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Full Length Research Paper

The use of GIS in high voltage transmission line routing in Kenya: A case study of 132 KvKilimambogo-Thika-Kiganjo Line

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Energy is an essential input in the productive process of an economy. The Kenya Vision 2030 aims at transforming Kenya into a newly industrialized, middle-income country by 2030.Consequently Kenya Electricity Transmission Company (KETRACO) built a 43.6 km transmission line linking Kilimambogo, Thika and Kiganjo townships. Transmission line routingin Kenya has lately proved challenging due to growth in population and an increase in social and environmental awareness. In this study a model route was developed incorporating transmission line length, topography, geology, soils and land use to identify a least-cost pathway. First, factors affecting the routing process were identified, followed by weighting of the various factors to get the relative importance of each and finally Geospatial Information System (GIS) analysis used for spatial modeling and overlay to generate the route with the least technical, social and environmental resistance. This was compared with the existing line determinedby traditionalapproach. The existing path is 43.6 km long and the least cost pathway is 41.4 km. The results of this study demonstrate the benefits of integrating data within a GIS environment which acted as a spatial decision support system for transmission line routing.

Key words: Least cost path, Weighting, Geographical information system (GIS), Spatial modeling.

INTRODUCTION

High voltage transmission lines deliver generated power from generating stations to targeted areas for distribution to consumers. By increasing the voltage in transmission lines, power loss is minimized, and for this reason transmission of electricity is done at high voltages to reduce losses that occur over long distances. High voltages imply wide clearances from buildings and other infrastructure for safe operation. Though investments in new and improved technologies may increase the capacities of existing lines, additional new ones are necessary to raise transmission capacity and levels of reliability. In the site evaluation process for these facilities, it is necessary to carefully consider not only technical issues but also the impact on the natural environment, the influence on local communities and various government legislative and regulatory issues. Techniques for the routing of power lines and other linear infrastructure have evolved through the years.Manual power line routing uses a variety of available maps, field surveys and lots of experience and expert judgment. Such an approach is cumbersome and tedious and may not be feasible when a variety of factors are to be considered (Saha et al. 2005).Successful choice of an optimal route depends on the effective collection, processing, storing and analysis of spatial data. GIS is a science and technology which combines different data from various sources for route design processes through spatial analysis. Thehighspeeds

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of processing and analytical capability help in predicting and justifying new optimal route corridors incorporating multiple perspectives of influence.This can aid in route approval by the affected public, regulatory authorities and the government as all issues and concerns that affect the said stakeholders are addressed. The optimal goal is to minimize the negative impacts on people and the environment while ensuring safety, reliability and cost savings for the utility (Murata, 1995).

Problem Statement

The Kenya Vision 2030 has identified energy as a key infrastructural enabler upon which the economic, social and political pillars of this long term development strategy will be built. The Ministry of Energy with other stakeholders in the energy sector by 2007 had identified for implementation on priority basis a total of 1,471 km of 132Kilovolt (Kv) lines, 645 km of 220Kv lines, 608 km of 400Kv lines and 686 km of 500Kv lines to be implemented(Ministry of planning and national development, 2007). To date 345km of 132Kv lines have been implemented while the rest are at various stages of implementation.

Considering the geographical spread of these projects over Kenya with diverse ecological zones, cultural and social settings and geophysical characteristics, a keen look at each aspect in the planning process of these projects is very necessary. The planning and implementation of these projects will certainly elicit various reactions from stakeholders, some dissenting. Environmentalists, individual land owners, government regulatory agencies among many will want their concerns addressed. Additionally funding agencies for example, the World Bank and United Kingdom's Department of International Development (DFID) link funding with an assessment of environmental, social and economic impacts of these projects.

It is also a reality that stakeholders may indefinitely delay or even terminate some of these critical projects if their concerns are not satisfactorily addressed. To address the various stakeholder concerns a routing methodology that addresses all these issues is the most appropriate.

