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TRANSMISSION SUITABILITY ROUTE MAP USING THE LEAST COST PATH ANALYSIS (LCPA)

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Abstract

This study uses a Least Cost Path Analysis (LCPA) to create a transmission suitability route map. Environmental issues including electromagnetic pollution, habitat fragmentation, forest clearing, and the sight of pylons and power lines, and electromagnetic pollution are just a few that may come up during the planning and construction phases. The study's objectives are to define the criteria for a suitable transmission route, map the current transmission from Kidurong to Kemena in Bintulu, Sarawak, and suggest a new, LCPA-based transmission route that meets these criteria. It is necessary to determine the criteria that influence the construction of the route. There are three main categories for the proposed routes. There are technical, human health, and natural environments. The road layer and slope layer are combined for the technical group. The residential layer is part of the human health group, and land use is associated with the natural environment. During the planning of a potential power line route, weight was assigned to the criterion maps. The outcome demonstrates that the suggested route was built based on most flat sections, with only a little portion passing through the sharpest sector because there is no other way to depart from the path to avoid it. The output route is nearly straight from the source location to the destination point. The route also curves in a couple of places to go around the step area. The proposed transmission line is inside the buffer zone, and there are no other routes in the area that are more than 1 km from the road. Class 1 has a low dwelling density; therefore, the route passes through it for the residential evaluation. Additionally, there are a few places where the route passes through class 2 because only class 2 has a lower housing density.

Keywords: Least Cost Path Analysis, Remote Sensing, Transmission Line, Weight Overlay, Multi-Criteria Analysis, Model Builder

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INTRODUCTION

Due to increased energy demand and the addition of new communities to the electrical network, transmission lines need to be regulated and designed in a way that minimizes potential effects on the population's health, maintains landscapes, and removes animal disturbances (Abd Latif Z, et al.,2022). Sarawak Energy Berhad (SEB), an energy development organization that transports and distributes electricity largely in Sarawak, is a vertically integrated power utility. Power transmission businesses have emerged as a result of the electric power sectors' exponential expansion in power demand (Atkinson DM, et al., 2005). Numerous aspects that have an impact on the route should all be taken into consideration while choosing an appropriate route. Due to things like pylon visibility, the clearing of forests, the fragmentation of habitats, electromagnetic pollution, and other factors. Power lines can significantly harm the environment during the planning and construction phases (Bailey K et al.,2005). More investigation is required in this area before starting any activity involving the transmission line's route.

This study aims to produce a transmission suitability route map using the Least Cost Path Analysis (LCPA) based on Geographical Information System (GIS) approach. This study has three objectives that must be accomplished. Finding the criteria for suitable transmission routes is the first objective of this study. The second objective is to map the current transmission going from Kidurong in Bintulu, Sarawak, to Kemena. The final objective is to suggest a new transmission path that would be suitable for using LCPA. GIS can be used to determine the optimal route for a transmission line and find an appropriate evaluation model. The best nodes of the energy tower must first be located. The Least Cost Path will then be used to find the "cheapest" route connecting two sites within a cost surface. Least-cost path analysis uses raster data. Find the path connecting cells with the lowest overall cost by using a cost raster that shows the cost of traversing cells. By creating an accumulated cost surface on which a line connecting the starting point and the destination can be determined, LCPA can be carried out. The accumulated cost surface is created from the cost surface by calculating the cumulative cost of each cell starting at the starting point (Bagli, Geneletti, & Orsi, 2011). This stated that designers should constantly consider alternate potential terminal locations while determining the ideal routing. It has also been shown that employing different weight scenarios can help in adapting the model to different social and environmental situations. A real-world case study in Bintulu Sarawak is reviewed to test this approach.

LITERATURE REVIEW

GIS in Management of Electricity

Over the past few decades, electricity firms have constructed power transmission networks to keep up with the rapidly increasing demand for electricity;

nevertheless, the availability of suitable locations for new transmission lines has been constrained by rural development and growing environmental concerns. Various types of analyses can be carried out, including optimal area selection, route choice, profile evaluation, engineering tower and wire design, and cost estimation utilizing GIS. Additional information, such as location, voltage, and information on electrical distribution, can be provided using GIS. The possibilities of GIS for managing electricity in a building have been practically proved in earlier studies (Saad N, 2021; Pullinger & Johnson 2010). This spatial technique has also been combined with MCDM/MCE to determine whether a certain application is appropriate (Ahmadi, S. et al., 2008; Mohd Zaini J C et al.,2021).

