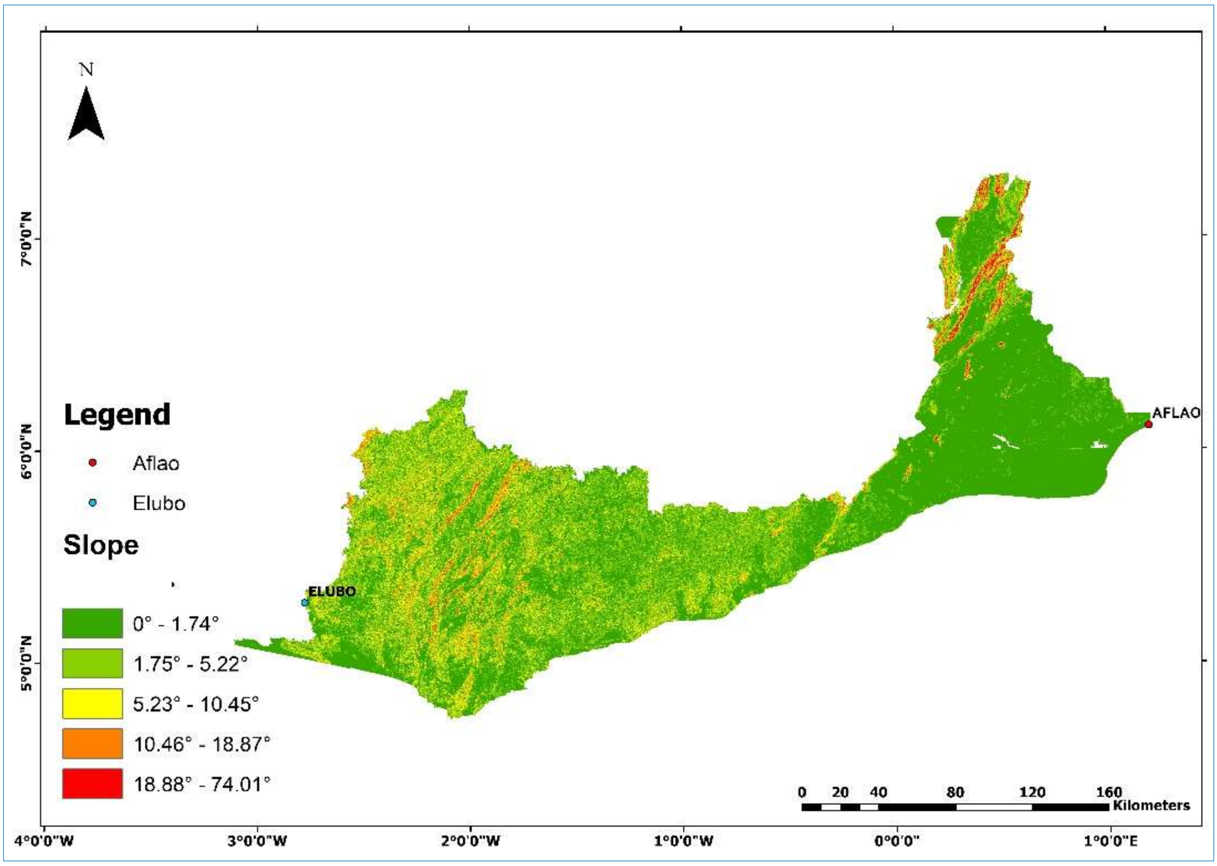

Fig. 4. Slope map

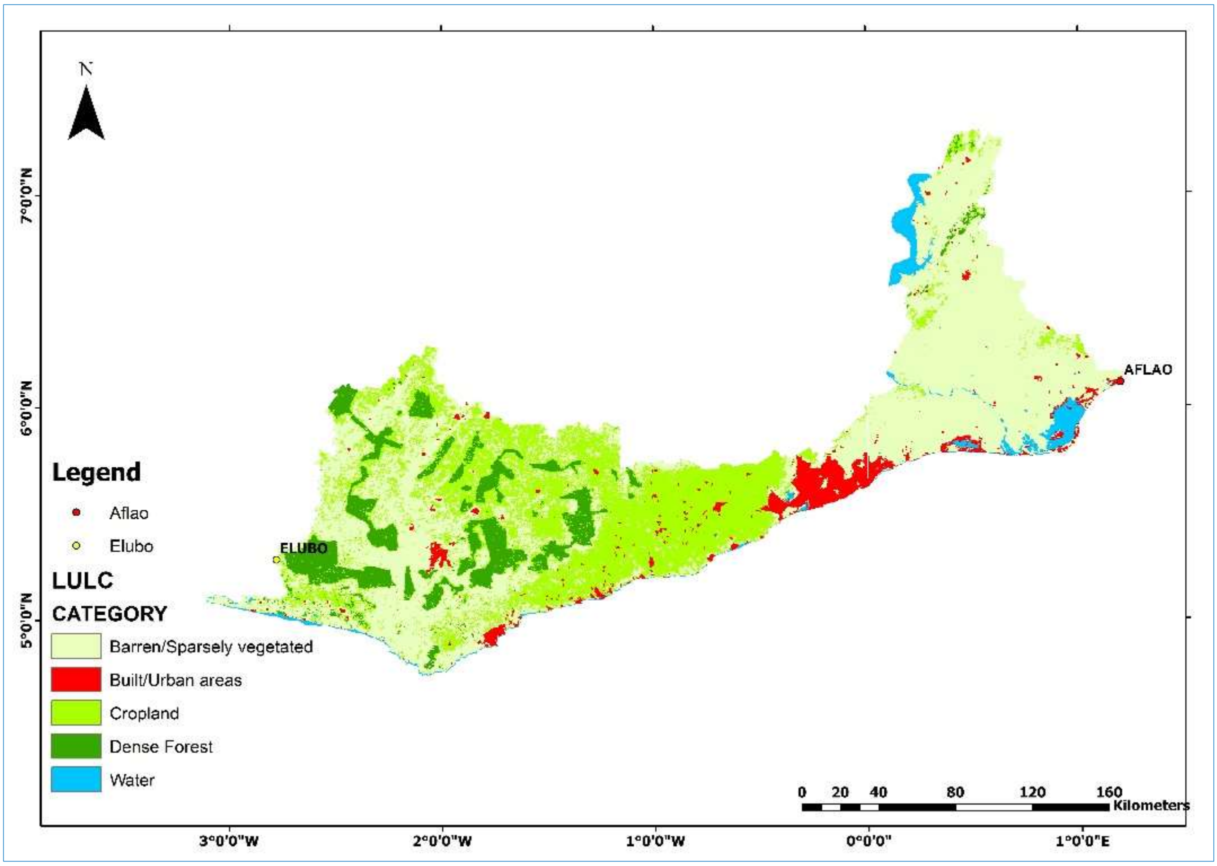

Fig. 5. Land use land cover

The area hosts majority of the Ministerial institutions, governmental and non-governmental agencies, public and private companies, which makes it one of the most populated regions in Ghana (Okyere et al., 2013). The topography is generally undulating with several hills making farming and other development activities a bit stressful (Akyen et al., 2017).

The geology of the coastal areas is dominated by basement crystalline rocks and to a lesser extent by minor geological formations including Cenozoic, Mesozoic, and Paleozoic sedimentary strata. The minor geological formations are made up of two coastal formations, namely, the coastal block-fault and the coastal-plain (Keelson, 2015). The coastal block-fault can be located in areas around Accra, Cape Coast and Sekondi-Takoradi. Fig. 1 represents a map of the coastal regions in Ghana.