Objectives

The main aim of this study is to identify by GIS analysis the optimal transmission line route between Kilimambogo, Thika and Kiganjo by the generation of a geodatabasefor Kilimambogo-Thika-Kiganjoroute, determination of a corridor with minimal impacts on social environmental and regulatory concerns and comparing the determined corridor with the existing containing the line determined by classical manual methods.

Significance

The expected increase in demand for energy in the country to meet the Vision 2030 will necessitate the implementation of the various planned transmission lines projects spread across Kenya. These projects pose unique social, technical and environmental challenges which the present conventional transmission line planning and routing method may notadequately address.

MATERIALS AND METHODS

Study area

Kiambu County is located in the central highlands of Kenya in the former Central province close to Kenya's capital Nairobi. It is considered one of the wealthiest counties in Kenya with its major urban centers being Kiambu, Thika, Ruiru, Limuru, Githunguri, Juja and Kiganjo among others. The county relies mostly on agriculture and industry to sustain its economy. The growth of the greater Nairobi region and improved infrastructure and services has led to the growth of small and medium enterprises in Thika, the first target point of the transmission line. Kiganjo Township which is the terminus of the transmission line is surrounded by five tea factories, constituting some of the major consumers of electricity. It is with this backdrop that The Ministry of Energy and KETRACO built a new 132Kv transmission line linking Thika and Kiganjo to meet current and future demand (Figure 1).

The approach used for the routing process of the transmission line is summarized in Figure 2. The GIS software used was ESRI ArcGIS and ESRI Spatial Analyst extension for mapping and analysis and Microsoft Excel for tabular data.

The area to which the proposed route passed (area of interest) was first identified considering the start and end points of the transmission line which were in Juja, Thika and Kiganjo. Because the starting point of the line and substations were fixed, avoiding difficult areas completely was not feasible. Instead, trade-offs were made between line attributes and site characteristics. First,problematic and unsuitable areas were avoided after a thorough study of existing maps and a site visit.Features avoided included built up areas, airstrips and military installations, schools, quarry pits, large water bodies etc.This resulted in a general corridor of interest averaging 3km wide upon which the routing would be done. This also enabled the identification of the required base maps covering the area.

Selection of factors affecting the route

The first step was the identification and selection of factors influencing the route.These were geology, soils, slope, land use, riparian reserves, proximity to settlements and communication.Next were the criteria by which these variables constrained therouting process. The criteria refer to the rules which the route should abide by. The con-