Details on a computer system that connects a database to a map can be more efficiently organized using GIS. A GIS may also enable the updating and reliability of the information. GIS should be able to support the requirements of large-scale energy infrastructure. Information detailing each customer's characteristics, such as location and electricity use, can be managed by GIS effectively (Burrough P.A & McDonnell R.A.,1998). GIS can also be utilized in the investigation, analysis, and design of electrical distribution systems in the field of electrical power. GIS technologies are also being developed to assist in the design of a new residential development's electrical supply network (Majid MR, et al., 2018). Furthermore, GIS can provide high-quality attendance for the automation process for electricity customers. In addition, the GIS application can recreate the design of electrical utility work methods.

Least Cost Path Analysis

Least-Cost Path Analysis is based on a raster and has a narrower focus. It discovers the path between cells with the lowest aggregated cost by using a cost raster that defines the cost of traveling through each cell (Hashim H, 2021). A source raster, a cost raster, cost distance measures, and an algorithm for determining the least accumulative cost path are all required for a least-cost path analysis. Examination of the LCPA is useful for route planning. It has been used to determine the best paths for power lines, for example (Bagli, S., Geneletti, D., & Orsi, F.,2011). In order to determine the best route for a power line, multi-criteria evaluation, and LCPA are coupled. Firstly, cost surfaces and alternative paths were identified using spatial multi-criteria. MCE was then utilized to compare and rank the alternatives based on their overall appropriateness. Lastly, A sensitivity analysis allows for the assessment of the resulting stability and the identification of the most essential aspects in the evaluation.

Least-cost path analysis is particularly appealing for power line routing since it is a quick and repeatable technique that allows the user to combine data from several sources. In the comparison phase, different evaluation viewpoints are employed to adapt the procedure to diverse circumstances. For example, if there is environmental regulation, an economic approach would most likely provide a good response, with the entire cost being the most important factor to consider. A common application of least-cost path analysis in wildlife management is corridor or connectivity studies (Rasam A R.A.,2013). In this research, the origin cells reflect places of high habitat concentration, and the cost raster is the weighted sum of cost elements such as slope, land cover, altitude, water, and human activity (e.g., population density and roads). The study's findings will identify the least expensive wildlife movement routes. LCPA can be accomplished by constructing an accumulated cost surface on which a line can be drawn from the origin to the destination sources (Douglas D.H.,1994).

The accumulated cost surface is formed from the cost surface by calculating the cumulative cost of each cell from the beginning point. An algorithm searches among the nearby cells of the beginning location for the cell with the lowest value. After selecting these cells, the algorithm iterates its procedure: the selected one is now the starting point, and its nearby cells are searched to locate the one with the lowest value. The least-cost path between any destination point and the pre-defined beginning point is eventually discovered by traveling backward from the destination point through the accumulated cost surface, picking cells with decreasing values (Lee J, Stucky D.,1998). Low-cost route mapping has also been used in recent years in archaeology to analyze past social and economic relationships (Yu C, Lee J, Munro Stasiuk M.J.,2003) as well as in usability research such as accessibility to medical services.

METHODOLOGY

The designation of the study region is the first step in this investigation (Figure 1). Then comes the data acquisition phase, in which the study's data is acquired (Figure 2), and after the acquisition process is completed, the data processing processes are taken over. The data processing is analyzed using LCPA. Finally, the analysis and output of the final findings of the study will be generated.