3. Resources and Methods

3.1. Resources

The geo-environmental variables used for the studies were obtained from the Survey and Mapping division of the Land Commission of Ghana. They include; slope, geology, soil type, water bodies, land use and land cover data (LULC), transport network (roads and railways). The LULC data was downloaded from the earth explorer website (https://earthexplorer.usgs.gov).

Digital Elevation Model (DEM) downloaded from (https://lpdaac.usgs.gov/products/astgtmv003/).

3.2. Methods

3.2.1. Model generation

The adopted approach depends on weighted overlay of six (6) thematic layers derived from the Survey and Mapping division and remotely sensed data. Weights were estimated using Entropy and TOPSIS. The initial weights were determined using the method of Entropy whiles the final weights were obtained from TOPSIS based on calculation of the Euclidean distance. Each parameter was ranked based on its relative importance using the performance values of the TOPSIS method. The Cost model was carried out in the ArcGIS environment according to *Equation 1* (Peprah et al., 2018); Fig. 2 shows the flow chart of the methods used in the LCPA.

$$C = \sum_{i=1}^{n} W_i C_i \prod_{j=1}^{n} r_j \tag{1}$$

where; C = Cost model, W_i = weights of variables, C_i = Cost criteria and r_j = restriction.

3.2.2. Entropy

Entropy, a method commonly applied in transportation models and uncertain situations to measure the dispersion of trips between origin and destination (Waldrip et al., 2017). Entropy was used to generate initial weights for the cost factors in the process of calculation using the TOPSIS method. The reason is to generate objective weights to define the degree of how the various alternatives approach each other with respect to a specified criterion (Ma et al., 2017; Wang et al., 2022). The original data matrix is denoted by *Equation 2*.

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{1m} \\ x_{21} & x_{22} & x_{2m} \\ x_{n1} & x_{n2} & x_{nm} \end{bmatrix} \tag{2}$$

where; n represents the number of alternatives; m represents the number of evaluation index. The original matrix is then normalized according to *Equation 3*;

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{3}$$

where; i, i =1… n j, j =1…m.

The entropy is computed according to *Equation 4*;

$$e_j = -h\sum_{i=1}^{n} r_{ij} In\, r_{ij},\ j = 1,2\ldots,n \tag{4}$$

where; value of $h = \frac{1}{In(n)}$.

The weight vector is given by *Equation 5*;

$$w_j = \frac{1-e_j}{\sum_{j-1}^{n}\left(1-e_j\right)},\ j = 1,2,\ldots,n \tag{5}$$

where; $\left(1-e_j\right)$ is the degree of diversification.

3.2.3. TOPSIS

TOPSIS, which is Technique for Order Preference by Similarity to Ideal solution is a practical and useful technique for ranking and selection of a number of externally determined alternatives through distance measures (Shih et al., 2006). TOPSIS was used to assign the final ranks and weights to the alternatives. The reason is for the selected alternatives to achieve the shortest geometric distance from the positive ideal solution (PIS) and the largest distance from the negative ideal solution (NIS) thereby ensuring a stable performance in the event of varying input data (Latuszynka, 2013; Shih et al., 2006). The structure of the decision matrix (DM) can be expressed using *Equation 6*.

$$D^k = \begin{array}{c c} & \begin{array}{ccccc} X_1 & X_2 & \cdots & X_j & \cdots & X_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} & \begin{bmatrix} x_{11}^k & x_{12}^k & \cdots & x_{ij}^k & \cdots & x_{1n}^k \\ x_{21}^k & x_{22}^k & \cdots & x_{2j}^k & \cdots & x_{2n}^k \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1}^k & x_{i2}^k & \cdots & x_{ij}^k & \cdots & x_{in}^k \\ x_{m1}^k & x_{m2}^k & \cdots & x_{mj}^k & \cdots & x_{mn}^k \\ & & & & & \end{bmatrix} \end{array} \tag{6}$$

where; A_i denotes the alternative i, i =1,…,m; X_j represents the attribute j, j =1,…n; with quantitative and qualitative data. x_{ij}^k indicates performance rating of alternative A_i with respect to attribute X_j by decision maker k, k =1…k, and x_{ij}^k is the element of D^k

The decision matrix is then normalized using the vector normalization approach given by *Equation 7*;

$$r_{ij}^k = \frac{x_{ij}^k}{\sqrt{\sum_{j=1}^{n}\left(x_{ij}^k\right)^2}} \tag{7}$$

where; r_{ij}^k is the normalized decision matrix.

Weight vectors are assigned to the normalized decision matrix, $\sum_{j=1}^{n} w_j^k = 1$; each decision matrix will have weights for attributes as w_j^k, where j = 1… n and for each decision matrix k=1… K. Each element of the weight vector W will be the operation of the corresponding elements of the attributes weight per decision matrix (Shih et al., 2006).

The positive (v^{k+}) and negative ideal solution (v^{k-}) is represented by Equation 8 and 9 respectively (Zhang et al., 2021).

$$v^{k+} = \left\{r_1^{k+},\ldots,r_n^{k+}\right\} = \left\{\left(\max_i r_{ij}^k \mid j \in J\right),\left(\min_i r_{ij}^k \mid j \in J^1\right)\right\}, \tag{8}$$

$$v^{k-} = \left\{r_1^{k-},\ldots,r_n^{k-}\right\} = \left\{\left(\min_i r_{ij}^k \mid j \in J\right),\left(\max_i r_{ij}^k \mid j \in J^1\right)\right\}, \tag{9}$$

where; J is associated with the benefit criteria; J^1 is associated with the cost criteria; i =1,…,m; j=1,…,n; and k=1,…, k.

The Euclidean distance from the positive (PIS) and negative ideal solution (NIS) of each alternative are represented by *Equation 10* and *Equation 11*, respectively (Latuszynka, 2013);

$$S_i^{k+} = \sqrt{\sum_{j=1}^{n}\left(v_{ij}^k - v_j^{k+}\right)^2}\text{ , for alternative i, i= 1…m} \tag{10}$$

$$S_i^{k-} = \sqrt{\sum_{j=1}^{n}\left(v_{ij}^k - v_j^{k-}\right)^2}\text{ , for alternative i, i= 1…m} \tag{11}$$

where; S_i^{k+} = Euclidean distance from the ideal best solution; S_i^{k-} = Euclidean distance from the ideal worst solution; and v_{ij}^k = normalized weighted decision matrix.

The performance score ($\overline{P_i^*}$) to the ideal solution is given by *Equation 12*;

$$\overline{P_i^*} == \frac{S_i^{k-}}{S_i^{k+} + S_i^{k-}} \tag{12}$$

3.2.4. Cost criteria

The cost distance analysis depends on a "cost surface", which is a raster dataset. The value of each cell represents the cost per unit distance of crossing that cell. The cost is based on a set of defined criteria such as slope, LULC, geology, soil type and water bodies. Cost factors for this study were identified and classified into six (6) criteria. The cost criteria are described as follows:

Slope: Topography plays an important role in route selection. Slope is the measure of the average rate of change of altitude in a given area. Elevation is the vertical distance from a specified surface to a reference datum. Areas of mild slope are deemed less expensive compared to areas of steep slopes.

The slope map was generated from an Aster downloaded DEM data from the USGS website (http://lpdaac.usgs.gov/products/astgtmv003/). The slope data is given by Fig. 4.