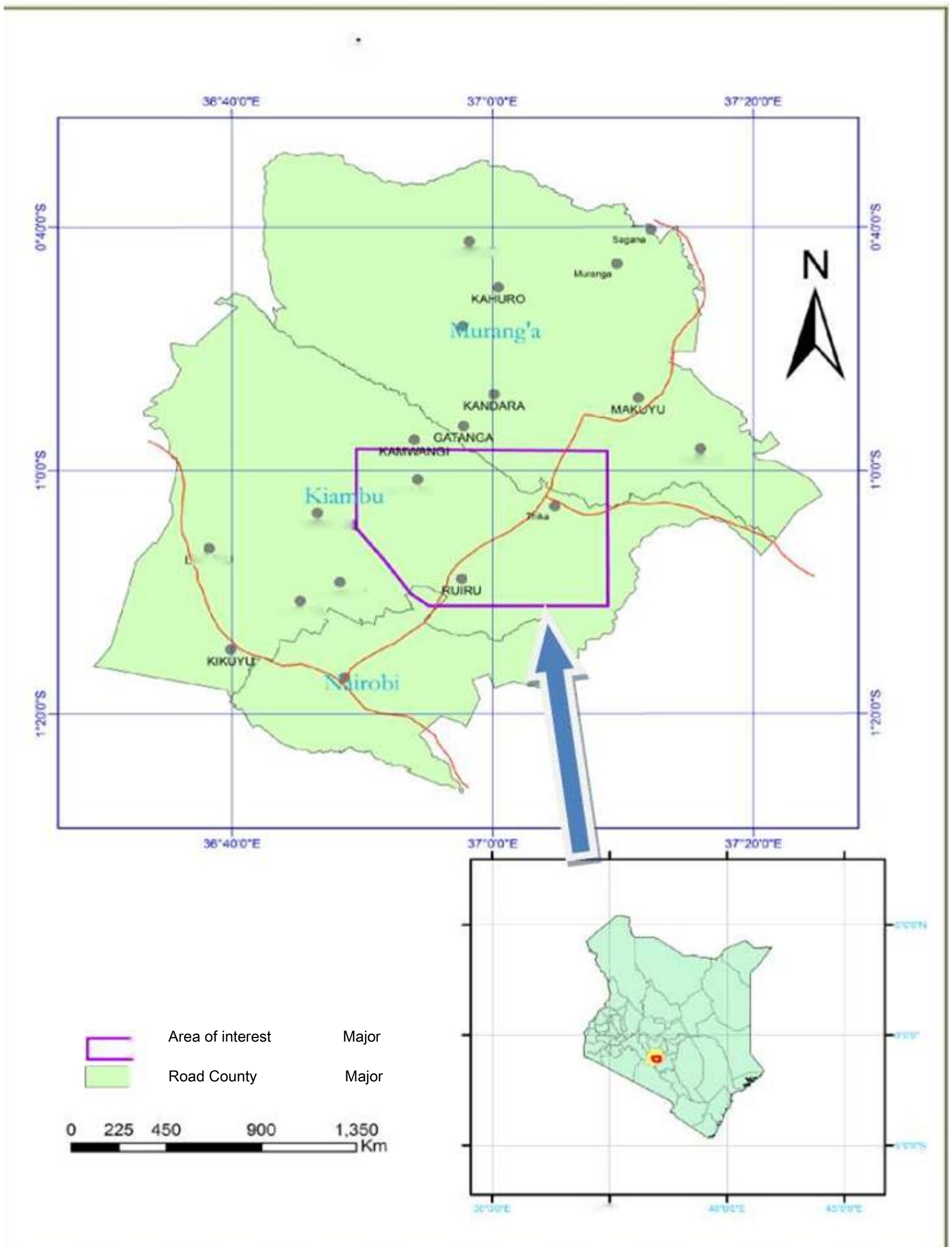

Figure 1. Location of the Study Area.

straints imposed in this particular route determination were avoidance of proximity to settlements, steep slopes, prohibited areas (airstrips, communication masts and riparian reserves), poor engineering soil types and poor geological formations. A variety of base maps (Table 1) were sought to provide the necessary secondary data. Field surveys were employed for additional and complementary data.

Data input

The topographic maps of the area were scanned, geo referenced and prepared for further analysis. This enabled the creation of a spatial database with framework data