Figure 1: Study Area: Bintulu Sarawak
Map Source: OpenStreetMap

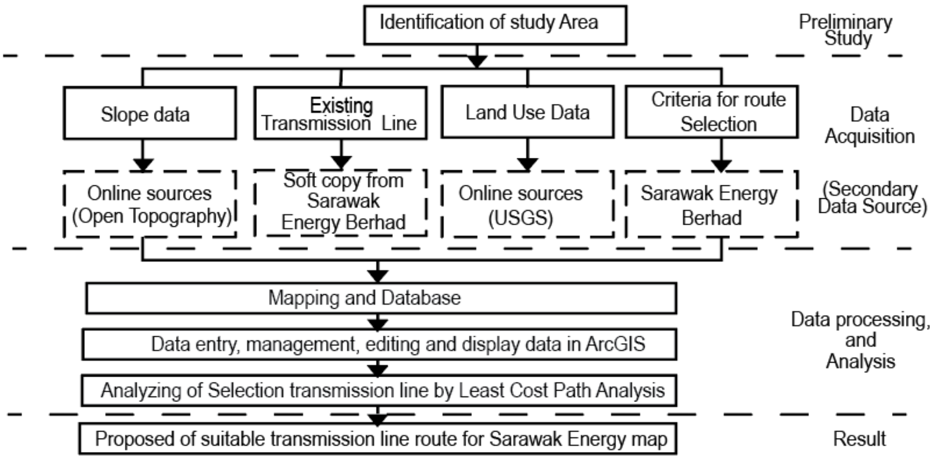

Figure 2: Methodology Flowchart
Source: Author's Flowchart

Data Acquisition

Figure 2 shows that road and residential data is in shapefile (.shp) format, which can be opened immediately using ArcGIS software. Aside from the digital topographic map, the location of the existing transmission line was determined using data provided by Sarawak Energy Berhad (SEB). The coordinates of the origin and destination sources will then be imported into ArcMap. The data soil contains information about the type of soil. The data comprises a complete set of attribute codes as well as topological structuring. The attribute codes are used to characterize the feature-represented area's characteristics. The data can be accessed in GeoTIFF format from USGS online sources.

Data Processing

Generation of the Land Use Map

Two types of software have been used to create land use maps. The data is processed using ERDAS software, then ArcGIS is utilized to convert the raster image to features for spatial analysis. ERDAS software is used to process the data, and ArcGIS is utilized to convert the raster image to features for spatial analysis. Removing Haze - The data is obtained straight from the USGS. The first step in image processing is radiometric enhancement. Radiometric enhancement is the process of removing haze from an image. A cloud in the image can affect the accuracy of the results.

Geometric Correction - Image registration and image-to-map registration are the two methods of geometric rectification. In the viewer, collect ground control points (GCPs) for the source image. The transformation to resample or calibrate the image is computed using corresponding reference points. Subset - Image files frequently contain areas that are substantially larger than the research area. It is used in these circumstances to minimize the size of an image file so that only the area of interest is included (AOI). This not only removes unnecessary data from the file but also speeds up processing because there is fewer data to process. To acquire the desired area, a subset is created. A subset is made to obtain the desired area.

Image Classification - Classification is the process of categorizing pixels based on their data file values into a finite number of separate classes or categories of data. If a pixel meets a set of criteria, it is allocated to the class that corresponds to those criteria. The computer system must be trained to recognize a pattern in the data as the first step in the classification process. Training is the process of developing the criteria for recognizing these patterns. Training produces a set of signatures that serve as the criterion for a set of proposed classes. There are two methods for categorizing pixels into distinct groups. There are two types of classification: supervised classification and unsupervised classification. Unsupervised image classification was utilized in this study to build a land use map of the study area.

Recode - Figure 3 depicts the outcomes of applying to recode to the image. The goal of Recode is to limit categorization to a few classes. Recode can be used to condense all of the learner sections into a few classes. This project has only 5 classes, according to the results. There are forests, bodies of water, cities, farms, and bare earth. Accuracy Assessment - Accuracy evaluation was the process of determining how close outcomes were to values acknowledged as true. The Erdas Imagine software can detect discrepancies in images. If the findings are greater than 80%, the data is considered accurate. The accuracy testing yielded an overall accuracy of 94.00% with a kappa coefficient of 0.9067, which was regarded as adequate by modern picture categorization standards.

