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GIS Analysis and Spatial Modelling for Optimal Oil Pipeline Route Location: A Case Study of Proposed Isiolo Nakuru Pipeline Route

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Abstract: ***Large reserves of commercially viable oil have been discovered in Turkana Kenya. In order to accrue benefits sustainably, optimize supply, and satisfy oil demands in the region, there is a need for an optimal oil pipeline distribution system that strikes a balance among environmental, engineering, technical and social factors. Using Isiolo and Nakuru town as start and end nodes, this study utilized spatial modeling and Geospatial Information System (GIS) analysis to come up with an optimal oil pipeline route. This involved deriving weights for the variables using Analytical Hierarchy Process (AHP) and modeling the routing process using them. A model was developed incorporating pipeline length, topography, geology, soil types, populated areas, game parks, forests, rivers, wetlands, roads, ground water points, rail-line and roads to identify an optimal route. GIS was used for spatial modeling, analysis and data overlay. The variables were weighted using AHP to determine their relative preferences. This was achieved by running questionnaires to various stake holders and experts and professionals. The output for weighting showed high levels of preference given to environmental factors, followed by social factors and engineering factors having least preference. The mean of the weights resulted to the optimal route. The route proposed by the engineers was the best alternative identified by use of standard deviation. The optimal route realized savings by avoiding higher cost environmental and populated centers cells. The results of this analysis demonstrated the benefits of integrating various data sources with GIS analysis as a first look for pipeline routing. The benefits of combining GIS and AHP as a decision support system for the oil pipeline routing process was depicted. This can be applied in routing of other linear structures in Kenya.***

Keywords: AHP, GIS, Modeling, Pipeline Route Selection.

1. Introduction

The world's demand for oil has overtaken its supply, Kenya being inclusive. Turkana in Kenya holds large quantities of oil. Alongside the discovered oil, tests have been continually carried out to the oil reserves to establish commercial viability [1].

The Kenyan government plans to satisfy oil demand in Kenya through products processed at a refinery to be put up in Isiolo town [2]. Several options have been suggested on where to refine the oil and the means of transportation. This research explored one of the options; constructing a pipeline from Isiolo to Nakuru town.

Pipelines are needed to transport the oil for refining and distribution over long distances to meet the demand. They are the most efficient, cost effective and environmentally friendly means of fluid transport [3]. The evaluation of the best route is a complex multicriteria problem with conflicting objectives that need balancing. This research used spatial modelling and GIS analysis to derive an optimal route together with deriving a weighting criterion using AHP and modeling using the derived weightages.

Routing a pipeline is an important task thus proper planning is essential in-order to maximize the benefits derivable from the use of pipelines. With the scientific planning of a route, cost, time, and operating expenses can be saved, ensuring longer operational life and minimizing environmental fallouts [3]. The use of pipelines reduces the probability of oil spillage and eases traffic congestion due to road transport.

The inefficient and traditional methods of optimal routing in pipelines are mainly based on expensive and protracted methods. These methods utilize static paper maps which are huge and bulky, furthermore, they are not precise and the role of all effective parameters in pipeline routings cannot be easily considered. Technical, economic and environmental concerns are not observed in designed paths as a result of these outdated methods. GIS tools bring new approaches to routing enabling all factors affecting the route be considered and weighted under one umbrella. GIS includes scientific tools that enable the integration of data from different sources into a centralized database from which the data is modeled and analyzed. GIS-based tools and processes addresses the challenges of optimizing routes based on the collection, processing and analysis of spatial data. It's an approach routing that is systematic and effective.

The GIS approach to pipeline routing optimization is based on relative rankings and weights assigned to project specific factors that affect the potential route. This results to an optimal path between the start and the destination point [4]. The factors influencing pipeline route selection are technical and engineering requirements, environmental considerations, and population density [5].