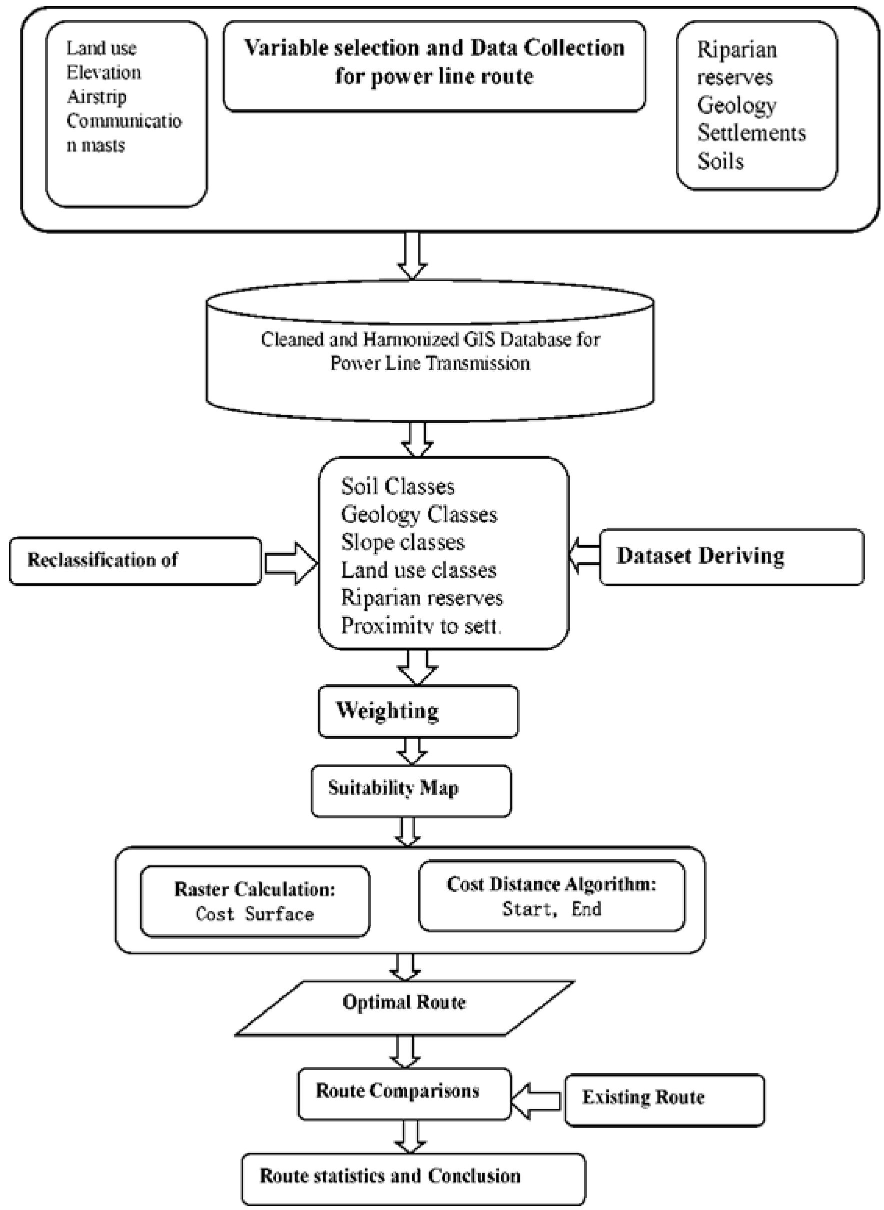

Figure 2. Schematic representation of the methodology.

showing rivers, soil and geology types and other influence factors. The secondary data containing 132kv power line as built was obtained from Kenya Power as shape files to be integrated with the framework data. Finally the field data obtained by the use of GPS was keyed in together with their attribute elements (alphanumeric data).

Data harmonization and database creation

The harmonization process of the data captured involved cleaning for any errors that might have resulted from the initial method of data capture.

Digitization errors corrected include elimination of double polygons to ensure that there were no voids within a single polygon or between adjacent polygons forming continuous surfaces.

Undershoots and overshoots were also eliminated, and endpoints that were not connected to any other line (dangles) were corrected. Correction of these errors ensured connectivity of linear features such as riversand transmission power lines. The last of the data harmonization involved transforming all the data sets to Geographic Coordinate System, Arc 1960 datum and deg-

Figure 3. Existing power line trace (L) and a newly cleared route corridor(R).
Source: KETRACO (2007).

Table 1. Source and data types.