LULC: The LULC encompasses dense forest, cropland, built/urban areas, barren/sparsely vegetated and water. Higher costs were assigned to the built-up areas, forest and water compared to the forest reserves due to compensation costs, bridge construction on water and additional cost of felling trees in the process of construction. The LULC data was obtained from MODIS satellite imagery data and classified using the IGBP classification scheme (https://earthexplorer.usgs.gov). Fig. 5 is the land use land cover map.

Table 1. Description of LULC classes (IGBP classification scheme)

LULC Classes (Level 1)	Description
Barren/Sparsely Vegetated	Lands with exposed soil, sand and rocks with more than (>10%) vegetated cover during any time of the year.
Forest	Land dominated by tree canopy with a percent cover (> 60%) and height exceeding 2 m. Consist of tree communities with interspersed mixtures or mosaics of other forest types. Has an intra-annual cycle of leaf -on and leaf-off periods.
Croplands	Lands covered with temporary crops followed by harvest and a bare soil period (eg. Single and multiple cropping system).
Urban and Built up areas	Rural and urban settlements.
Water	Land with permanent water.

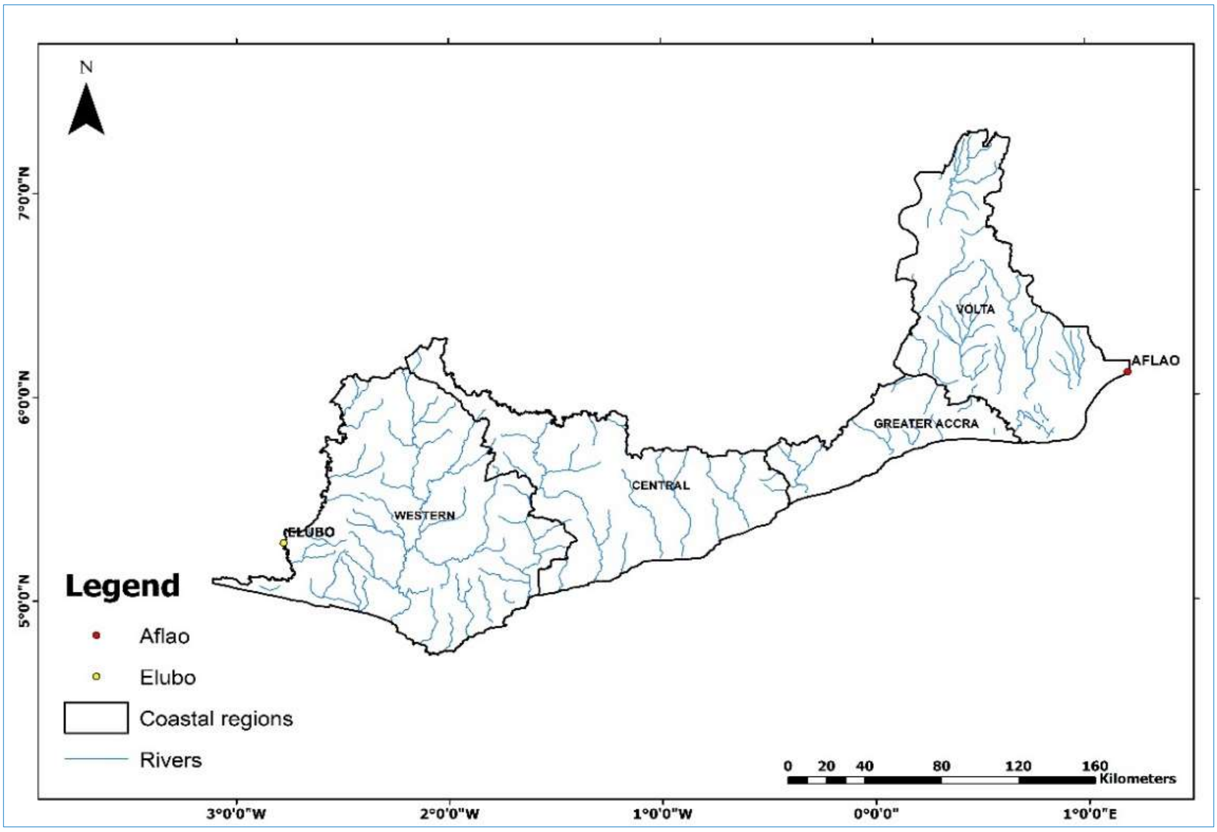

Fig. 6. Water body

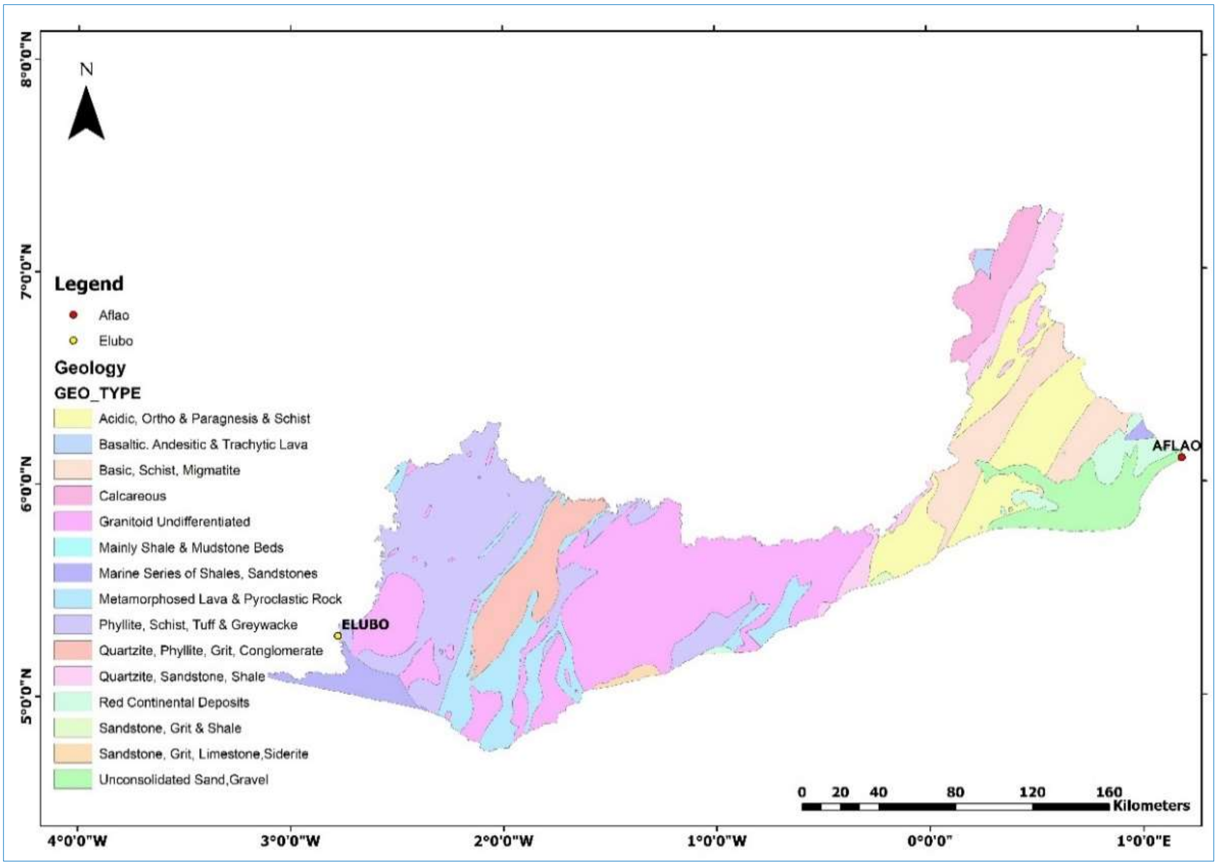

Fig. 7. Geology map

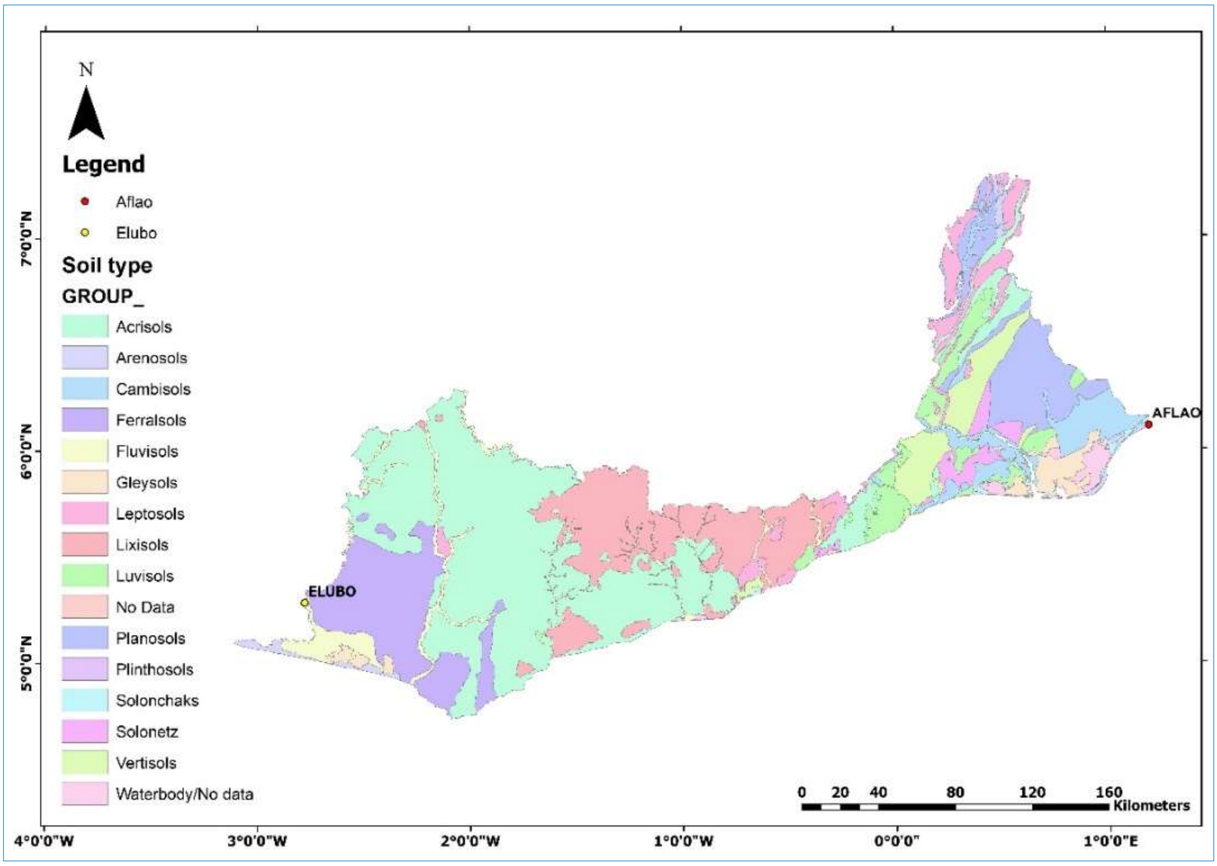

Fig. 8. Soil types

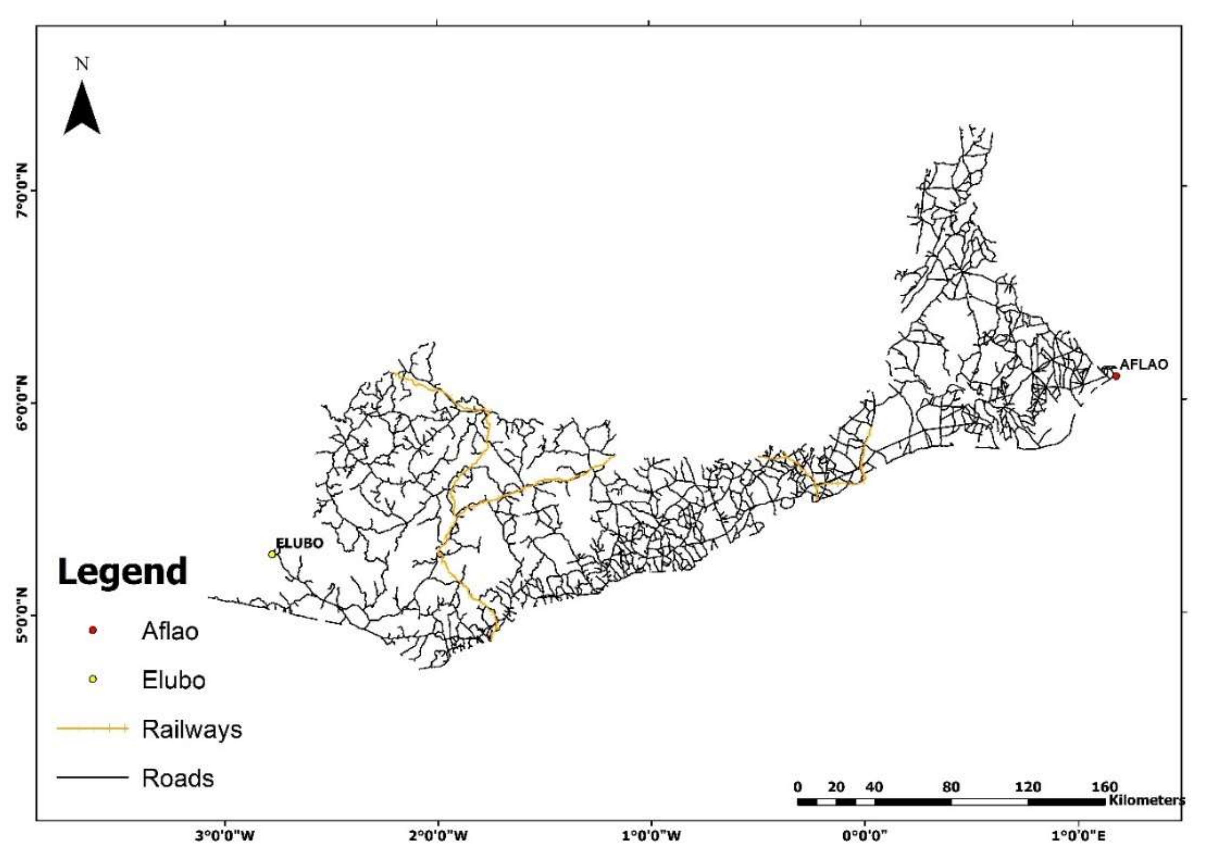

Fig. 9. Transport system

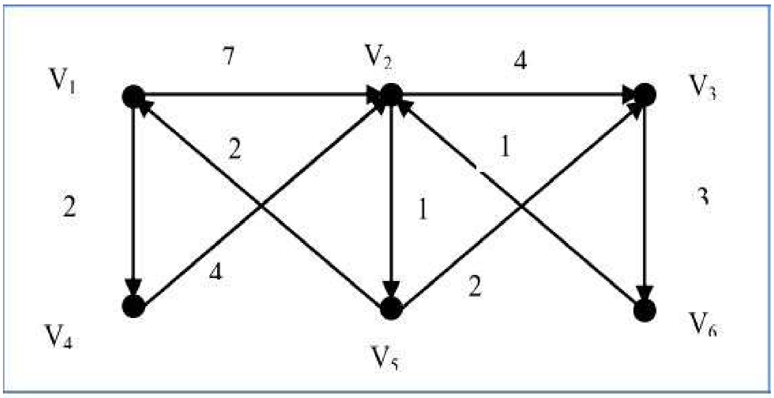

Fig. 10. Dijsktra Algorithm (AbuSalim et al., 2020)