2. Route Selection

A. Case studies

During the last decade, a few attempts have been made to automate the route planning process using GIS technology and the methodology is still at an exploratory stage. Studies in this line include; a study done by Saha concluded that computer-assisted methodology of route planning is fast in comparison with the conventional manual practice. [6]. A study done in the Caspian Sea, the least-cost path derived was 21% longer than the straight-line path between the source and destination, but it led to a reduction in construction costs by 14% [5].

A research to come up with an optimal oil pipeline route in Malaysia using GIS demonstrated the integration of GIS and Multi-criteria decision Analysis in oil pipeline route selection [3]. A prototype of least cost pipeline routing was performed in south west of Iran with the resultant pipeline longer in length but 29% cheaper than the existing pipeline path [7].

B. Key Routing factors

The pipeline route should be routed away from the populated and settlements areas for the public safety in case of an accident [5]. Oil leakage can cause contamination of underground water supplies and water bodies, thus minimizing crossing water bodies [8]. The engineering factors; include, topography, geology, soils, road, and railroad crossings. Different classes and its subclasses pose different hardships [9].

Utilizing existing linear disturbances reduces environmental hazards and minimizes construction cost associated with clearing of vegetation. To estimate the number of landowners for compensation, a catalog of land owners will be needed. The impacts of the route on the environment have to be considered, justified and approved by regulators and the general public through consultation [10]. Environmental Impact Assessment studies should be carried to compliment the studies [11]. Land use land cover need consideration.

C. Weighting

The various variables under consideration are not equally weighted, ranking each variable in order of importance is required. Examination of relevant literature, analytical study, and experts' opinions are the three most commonly used systems to develop evaluation criteria for any given project [3].

The technique of weight allocation, combination of many different factors to create a suitable average adverse score grid, incorporation of the differing weighting scenarios and differing points of view in the routing are not well supported in commercial GIS packages. [12].

The critical issue in the GIS methodology is assigning the weights to the factors. In this study the AHP that involves making alternatives by developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria was used. In AHP, one constructs hierarchies, then makes judgments on pairs of elements to obtain weights. The weights are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value [13].

3. Methodology

The starting point for the route was Isiolo town while the end point was the oil deport in Nakuru. The study area covered between 0°51'N and 1°7'S and between 38°36'E and 35°18'E.

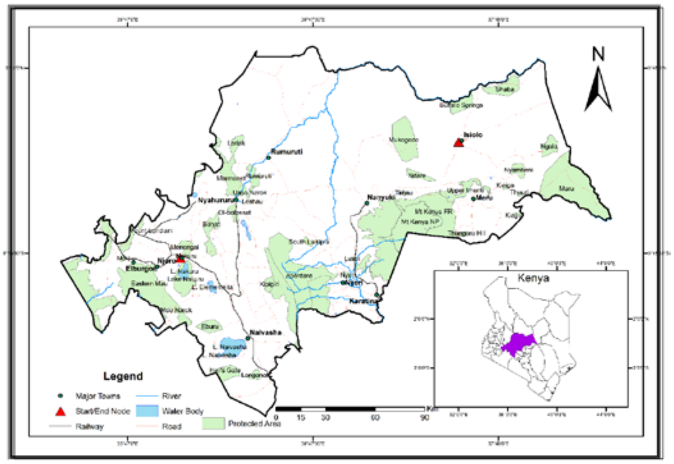

Figure 1: Location of the study area

D. Datasets

Various data sets were used to map and carry out analysis on the study area. They included roads, railway, forest, gamepark and reserves, administrative boundaries and soils all in shape file format obtained from NEMA (National Environmental Management Authority), geology, bare land, agricultural land, lakes, underground water points, settlements and wetlands all in shape file from ILRI (International Livestock Research Institute), towns in shape file from Virtual Kenya and DEM (Digital Elevation Model) from NASA website. The approach used for the routing process in this research is summarized in Fig. 2.