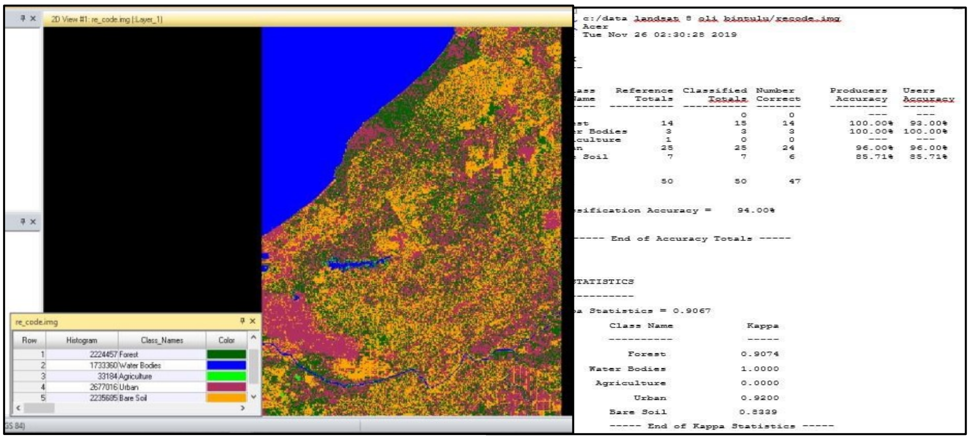

Figure 3: Result of image recode and classification.
Source: Results of the Author's analysis

Designing Potential LCPA Routes

Model Builder Development

Model Builder is designed to assist in the selection or design process of determining the optimal path for transmission line sitting. A new toolbox is constructed in this study using a few model builders. Figure 4 depicts the model builder that is used to solve the choice problem. Each operation in the model builder is represented by a rectangle, and each dataset by an eclipse. The blue ellipse represents the input dataset, while the green eclipse represents the processed result. he inaccuracy is easily detectable, the process will be repeated for the duration of the project.

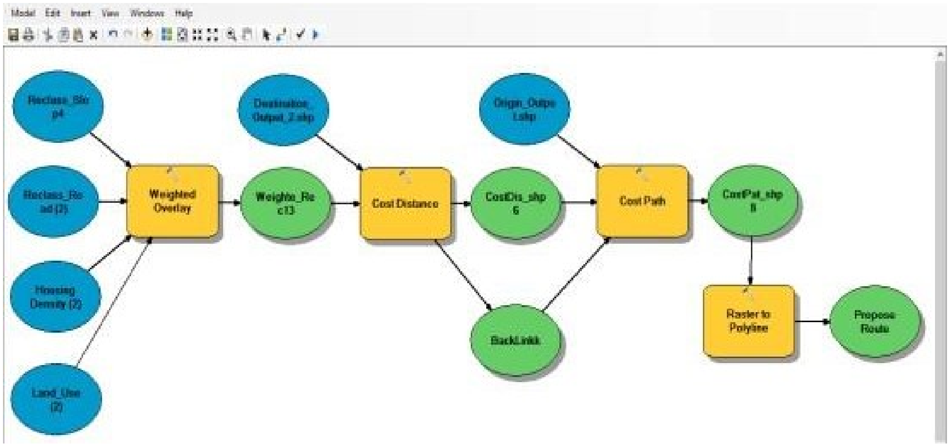

Figure 4: Model Builder for the best Transmission line route
Source: Author's Flowchart

Weight Overlay Analysis

The LCPA technique is based on the definition of a cost surface, which is a raster map with values reflecting the "cost" of passing over each cell. The cost surface can be computed by taking into account all of the parameters that influence the routing process of the linear infrastructure and integrating them using a multi-criteria evaluation. The re-classified slope layer will be integrated and weighted with another dataset in this project to construct a dataset to estimate the cost of creating a path.

Cost Distances Analysis

The cost distance (or cost-weighted distance) function operates an output raster with the source and the accumulated cost surface, assigning a value to each wax cell that is the least accumulative transmission line cost from each cell back to the source. The value influences the cost, the lower the value, the lower the cost. Each cell in the cost-weighted raster has the least amount of influence on the total. The cost-weighted distance function generates two costs: a cost-weighted distance raster and a cost-weighted raster direction. The cost range raster displays the lowest cumulative cost to the nearest origin for each node, but it does not specify how to get there. The direction raster provides a road map to identify the quickest and cheapest route back to any cell. Calculating the raster direction for each cell to determine the code identical to the neighboring cell is the best way back to the nearest integer numbered 0 to 9. The value 0 is used to represent the source's location. The numbers 1 through 9 represent the direction, clockwise from the right.