Water body: Water bodies such as streams and rivers were also considered in the cost criteria. Routes over rivers are very expensive due to bridge construction. Rivers which go through forests costs more than those which do not, due to the additional cost of felling the trees. The river network was obtained from the Survey and Mapping Division of the Ghana Land Commission. Fig. 6 represents a map of water bodies

Geology and soil types: Geology and soil types of the area were considered and evaluated to see whether their physical and chemical properties will be suitable for the railway construction. The geology and soil data were obtained from the Survey and Mapping Division of the Ghana Land Commission. The geology and soil maps are shown in Figs. 7-8, respectively.

Transport network: Roads and railways were considered as the main transport network in this present studies. The study area is characterised by an intermodal transport system of roads, railways and rivers. This was factored in so as to consider the need of rehabilitation of existing dilapidated rails and roads crossing or along the path of the proposed optimal rail route to assist in the planning options in the construction process. Fig. 9 represents the transport system in the study area.

3.2.5. Standardization of criteria maps

Standardization of the attributes were performed for each of the cost maps in ArcGIS environment. Spatial Analyst tool was used for the reclassification module. Linear transformation was used to transform the criteria attributes into a cost scale that ranges from 1 to 5 where the value 1 is the least cost and 5 is the highest cost.

3.2.6. LCPA

Selecting an optimal route based on several criteria is the first step in route design and construction (Kang and Lee, 2003). To attain the final optimal solution, several methodologies must be accomplished. Firstly, score grids are created for each evaluation criterion as selected. Multiple score grids are further combined to find the total cost in moving in each cell (Larbi et al., 2018). A spreading function is used to combine the average score grid or the cost surface with the destination point to generate the accumulated cost surface. The lowest cost line is then traced through the accumulated cost surface from the source to the destination point. The lowest score line generated in the LCPA is the optimal path (Choi et al., 2009). This technique is well implemented in GIS environment. The closer the departure point is to the destination, the smaller the travel cost will be, so the route planning algorithm calculates the cost cumulatively from the destination point, and creates a "cost accumulation raster" (Albert and Sárközy, 2021; Etherington and Holland, 2013).

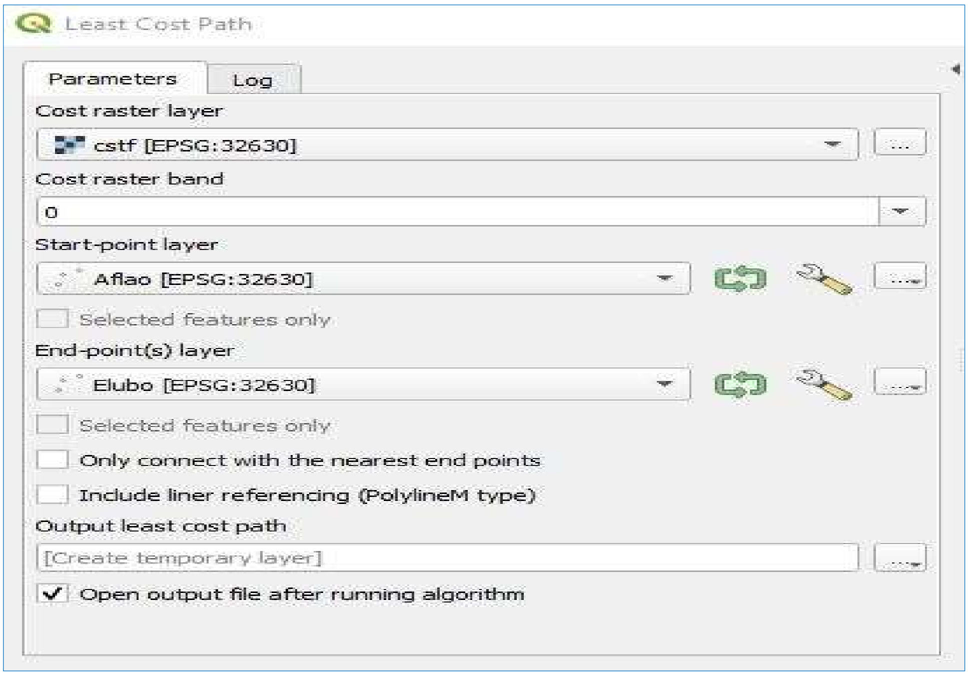

Fig. 11. LCPA plugin

The ideal route between a departure point and the destination point is planned on the accumulation raster, by selecting consequently the grid node in the neighbourhood, which has the smallest accumulated cost value (Albert and Sárközy, 2021). The LCPA was performed using QGIS 3.24 software. The LCPA plugin was built using the Dijskra algorithm which was then applied to the calculated cost grid surface after choosing the source and destination file. In the Dijkstra algorithm, the path is not known.

The nodes are divided into two groups: temporary (t) and permanent (p). First, the distance of source node is set to zero value (distance (a) = 0), the distance for other nodes are set to infinity (distance(x) = ∞). Step 2, node x is located with the smallest value of d(x). If no temporary nodes exist or the value of d(x) equal to infinity, the node x is labelled as permanent that means that the d(x) and parent of d(x) will not change anymore. Step 3, *Equation 13* is then applied for each temporary node labelled vertex y adjacent to x (AbuSalim et al., 2020):

If;

$$d(x)+w(x,y)<d(y) \qquad (13)$$

then;

$$D(y)=d(x)+w(x,y) \qquad (5)$$

Figs. 10-11 represent the Dijsktra Algorithm and the QGIS Least Cost Path Plugin, respectively. Fig. 12 is the workflow of the LCPA.

4 Results and Discussions

The paper aims to employ an integrated approach of a GIS - based LCPA (Dijsktra Algorithm) and MCDM techniques comprising of ENTROPY and TOPSIS for the selection of the optimal route from Aflao to Elubo based on calculation of the cost grid surface. The Cost model consists of the weights, selected criteria and the restriction model given by *Equation 1*.

Fig. 2 shows the flow chart of methodology used in the study process. The initial weights were generated using Entropy from the decision matrix according to *Equation 2*. The reason is to generate objective weights to define the degree of how the various alternatives approach each other with respect to a specified criteria and to deal with the uncertainties experienced in the traditional AHP as denoted by *Equation 2*. The decision matrix used in the studies represented by Table 2 was employed from the pairwise comparison of the AHP method with a valid consistency ratio of 0.09. This was done to eliminate any subjectivity in the cost criteria analysis. TOPSIS method was used to generate the final weights and rank from the performance score using the Euclidean distance given by *Equation 12*.