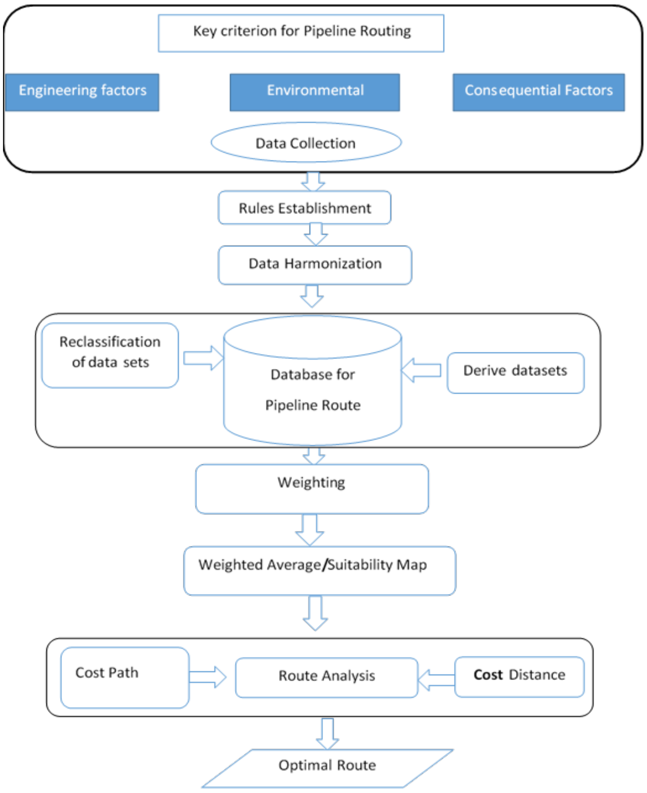

Figure 2: Study Methodology

The first step involved the selection of spatial and nonspatial factors affecting the pipeline route; engineering, environmental and social factors. The rules that were established were: minimize crossing; rivers, wetlands, roads, railway agricultural land, forest, game parks/reserves, ground water points and lakes. Maximize on low lying areas and bare land, avoid hard rocks and clay soils. Routing near roads and avoiding the settlements.

Harmonization involved cleaning data for errors and coordinate systems transformation. Datasets were rasterized except the raster DEM. Datasets deriving, involved deriving slope from the DEM, deriving distance from roads, railways, ground water sites, settlements and rivers using Euclidean distance. The derived data sets were combined to create a suitability map. This was done by setting all the data sets to a common measurement scale, from 1 to 9 unit that determined how suitable a particular cell was suitable for pipeline route location. Lower values indicated more suitable areas. Reclassification was done to reassign each pixel of the derived dataset a new value that tallied with its contributory effect to the routing. Using AHP variables were compared one against the other by experts and professionals. A matrix was formed, CR calculated. If the CR was acceptable weights were calculated, otherwise, a new process was initiated. In this study a consistency ratio of 0.5 or less was considered acceptable. After the feature layers ranking they were combined into one layer based on weights that the basis of GIS analytical work. The suitability map was used to create an overall Discrete Cost Surface that identified the relative cost of locating a route at any location. The Cost Path tool was used to determine the least-cost path from Nakuru to Isiolo town.

4. Results

Give the results of analyzing questionnaires for each category of experts.

Table 1: Grouped weights

Variable	Eng.	Geo	CoA	HC	Envi	Oil	Mean
GWP	11	17	10	13	15	11	12.7
Settlements Proximity	14	6	20	13	8	12	12
Wetlands /Lakes	12	16	8	8	17	5	11.1
Agricultural Land	10	7	16	9	9	10	10.2
GP/R/F	14	14	9	8	9	5	9.6
River Crossing	10	12	8	7	7	7	8.6
Slope	9	6	3	10	8	9	7.7
Geology	5	4	2	10	7	10	6.1
Soil Type	3	5	8	6	7	5	5.5
Bare Land	3	2	1	2	3	16	4.6
Rail Crossing	4	4	5	6	3	5	4.5
Road Proximity	3	3	7	3	4	3	3.9
Road Crossing	4	3	4	6	4	3	3.8
Standard Deviation	1.8	3.2	3.7	1.9	2.3	4.1	

All quantities are in percentages
GWP = ground water points, GP/R/F = Game park/ Reserves/ forests, Eng. = Engineers; Geo = Geoscientists, CoA = County Administrators, HC = Host Community, Envi = Environmentalists, Oil = Oil and Pipeline Industry.