Cost Path Analysis
The following step is to construct a Cost Path that is continuous from cost distances. The cost path makes use of two rasters generated by a cost distances tool: the least cost distances and the backlink raster. The cost distances or path distance tools are used to generate these rasters. The backlink raster is used to retrace the cheapest path from the destination to the sources over the cost distances surface.

RESULT AND ANALYSIS
The next step is to design a Cost Path that is continuous from cost distances. The cost path employs two rasters created from a cost distances tool: the least cost distances and the backlink raster. These rasters are generated using the cost distances or path distance tools. The backlink raster is used to retrace the least expensive route from the destination to the sources over the cost distances surface.

Criteria for Route Selection
The electrical transmission line route should be designed with the optimum time, cost, and labor in mind. The ideal cost may be examined under two primary headings: expropriation and construction costs. The slope, land usage, and residential and road information all influence the route's construction cost. Land usage determines whether expropriation costs are high or low by influencing real estate value. According to SEB technical regulations, the following criteria must be met for the route to be determined:

a) The elevations throughout the route are kept to a minimum by passing as close to roadways as feasible.
b) The high transmission line path should run near highways to ease traffic and reduce maintenance costs for electric transmission lines.
c) The density of dwellings along the route should be kept as low as feasible.
d) Land use is critical in determining the location of the utility pole. The path should not go through valuable terrain, which raises the cost of expropriation, or through troop locations.

By combining multiple conditions, the "cheapest" approach to connecting two places within a cost surface can be calculated. Transmission lines carry a high voltage of electricity over a long distance from the power plant to towns. The SEB's main concern in planning a new route for transmission lines is the state of human health. As a result, the planning stage of nodes planted in communities must prevent other issues such as being close to dwelling areas. SEB also wants to avoid visible exposure of the transmission line to residential areas since it can transmit waves and disrupt television signals, among other things.

For technical reasons, the heights throughout the route are as close to roadways as possible. The steepest surface is unsuitable for building. This is because the construction at the steepest surface may be costly. As a result, a value greater than 300 is not acceptable for construction Another technical feature is identified by the road layer. Routes that are more than one kilometer from the road are not acceptable zones for the transmission line. This is since the longer the travel, the higher the cost. A location near the road is chosen to reduce maintenance costs. The impact of transmission line routing on the natural environment is also considered. The usage of land is critical in determining the location of the utility pole. Line siting near wetlands and water bodies is avoided since it may have an impact on the habitat and wetland species, such as the electrocution of birds and sediment deposition in water bodies during construction, among other reasons.

The Existing Transmission Line

The existing transmission line in the study region spans 17.4375 kilometers between two substations (Figure 5). PMU Kidurong, located in Tanjung Kidurong, is the generation origin, while PMU Kemena, located in Kg Kemena, is the generation destination. The following are the coordinate origin and destination sources: (Table 2):

Table 2: Coordinate the sources and destination Point

Name	X (meter)	Y (meter)
Sources Point (PMU Kidurong)	73 2561.71	36 3563.66
Destination Point (PMU Kemena)	73 5137.49	34 8464.96

Source: Author's Calculation

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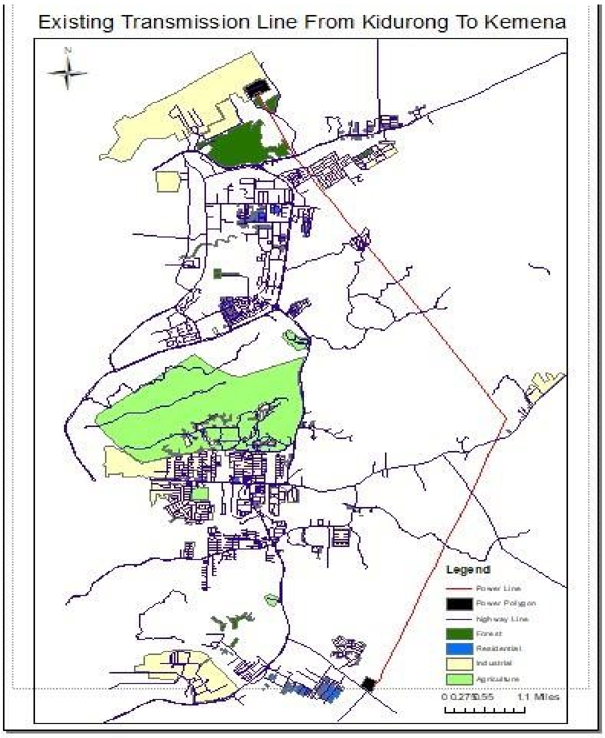