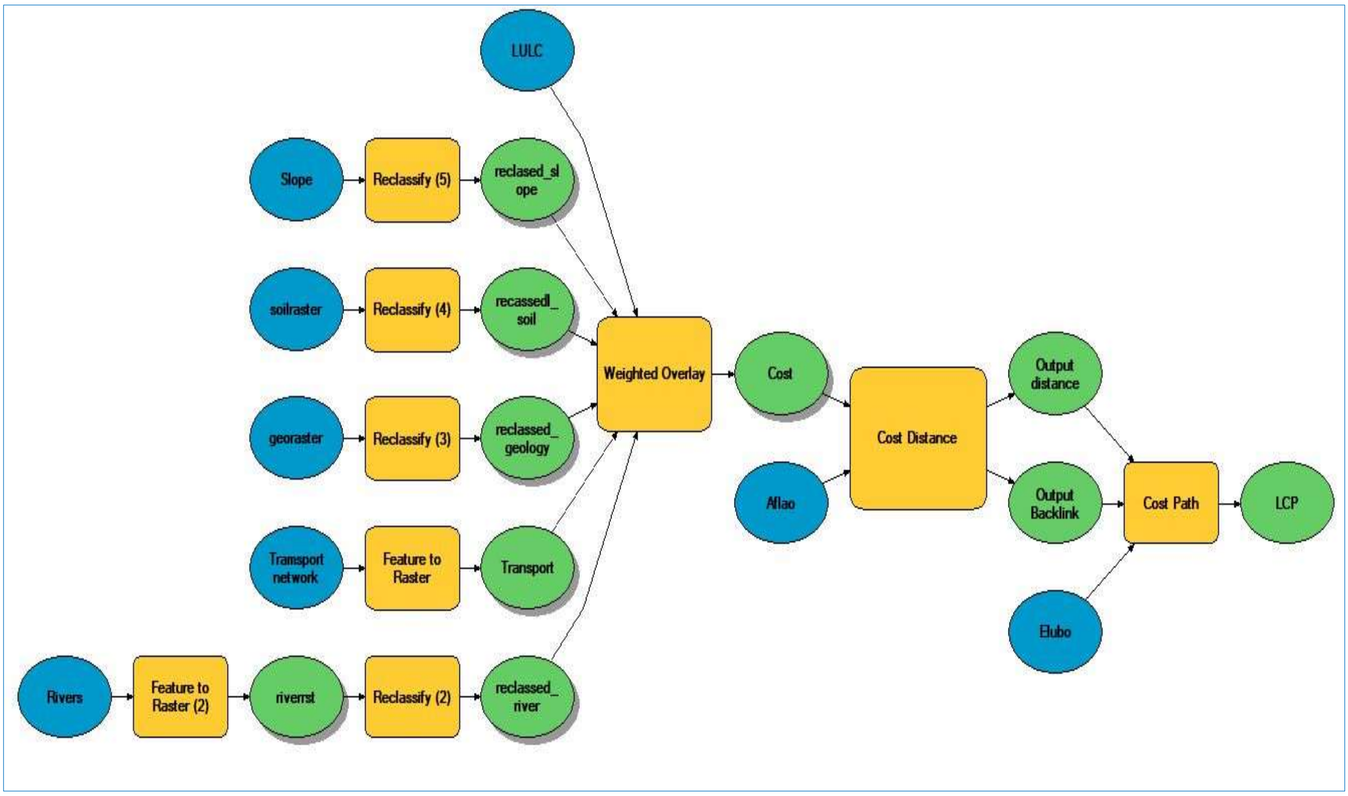

Fig. 12. Orkflow of the LCPA

The cost criteria used in the studies comprises of remotely sensed data and secondary data obtained from the Survey and Mapping Division of Ghana. All maps of the weighted alternatives were carried out using ArcGIS 10.4 software.

The Entropy decision matrix is denoted by *Equation 2* and Table 2. The matrix is normalized by *Equation 3* as depicted in Table 3. The computation of the entropy values is represented by *Equation 4* and Table 4. The Entropy weights is shown in Table 4 according to *Equation 5*. The degree of diversification can be seen in Table 4. The TOPSIS method was used to assign the final ranks and weights to the alternatives. The reason is for the selected alternatives to achieve the shortest geometric distance from the PIS and the largest distance from the NIS. *Equation 6* depicts the decision matrix employed in the TOPSIS method. The decision matrix is then normalized using the vector normalization method which is given by *Equation 7* as observed in Table 5.

Table 2. Entropy Decision matrix

Criteria(n)	**Slope**	**Soil type**	**LULC**	**Geology**	**Water**	**Transport**
Slope	1.0000	1.0000	1.0000	1.0000	1.0000	2.0000
Soil type	1.0000	1.0000	1.0000	2.0000	0.5000	1.0000
LULC	1.0000	2.0000	1.0000	2.0000	0.5000	1.0000
Geology	1.0000	1.0000	0.5000	1.0000	0.5000	1.0000
Water	1.0000	2.0000	2.0000	2.0000	1.0000	2.0000
Transport	0.5000	1.0000	1.0000	1.0000	0.5000	1.0000
Sum	*5.5000*	*8.0000*	*6.5000*	*9.0000*	*4.0000*	*8.0000*

Table 3. Entropy Normalization sequence

Criteria(n)	Slope	Soil type	LULC	Geology	Water	Transport
Slope	0.181818	0.125	0.153846	0.111111	0.25	0.25
Soil type	0.181818	0.125	0.153846	0.222222	0.125	0.125
LULC	0.181818	0.25	0.153846	0.222222	0.125	0.125
Geology	0.181818	0.125	0.076923	0.111111	0.125	0.125
Water	0.181818	0.25	0.307692	0.222222	0.25	0.25
Transport	0.090909	0.125	0.153846	0.111111	0.125	0.125

Table 4. Calculation of Entropy and weight

Criteria(n)	Slope	Soil type	LULC	Geology	Water	Transport
Slope	-0.30995	-0.25993	-0.28797	-0.24414	-0.34657	-0.34657
Soil type	-0.30995	-0.25993	-0.28797	-0.33424	-0.25993	-0.25993
LULC	-0.30995	-0.34657	-0.28797	-0.33424	-0.25993	-0.25993
Geology	-0.30995	-0.25993	-0.1973	-0.24414	-0.25993	-0.25993
Water	-0.30995	-0.34657	-0.36266	-0.33424	-0.34657	-0.34657
Transport	-0.21799	-0.25993	-0.28797	-0.24414	-0.25993	-0.25993
Sum	-1.76775	-1.73287	-1.71184	-1.73513	-1.73287	-1.73287
ej	0.986602	0.967131	0.955398	0.968394	0.967131	0.967131
1-ej=dj	0.013398	0.032869	0.044602	0.031606	0.032869	0.032869
Wj	0.071184	0.174639	0.236975	0.167925	0.174639	0.174639