The mean of the six categories formed the final weights used. Environmental factors were the highest rated together with consequential factors. Slope, geology and soil types were the engineering factors that had the largest effect. Road and rail crossing, road proximity and bare land had a small effect. The standard deviation indicated that engineer's route was the most similar to the optimal route.

In a sample of 32 respondents, the overall CR was 72. The engineers and host communities were 100% consistent while geoscientists, county administrators, environmentalist and oil/pipeline experts were 80%, 75%, 50% and 40% consistent respectively.

The slope was reclassified into nine classes, 9 was assigned to least suitable area (mountainous), and 1 to the most suitable. Distance to settlements was similarly reclassified, a value of 9 assigned to areas near settlements. The same was done to distance to ground water points. The distance from roads was reclassified into nine categories with 1 showing the most suitable locations near roads.

Four soil types were encountered; very clayey was the most unsuitable with a value of 5-with sand being the most favorable with a value of 2. Four rock types were traversed, metamorphic was assigned a value of 3 while igneous 1 and sedimentary 2. The variables that didn't have a variation were reclassified values informed from literature. From the resultant map, pixels values showed that there was no best areas nor worst areas to route. Seven routes were generated based on the different experts with the seventh one the optimal. The optimal route and the suitability layer are in figure 3. The results of comparisons of the routes is given in Table 2.

Table 2: Routes Comparison

Variable	Optimal	HC	Envi	Oil	Eng.	Geo	CoA
Length	194	194.8	195.7	193.8	194.7	196.1	194
Wetlands C.	1	1	1	1	1	1	1
Rivers C.	15	14	4	16	14	14	114
Roads C.	43	50	43	51	44	60	62
Rail line C.	2	2	2	2	2	2	2
Settlements within 100m	3	1	1	1	0	2	2
AA C.	400.5	387.3	466	424.8	357.6	451.3	448
GWP within 250m	0	1	0	0	0	0	0
Forest Area C.	123.4	127.9	96	191.5	108.5	110.9	214.6

Length in Kilometers, Area in Hectares, Areas taken with a 25 meter Buffer

GWP = ground water points, C. Crossed, AA = Agricultural Area, Eng. = Engineers; Geo = Geoscientists, CoA = County Administrators, HC = Host Community, Envi = Environmentalists, Oil = Oil and Pipeline Industry.

Within a 25m buffer, the geology area covered by the routes indicated that optimal route was the third best in terms traversing soft rocks. Similarly in terms of soil type's coverage, optimal route was the second best in traversing sand soils rather than clay soil.