Data Type	Source
Topographical Sheets 1:50,000 (134/4,148/2,149/1)	Survey of Kenya
Settlement data	Aster Website
Geological Maps 1:125,000 (degree sheets 43,51 and 52)	Mines and Geology Department
Soil Map 1:1,000,000 Exploratory Soil map of Kenya(1980)	Kenya Soil Survey
National and County Map	Survey of Kenya
Transmission Line data	Kenya Power
Communication mast, airstrip start and end positions	Field collection

rees angular units from the various coordinate systems that the original data had. The model for route analysis processes requires the data be in raster format. Except the Digital Elevation Model (DEM), all the other data sets were in vector formats and neededrasterization.

The Euclidean distance tools described each cell's relationship to a set of sources based on the straight-line distance where the source identified the location of the objects of interest i.e. rivers, communication masts, DEM, soils and settlements. The Euclidean distance output raster contained the measured distance from every cell to the nearest source. The distances were measured as the crow fly in meters, and computed from cell center to cell center.

In order to create the suitability map that identified the potential locations for the transmission line route there was need to combine the derived datasets. However, it was not possible to combine them in their present form and get a

Table 2. Elements and criteria of transmission line routing suitability.

Factors	Prohibited	Least favourable	Favourable	Most favourable
Soils		Vertisols, Arenesols	Fluvisols	Ferralsols, Luvisols
Land use	Public purpose	Residential	Agriculture	Bare, grazing
Geology	–	Sediments, basalts	Welded tufts	Trachytic tuffs
Slope	_	20-30%	10-20%	0-10%
Airstrip	<1000m	1000-1500m	1500-2000m	>2000m
Riparian reserves	0-100m	100-200m	200-300m	>300m
Masts Proximity	<100m	100-150m	150-200m	>200m

Table 3. Number and categories of professionals sampled.

Professional	Number
Land Surveyors	3
Land Economists (Valuers)	3
Electrical Engineers	2
Civil Engineers	1
Environmentalists	1
Socioeconomists	2
Way Leave officers	3
Total	15

meaningful layer for comparison purposes of different sections within the study area. To combine the datasets, they were first set to a common measurement scale by reclassification.

Reclassification

Reclassification is replacing or giving new values in the input raster with new values, or change cell values to alternative values hence giving a common homogenous scale throughout the layers. The soils layer had five soil types, slope five classes, proximity to settlements five classes, geology three classes and land use three classes. To combine the datasets, they were first set to a common measurement scale. This common measurement scale is what determined how suitable a particular location (each cell) was for transmission line route location. Thus reclassification tool was used to assign each pixel of the derived dataset a new value that tallied with its contributory effect to the routing of the transmission line (Table 2).

Weighting

A weighting system was devised for weighting each of the map layers. The weighting system forms the backbone of

Table 4. Pairwise questionnaire to gather expert opinion on relative importance.

More important										Less important
Proximity to Settlements	9	7	5	3	1	3	5	7	9	Geology
	9	7	5	3	1	3	5	7	9	Soil
	9	7	5	3	1	3	5	7	9	Riparian reserves
	9	7	5	3	1	3	5	7	9	Slope
	9	7	5	3	1	3	5	7	9	Agricultural land
	9	7	5	3	1	3	5	7	9	Bare Land

Source: Adopted from Saaty (1977;1980)

Table 5. Group averaged weights.

Variable	Engineers	Surveyors	Valuers	SocioEcono	WayLeaves	Environ	Average
Proximity to Settlements	31%	31%	38%	43%	38%	38%	37%
Geology	14%	10%	6%	4%	6%	3%	7%
Soil	16%	10%	6%	5%	6%	3%	8%
Proximity to riparian reserve	8%	13%	19%	12%	19%	27%	16%
Slope	10%	10%	8%	6%	8%	3%	7%
Agricultural Land	10%	12%	12%	16%	12%	17%	13%
Bare Land	11%	14%	11%	15%	11%	9%	12%

the methodology. The weighted layers are all summed up to form the suitability layer. This layer forms the basis of the GIS analysis. The Analytical Hierarchy Process (AHP) was used to derive weightages for the thematic layers. To carry out weighting a questionnaire was designed to present all the pair wise comparisons of the criteria to the experts and quantitatively, could rank one criterion over another and establish comparative judgments. The questionnaire developed was presented to 23 line routing experts working with Kenya Power but from different professional backgrounds. Only 15 responded and the following were the categories of professionals successfully enumerated (Table 3).