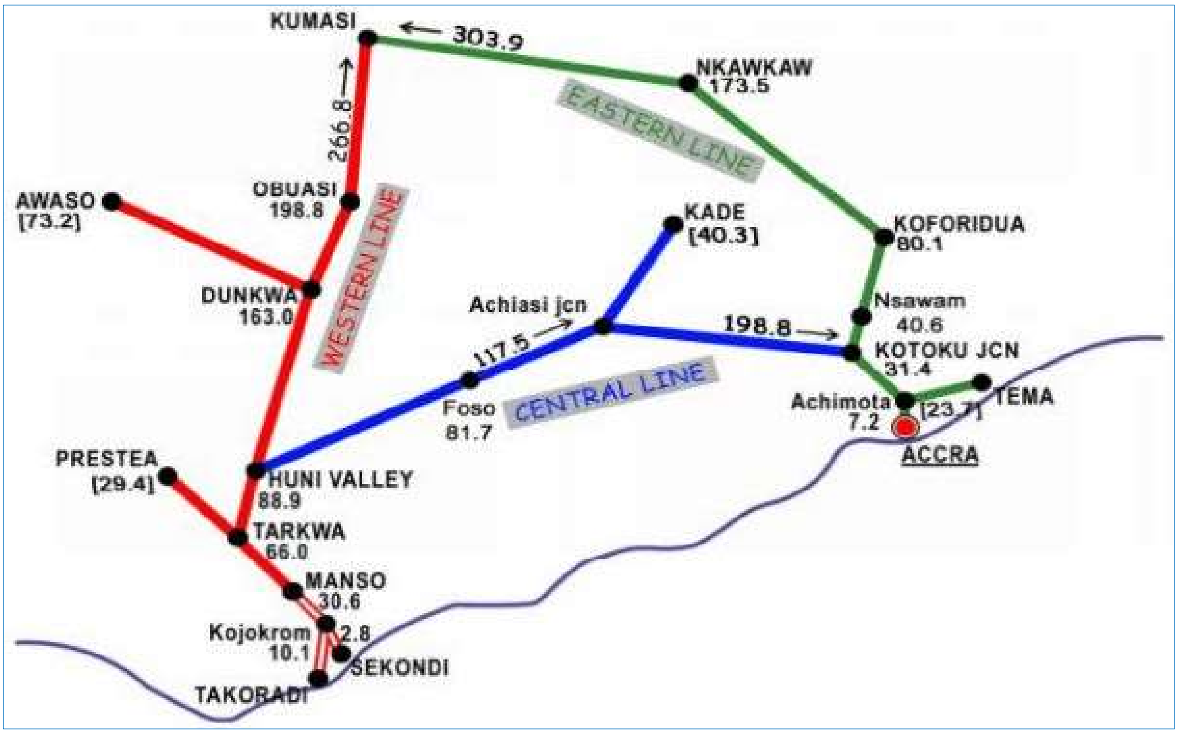

Fig. 13. Ghana Railway lines (Ghana Railways Master Plan, 2013)

In order to generate the weighted matrix using TOPSIS, initial optimal weights obtained from the Entropy method was multiplied by each corresponding row element of the vector normalized matrix as shown in Table 5. The positive and negative ideal solutions were then obtained from each criteria column according to *Equation 8* and *Equation 9* as observed in Table 6. The Euclidean distance from the positive and negative ideal solution is denoted by *Equation 10* and *Equation 11*, respectively. The alternatives are ranked and weighted by the performance score given by *Equation 12* as observed in Table 7.

Fig. 3 elaborates on the idea of Euclidean distance employed in the TOPSIS method. Various cost factors were used in developing the thematic maps namely; geology, water, land use and land cover, slope, transport network and soil types. This was done due to the interdependencies between the cost factors so as to improve the reliability of the studies.

Topography plays a major role in terrain characteristics in the process of route selection. The slope which is the average rate of change of altitude in a given area is represented in Fig. 4. Areas of mild slope are deemed less expensive compared to areas of steep slopes. The western sector of the study area is marked by steeper slopes whiles the southern region has a gentler slope gradient comparatively. The LULC map is represented in Fig. 5.

The LULC was classified into five (5) main groups which are; dense forest, barren/sparsely vegetated, water, cropland and built/urban areas according to the IGBP classification scheme observed and described in Table 1.

Fig. 6 represents a map of a network of water bodies. Geology and soil types of the area were considered and evaluated to see whether their physical and chemical properties will be suitable for the railway construction.

The geological map can be observed in Fig. 7. It includes schist, migmatite, phyllite, quartzite, sandstone, calcareous, grit, shale, tuff, greywacke, metamorphosed larva, pyroclastic rocks and granitoid undifferentiated.

Table 5. TOPSIS normalized performance values

Criteria(n)	Slope	Soil type	LULC	Geology	Water	Transport	*Weights*
Slope	0.436436	0.288675	0.348155	0.258199	0.57735	0.57735	*0.071184*
Soil type	0.436436	0.288675	0.348155	0.516398	0.288675	0.288675	*0.174639*
LULC	0.436436	0.57735	0.348155	0.516398	0.288675	0.288675	*0.236975*
Geology	0.436436	0.288675	0.174078	0.258199	0.288675	0.288675	*0.167925*
Water	0.436436	0.57735	0.696311	0.516398	0.57735	0.57735	*0.174639*
Transport	0.218218	0.288675	0.348155	0.258199	0.288675	0.288675	*0.174639*

Table 6. Weighted matrix

Criteria(n)	Slope	Soil type	LULC	Geology	Water	Transport
Slope	0.031067	0.020549	0.024783	0.01838	0.041098	0.041098
Soil type	0.076219	0.050414	0.060801	0.090183	0.050414	0.050414
LULC	0.103424	0.136818	0.082504	0.122373	0.068409	0.068409
Geology	0.073288	0.048476	0.029232	0.043358	0.048476	0.048476
Water	0.076219	0.100828	0.121603	0.090183	0.100828	0.100828
Transport	0.038109	0.050414	0.060801	0.045092	0.050414	0.050414
PIS	0.031067	0.136818	0.024783	0.01838	0.041098	0.100828
NIS	0.103424	0.020549	0.121603	0.122373	0.100828	0.041098

Table 7. Euclidean Distance, Performance Score and Final Weights

Euclidean distance+(S_i^{k+})	Euclidean distance (S_i^{k-})	(S_i^{k+}) + (S_i^{k-})	$\overline{P_i^*}$	Rank	Weights (%)
0.13071349	0.17027034	0.300983833	0.565713	1	19.0665
0.136329275	0.09483374	0.231163015	0.410246	6	13.82674
0.145529505	0.1297843	0.275313804	0.471405	4	15.888
0.114130602	0.13877704	0.252907647	0.548726	2	18.494
0.146394687	0.10857573	0.254970422	0.425837	5	14.35219
0.11024693	0.13211967	0.242366595	0.545123	3	18.37257

The western side of the study area is characterised by phyllite, schist, tuff and grey wacke, the main geological expression in the destination town (Elubo). The middle area is predominantly characterised by granitoid undifferentiated. The eastern area is defined by acidic, ortho, paragnesis, schist, migmatite, unconsolidated sand and gravel, the main geological expression in the origin (Aflao).

Fig. 8 represents the soil map of the area. The western section is defined by fluvisols, ferrasols and acrisols. The middle regions are predominantly characterised by lixisols, acrisols and luvisols. Planosols, cambisols, gleysols, leptosols and luvisols have their expressions in the eastern area.

Fig. 9 represents the transport system in the study area. The main transport network comprises of roads and railways. The LCPA was performed using QGIS 3.24 software. The LCPA plugin was built using the Dijskra algorithm which was then applied to the calculated cost grid surface after choosing the source and destination file. *Equation 13* represents the distance covered by the Dijsktra Algorithm.