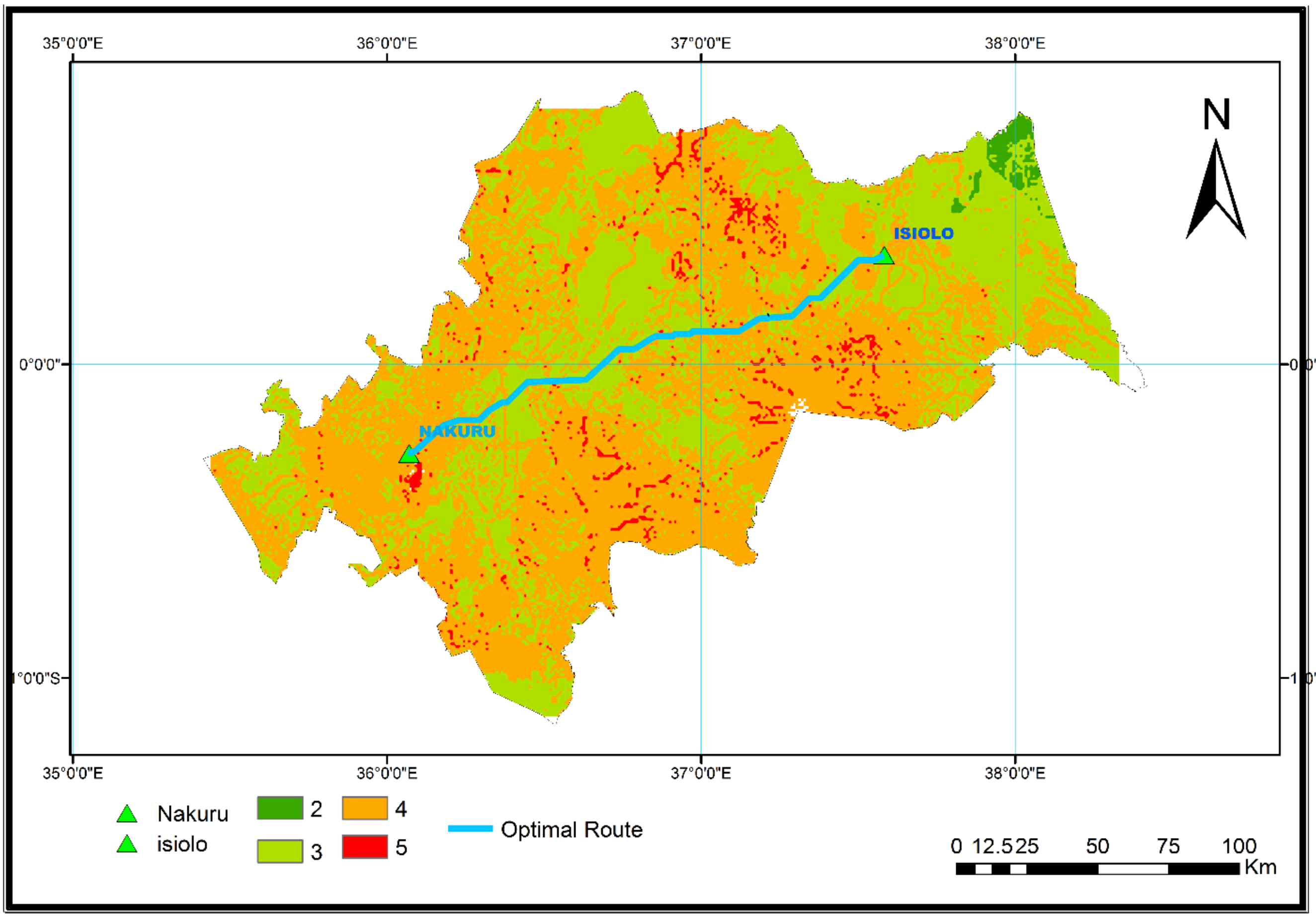

Figure 3: A Map of the suitability layer and the Optimal Route

5. Conclusion

An optimal oil pipeline route was generated using GIS analysis and spatial modelling incorporating multicriteria decision with environmental, engineering, technical and social factors being the key criteria. The model developed incorporated 13 variables. The results of weighting showed very high preference for ground water sites, agriculture land, rivers, settlements and game parks/reserves and or forests. Slope, geology and soil types were the engineering factors that are hard to navigate. Bare land, rail crossing, roads proximity and road crossing ranged were weighted low. There were high standard deviations observed from respondents within the same category. The CR used was 0.5 as opposed to the conventional 0.1, due to the high number of variables and lack of clear criteria on what CR should be used for how many variables. The route profile generated had a peak of 2780 and the lowest with about 1110 msl as opposed to the highest point in the study area with 5000msl, a reduction in elevation given the weight.