Figure 5: The current transmission line and its sources.
Source: Results of the Author's analysis

Results of the Weighted Overlay Analysis

After overlaying all the layers and assigning their final weight based on the prior literature assessment, several outcomes are produced. According to the prior literature analysis of the expertise in this subject, the opinion regarding the rating of suitability for each layer in this project varies.

Proposed Route

The route is determined by relying on the findings of the literature review. The majority of them divide the layer into three key categories: technical, human health, and natural environment (Table 3). The slope layer and road layer are organized for the technical group. The residential layer is part of the human health group, and land usage is part of the natural environment group. During the planning of a potential power line route, the criteria maps were given weight.

Table 3: Weight was assigned to the criteria maps.

Criteria	Weight for Criteria	Sub Criteria
Technical	26	4.3.1
		4.3.2
Human Health	62	4.3.3
Natural Environment	12	4.3.4

Source: Author's Calculation

Evaluation Of the Route

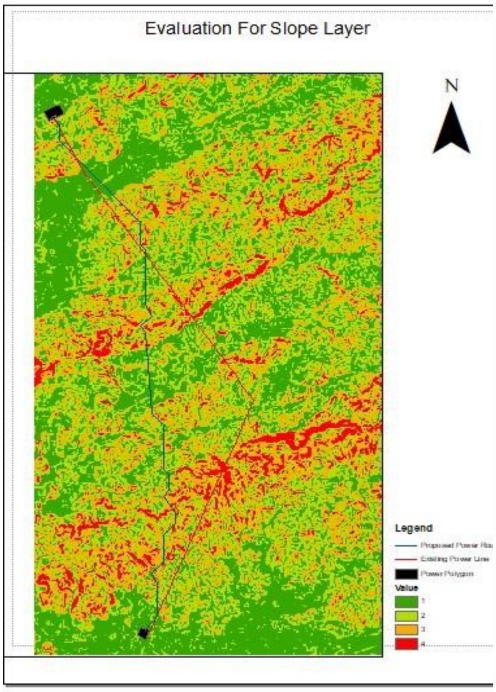
The output of an existing transmission line and the output of a new transmission line are assessed. The evaluation is necessary to investigate the factors that influence transmission line routing.

Evaluation of Slope Layer

Figure 6 depicts the slope layer route transmission line. Only a few parts of the route travel through the steepest area because there is no other route that can be deviated from the path to avoid it. From the source location to the destination point, the output route is nearly straight. Of course, it is not a completely straight line; there are a few sections where the route curves to avoid the step area.

Evaluation of Road Layer

Figure 7 depicts the transmission line routing in the road layer. The existing transmission line and the proposed transmission route are both inside the buffer zone; no route is more than 1 km from the road. The red line depicts the existing transmission route, whereas the blue line represents the transmission route developed using LCP. The existing transmission route is 17.4375 kilometers long, while the Least Cost Path route is 17.1425 kilometers long. The length difference between the two routes is 0.295 km.