Figs. 10-11 represent the Dijsktra Algorithm and the QGIS Least Cost Path Plugin, respectively. Fig. 12 is the workflow of the LCPA. Fig. 13 is the proposed map of the Ghana Railway Lines. The optimal least cost route proposed by the studies can be observed in Fig. 14. The total length of the least cost route proposed for the railway is 471.34 kilometers as against the 540.60 kilometers distance by road. Hence, saving a travel distance of 69.26 kilometers.

Also, the proposed distance of the Trans-ECOWAS line was approximately 498 kilometers (Ghana Railways Master Plan, 2013), which is about 26.66 kilometers more than the length of the optimal route proposed by the study. The route passes through four (4) coastal regions namely Volta, Greater Accra, Central and Western Region from the east, source town (Aflao) to the west, destination town (Elubo).

Towns located along the route in the Volta Region includes; Tokpo, Mepe, Gefia, Dekpoyaa and Aflao. Tokuse, Weija, Ablekuma, Ofankor and Mobole are among the towns in the Greater Accra Region found along the stretch. In the Central Region; Efutu, Amissakrom, Ewuoyaa, Mankessim, Enyan Apaa and Gomoa Lome are located along the proposed route. Towns along the stretch in the Western Region includes pataho, Kofi Ashia, Ashiaem, Agege, Amoakwasuazo and completes at Elubo.

5. Conclusion and Recommendations

With reference to the socio-economic situation and the existing railway network in Ghana, for some years now the Government has given prior importance to the necessity for the rehabilitation, extension and development of the entire national network to take into account the necessities of northern Ghana, the bordering countries and the objectives of Ecowas, identifying a plan for a new railway network.

The research seeks to employ an integrated approach of a GIS-based LCPA and MCDM techniques comprising of ENTROPY and TOPSIS for the selection of the optimal route from Aflao to Elubo based on calculation of the cost grid surface.

The cost model consists of the weights, selected criteria and the restriction model. The initial weights were generated using Entropy from the decision matrix. The reason is to generate objective weights to define the degree of how the various alternatives approach each other with respect to a specified criteria and to deal with the uncertainties experienced in the traditional AHP. The decision matrix used in the studies was employed from the pairwise comparison of the AHP method with a valid consistency ratio of 0.09. This was done to eliminate any subjectivity in the cost criteria analysis.

TOPSIS method was used to generate the final weights and rank from the performance score using the Euclidean distance. The reason is for the selected alternatives to achieve the shortest geometric distance from the positive ideal solution (PIS) and the largest distance from the negative ideal solution (NIS). The cost criteria used in the studies comprises of remotely sensed data and secondary data obtained from the Survey and Mapping Division of Ghana. All maps of the weighted alternatives were carried out using ArcGIS 10.4 software. The total length of the least cost route proposed for the railway is 471.34 kilometers as against the 540.60 kilometer distance by road. Hence, saving a travel distance of 69.26 kilometers.

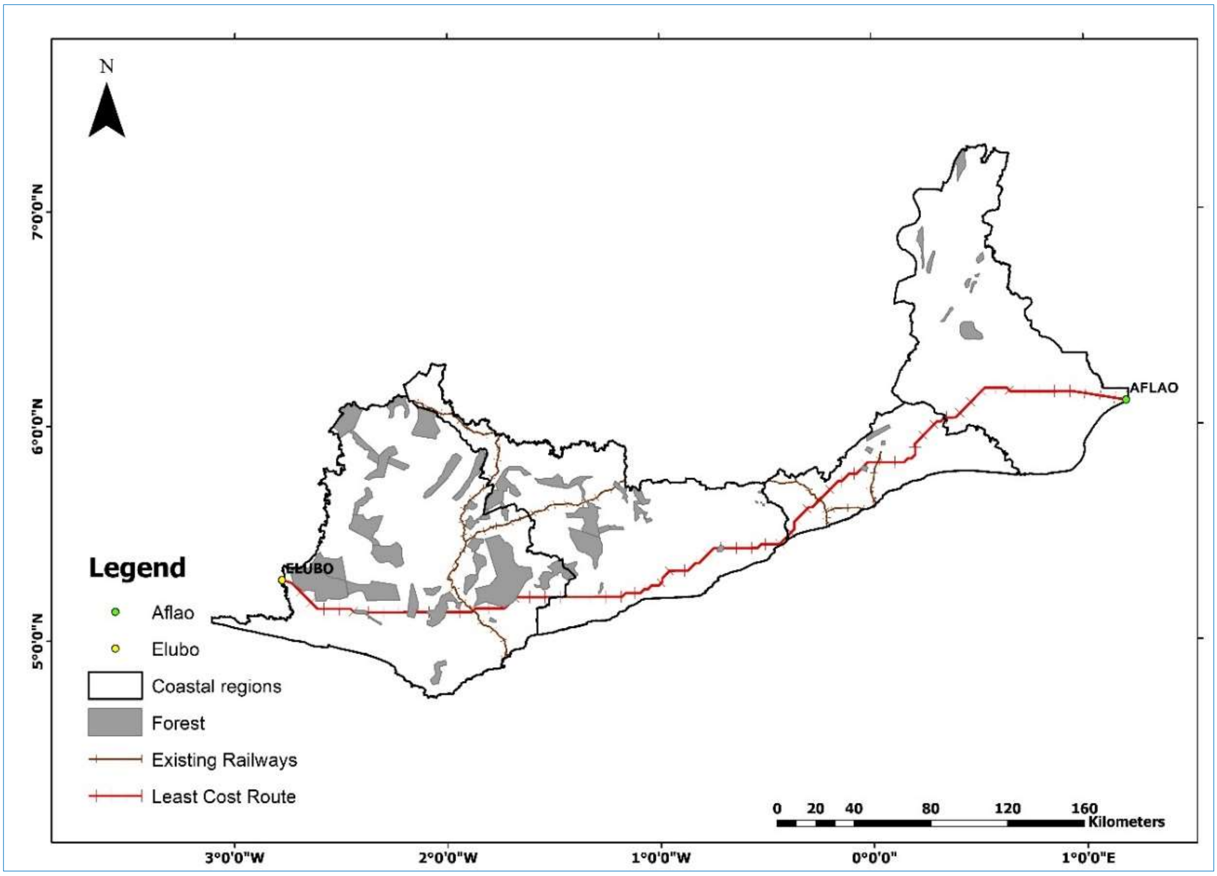

Fig. 14. Least Cost Route

Also, the proposed distance of the Trans-ECOWAS line was approximately 498 kilometers, which is about 26.66 kilometers further distance compared to the optimal route proposed by the study. Hence, an economical route has been proposed in terms of time, travel and construction cost. The findings from the research conducted reveals that, the utilization of GIS, MCDM, Remote Sensing and LCPA has proven to be very essential tools for optimal route selection and long term traffic management. It is recommended to the ministry in charge of railway development to make sure information regarding rail- way development is made available on their websites and other forms so that future researchers can access them with ease to facilitate research to conduct more research on the current Ghanaian railway development. The Ministry of roads and transport in Ghana and other developing countries that are confronted with traffic congestion and impending traffic pressure should take advantage of this important tool to their advantage. Moreover, government and decision makers in the road sector should adopt these tools in their route selection to cut down cost. Also, further research should be carried out to add more criteria depending on the specific topographic characteristics of interest by incorporating expert knowledge from the stake holders from the construction industry.

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