Results from weights indicated the importance environment conservation and protection of human life pipeline routing while engineering factors can be navigated using technology. The optimal route was generated using the mean weights and by use of standard deviation alternatives were given. The suitability layer indicated the study area was a fair routing area. The model developed can be used for modelling different types of linear structures in Kenya. This study presented the dynamics in pipeline routing and demonstrated the interrelationship among engineering, environmental and social factors in routing a pipeline.

Several ground realities that affect the route were not considered, they can be ascertained after a ground survey. Adoption of GIS techniques for routing of linear structures in Kenya, considering land ownership and developing an independent interface for non GIS professionals can be taken up to utilize the findings of this research and further them .

References

[1] E. Onyango. (2013, March, 26th) “Kenya strikes oil in Turkana,” Business Daily Newspaper, [Online]. Available: http://www.nation.co.ke/business/.

[2] A. Odhiambo. (2012, August, 12th) “Kenya plans pipeline to Arusha after oil discovery,” Business Daily newspaper, [Online]. Available: http://www.businessdailyafrica.com/.

[3] A. Balogun, A. Matori, D. U. Lawal, and I. Chandio, “Optimal Oil Pipeline Route Selection using GIS : Community Participation in Weight derivation and Disaster Mitigation,” *in proc International Conference on Future Environment and Energy 2012*, vol. 28, pp. 100–104.

[4] G. Henley and H. Dresp. 2012, “Pipeline Route Selection Process,” [Online]. Available: wiki.iploca.com/display/rtswiki/Appendix+5.1.1.

[5] S. C. Feldman, R. E. Pelletier, E. Waker, J. C. Smoot, and D. Ahl, “A Prototype for Pipeline Routing Using Remotely Sensed Data and Geographic Information System Analysis,” 1995, vol. 4257, no. 95.

[6] A. K. Saha, M. K. Arora, R. P. Gupta, and M. L. Virdi, “GIS based route planning in landslide prone areas,” in *International Journal of Geographical GIS 2005*, vol. 19, no. 10, pp. 1149–1175.

[7] M. R. Delavar and F. Naghibi, “Pipeline Routing Using Geospatial Information System Analysis,” 2003 [Online]. Available: www.scangis.org/scangis2003/papers/12.

[8] P. G. Fookes, E. M. Lee, and M. Sweeney, “Geological Society, London, Engineering Geology Special Publications Pipeline route selection and ground characterization, Algeria” 2013.

[9] J. Berry, M. King, and C. Lopez, “A Web-based Application for Identifying and Evaluating Alternative Pipeline Routes and Corridors,” *GITA Oil and Gas Conference*, 2004, pp. 1–8.

[10] B. Anifowose, D. M. Lawler, D. Van Der Horst, and L. Chapman, “Attacks on oil transport pipelines in Nigeria : A quantitative exploration and possible explanation of observed patterns,” *Applied Geography* 2012, vol. 32, no. 2, pp. 636–651.

[11] P. Taylor, T. Van Hinte, T. I. Gunton, and J. C. Day, “Evaluation of the assessment process for major projects: a case study of oil and gas pipelines in Canada,” *Impact Assessment and Project Appraisal* 2007, vol. 25, no. 2, pp. 123–137.

[12] Y. Choi, H. D. Park, C. Sunwoo, and C. Keith, “Multi criteria evaluation and least cost path analysis for optimal haulage routing of dump trucks in large scale open pit mines,” in *International Journal of Geographical Information Science* 2009, vol. 23, no. 12, pp. 1541–1567.

[13] K. S. Suresh and C. N. Nonis, “Investigation of an AHP based Multi Criteria Weighting Scheme for GIS Routing of Cross Country Pipeline Poject,” in *24th International Symposium on Automation & Robotics in Construction, 2007*.