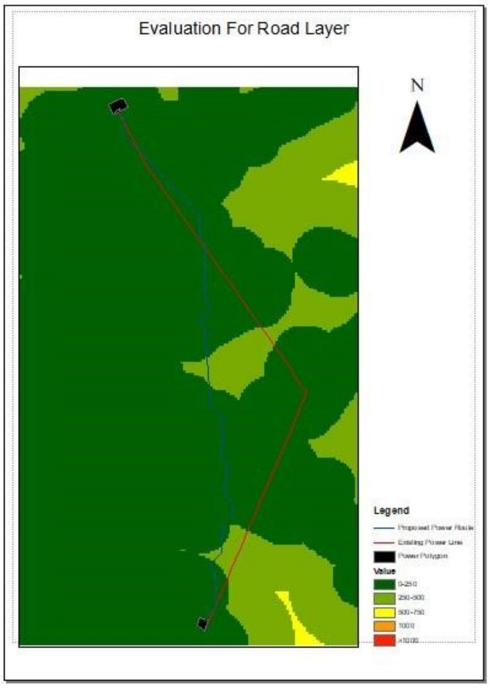


Figure 6: Evaluation of Slope Layer **Figure 7:** Evaluation of Road Layer

Source: Results of the Author's analysis

Evaluation of Residential Layer

Figure 8 depicts the housing layer rating criteria. The point density toolset is used to classify home density based on density. The transmission line should avoid areas with a high population density. Class 5 has the largest housing density in our analysis; however, neither the planned route nor the existing transmission line pass through this area. Because of the low house density, the route runs through class 1. There are also a few sections where the route passes through class 2 because only class 2 has a lower dwelling density.

Evaluation of Land Use Layer

Figure 9 depicts the land use layer rating criteria. Several types of land use are incompatible with construction. For this study, land use is divided into five categories: forest, water bodies, agriculture, urban, and bare soil. Water bodies have the highest scale value, although neither the proposed route nor the current transmission line must cross through the water bodies categories. Power transmission lines must be located far away from lakes or water bodies because lines located near water bodies can harm the habitat of the water bodies, particularly during silt deposition in water bodies during construction, among other reasons.

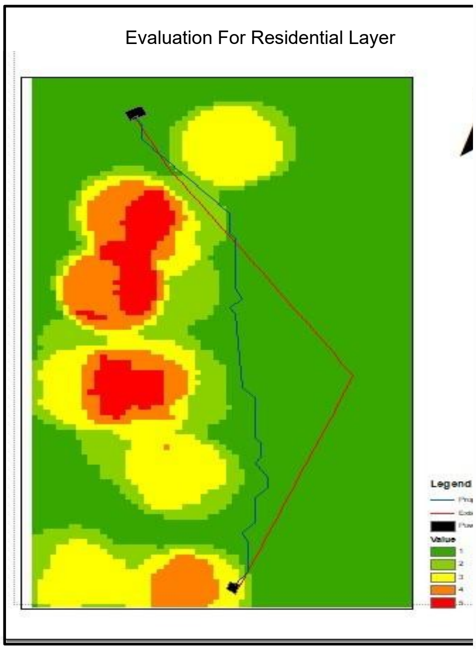


Figure 8: Evaluation of Residential Layer

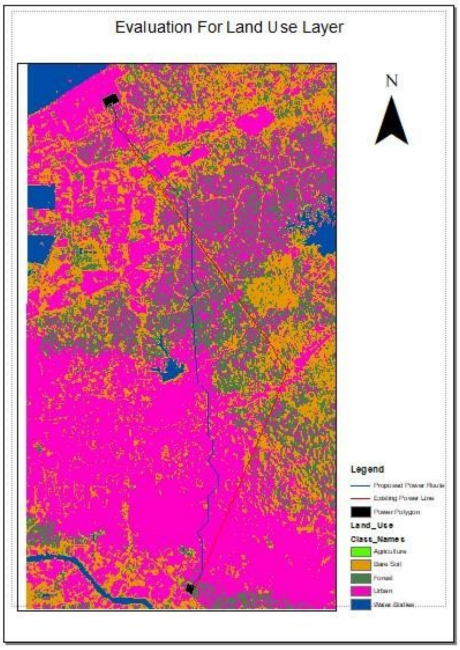


Figure 9: Evaluation of Land Use Layer

Source: Results of the Author's analysis

CONCLUSION

The study's three major goals are to discover a viable path to place a new transmission line using the Least Cost Path program. According to this research, the least-cost path analysis is particularly intriguing for power line routing since it is a quick and repeatable technique that allows the user to combine data from multiple sources. Various datasets have been classed into a similar class scale based on the routing criteria as GIS functions have advanced. These identified datasets are then weighted and aggregated to assess the appropriateness of a specific set of rules or parameters. GIS provides a wide range of software that can be applied in a variety of fields. It aids in the management and decision-making processes.

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