Seven variables, proximity to settlements, geology, soil, riparian reserves, slope, agricultural land and bare land were considered for pair wise comparison. Table 4 is an excerpt of the questionnaire with one factor, proximity to settlements being compared to geology, soil, riparian reserves slope, agricultural land and bare land. The process was repeated for all the other factors.

3.8 Weighted Average Suitability Map

Suitability is the characteristic of possessing the preferred attributes or requirements for a specific purpose. After the feature layers had been ranked the data layers were combined together into one single layer based on the numerical value factor derived from the weighting process using AHP as discussed above. Avoidance areas were removed from the cost surface using a mosaic method and reclassified. Next a cost distance analysis is run from both the start and end to determine the least accumulative cost distance for each cell. These two accumulative cost distance surfaces were then combined to form a compos-

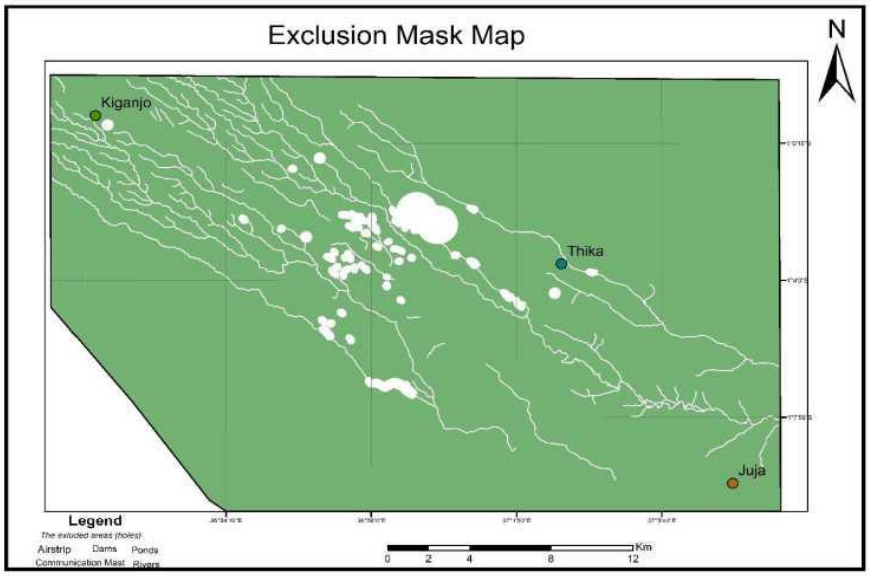

Figure 4. Avoidanceareas or exclusion map.

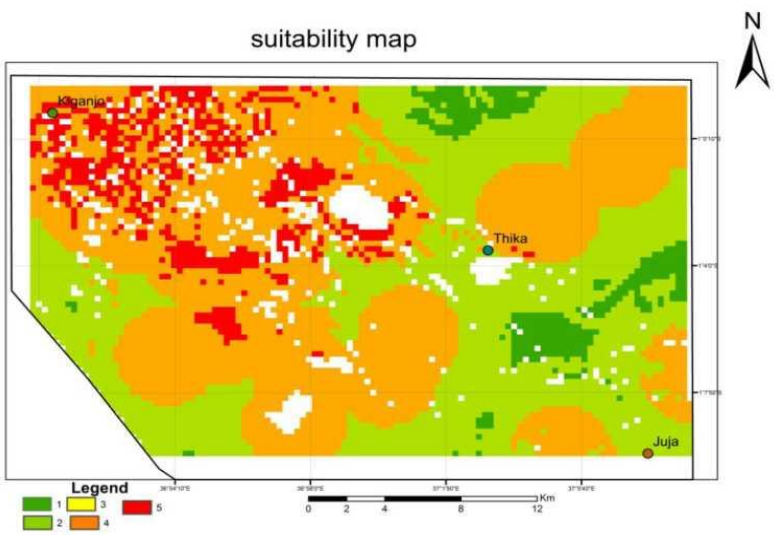

Figure 5. Suitability map.

composite cost distance suitability surface. Finally the least cost path algorithm tool was run to create the optimal route. The resultant layer is the suitability layer which formed the basis for the GIS analysis.

RESULTS AND DISCUSSIONS

Weights for each of the factors were calculated as the eigen vector of the matrix and the consistency ratio was calculated as the eigen value. The Consistency Ratio (CR) indicates the probability that the pair wise comparison matrix was randomly generated. In this study a consistency ratio of 0.50 or less was adopted. Microsoft Excel software was used to calculate the CR and the weights.

The averages for the professionals were calculated and the averages of the averages calculated. The results are as shown in Table 5 below.

The final averaged weightages derived above were used for weighting the datasets. From the above results, it is noted that in order of importance proximity to settlements

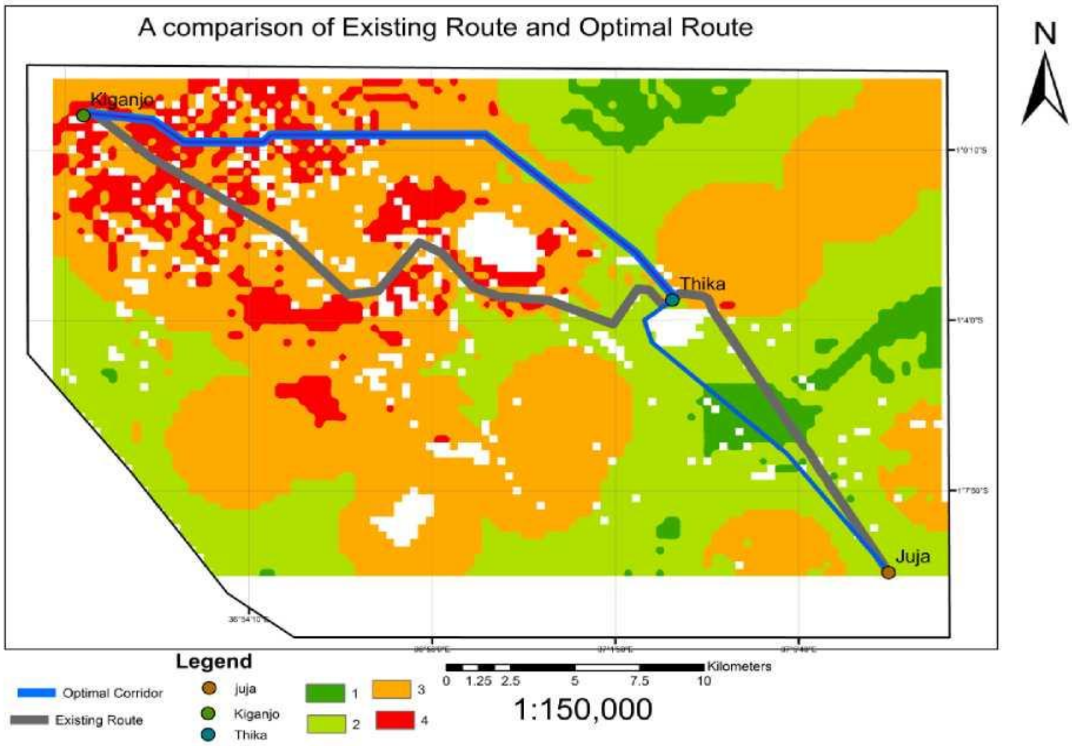

Figure 6. Existing and optimal route corridors.

Table 6. Comparison of existing and modeled LCPA route.

Examination criteria	Current Transmission Line	Optimum Transmission Line
Length of the transmission Line	43.6 km	41.4 km
Size of effect area (30m)	130.8 Ha	124.2Ha
Passage over open land	33 Ha	47 Ha
Passage over Agricultural area	27 Ha	22 Ha
Average distance to settlement area	37m	46m

with an average of 37% was highest followed by proximity to riparian reserves 16%, agricultural land 13%, bare land 12%, soil 8%, slope 7% and geology 7%. All the experts ranked proximity to settlements as a factor that was crucial in the siting of transmission lines. The further away from human settlements the better. Riparian reserves which is an environmental concern was second with a weight of16%.This indicates an awareness in environmental conservation along riparian reserves to protect the vital resource. The last category, geology and soil with7% each are technical which were not of major concern to the experts. This perhaps is because technical issues have technical solutions.

Avoidance areas or exclusion map

Avoidance areas were removed from the cost surface using a mosaic method and reclassified. These areas are the airstrip and a 1000m buffer, a 100m buffer on either side of rivers a 100m buffer from communication masts (Figure 4).

Suitability map

After the feature layers had been ranked the data layers were combined together into one single layer based on the numerical value factor derived from the weighting process. This resulted in a suitability map with five classes. (Figure 5).

Least cost path results

The suitability map, cost distance and direction rasters were obtained. Four route corridors were generated. The differences in emphasis for certain layers generate different corridors that directly reflect differences in stakeholder perspectives. When weighting was applied the methodology was able to correct the route as per the defined criteria. Proximity to settlements had the highest influence on selecting the corridor. The similarities and differences among the other factors of influence were noted. The final route was developed(Figure 6) by combining alternative route segments for a preferred route.

Route comparison

Two routes, one routed by classical routing procedures and the other by GIS Least Cost Path Analysis are shown in Figure 6.In terms of length the existing route is 43.6 km while the optimum by LCPA is 41.4 km. This is a difference of 2.2 km. This is mostly attributed to route alignment which is straighter in the LCPA method than the classical method which has many angles increasing the distance. The longer the length of the line the higher the trace area affected. Considering a buffer of 30 m the trace area acquiredby the existing route is130.8 Ha while that by LCPA is124.2Ha. In compensation for loss of land the route by LCPA will be less by 6.6 Hectares assuming the same land values.Passage over both open and agricultural land also differ, the existing route affecting more of both land uses than that by LCPA by 23 and 5 Hectares respectively. Finally the average distance to settlement in the LCPA method is 46m while that for the existing route is 37m (Table 6).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The objective of this research was to generate an optimal electric transmission route between Kilimambogo, Thika and Kiganjo by Least Cost Path Analysis and compare it with the existing line routed by classical means. This route is optimal in that it is shorter by 2.2 km, traverses more of open land than agricultural land and is on average further away from settlements than the existing one.

The route suggested by this study serves as an excellent aid for the execution team to make the preliminary changes and report the ground realities affecting the proposed route. Changes can be made considering these finer ground details and realities and arrive at a final route location. Thus the results of this study help immensely in reducing the numerous options for the design and the execution team in route selection.

The results of this study demonstrate the benefits of GIS serving as a decision support system for power transmission line routing.

RECOMMENDATIONS

A review of these results needs to be scrutinized to uncover weaknesses and potential flaws.

More case studies need to be done to assess applicability.

The models results are only as good as the data used. If an important data type to be used in the analysis misses or is incomplete then the result will be misleading. If errors are introduced into the analysis, the output will be erroneous too.

Methods also need to be developed to eliminate sharp angles from the least cost pathway which occur at the boundaries of feature classes with different suitabilities to make the determined route more realistic.

Sensibility analysis of the weights applied needs to be carried out in order to assess the effects on output.

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