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GIS Modelling for Optimal Alignment Selection: A Case Study of Karputar to Yamdi Section, Midhill Highway

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Abstract
Selection of highway alignment involves a number of technical issue, economic issues, environmental issues, interest groups, and agendas that are frequently observed during road alignment selection. This research work considers slope, aspect, geology, land cover, conservation area, existing roads, drainage order, land use such as agricultural land, settlement area, water or stream bodies as governing criteria for alignment selection which are further divided into three themes i.e. Technical, Economical and Environmental. Weightage assigned to the criteria map is based on expert questionnaire survey and is derived from Analytical Hierarchy Process (AHP). Search for the optimality of alignment is from the Least Cost Path Analysis (LCPA) using Geographic Information System (GIS) application. The shortest route connecting two points Karaputar and Yamdi is obtained when Technical theme is preferred.

Keywords
Alignment, Analytical Hierarchy Process , Least Cost Path, Geographical Information System

1. Introduction

1.1 Background

Highway Alignment selection process is highly complicated. When choosing a route for a highway, the physical components of the location and how these features connect to the geometric design constraints are the factors to be considered. Physical elements that influence route selection include topography, ground (soil) features, and nearby land use. At the planning stages of a highway development process a number of candidate highway alignments are explored. The traditional method of highway alignment is time-consuming and involves a lot of physical labor and a sophisticated process to account criteria associated with alignment selection principle while computerized highway optimization models can seek optimized horizontal and vertical alignments by minimizing aspects of total highway cost, selection of the final alignments is often influenced by environmental impact assessment and public and political participation [1].

This research presents an integration of Analytical Hierarchy Process (AHP) into GIS and develop the model to select the suitable alignment from Karputar to Yamdi which is a section of Mid hill highway. Mid-Hill highway project is the national pride project that runs from East to West across the central of country through 24 districts and 215 villages and serves nearly 7 million populations. Starting from Chiyobhangyang, Panchthhar in East it ends at Jhulaghat, Baitadi in Far West. This project was initiated in 2008 A.D with approximate length of 1776 km [2]. There are incremental benefits and costs to several economic means: government, private sectors, passengers, general publics and labors. Currently, this project is facing alignment selection problem in some of its section and Karputar – Yamdi section, the selected study area for this research is one of that kind.

1.2 Need of Research

Being a National Pride project Mid Hill highway is facing problem of alignment selection at Karputar-Yamdi section. In this section there even exists a contradictions within governmental authorities regarding the connecting points of this highway section i.e. Department of Roads has proposed the connecting points of alignment to be Karaputar-Bhagawatitar-Kahun-Bhalam-Lamachaur-Yamdi, Gandaki Province has proposed the connecting points to be Bhaise-Yambot-Mohoriya-Aantighar-Armala-Amalabisauni-Yamdi and Madi Rural Municipality's proposal regarding connecting points is Rudikhola-Bhaise- Sajha Betani-Jyamdu-Melbot-Panighat-Mauja-Bhalam-Lamachaur- Tallo Hemja. . In addition section passes through Pokhara Valley and high compensation of land and houses are expected if alignment is not well selected. This study area even comprises of Annapurna Conservation Area, Lakes and Agricultural lands that results in higher complexities from environmental and construction viewpoint. Construction costs are likely to be high if the search for optimality of alignment is ignored.

1.3 Research Objectives

The major objective of this research is to generate optimal alignment with respect to economic, environmental and social characteristics of study area. The specific objective is to perform least cost path analysis and find the shortest route.

1.4 Limitations

1. Rock map, existing roads map and conservation area map available were on vector format.
2. Soil map available was of resolution 250 m.
3. Traffic data and crash analysis are not considered on this research.
4. User costs are not considered for analysis.

2. Literature Review

2.1 Highway Alignment Optimization

For New Highway planning for connecting two cities i.e. Haridwar and Roorkie in Uttarakhand state of India, GIS technique was used. Landuse map, slope map, Aspect Map, Soil Map, Geology Map, Drainage map of the study area were considered as governing parameters. Assigning scales to subunits was done in such a way that avoids built up areas, forest, wet land, higher order drainage and preferring barren land, alluvial dun gravel. Cumulative weight map that works on the principle of spread algorithm were prepared and finally shortest path from source to destination was plotted with weighted cost distance function and direction function in Spatial Analyst Module of ArcGIS [3].

Thirteen (13) criteria maps were classified into three criteria groups (themes) as follows, in order to generate optimal alignment based on these themes i.e. Economic, Environmental and Social.Based on the preference of theme fifty percentage weightage was assigned to the main theme and twenty five percentage weightage each was assigned to the other themes. MCE approach used in the research as an integrated part of an Environmental Impact Assessment (EIA), was successful on finding the optimal by-pass alignments running through the Tlokweng Planning area in Botswana [4].

Highway link connecting three cities El Shatt, Nekhel and Taba of Egypt was modelled with GIS technique. Cost assignment to the criteria used was such that [5].

1. Mild slope was given low cost.
2. Stable track bed rocks were given low cost.
3. Buffer area of 200m on the fault line was given high cost.
4. Bare desert was given low cost and sand dune was given high cost.
5. Protected area crossing was given high cost.
6. Buffer area of 500m around archaeological site was assigned high cost.

2.2 Least Cost Path Method

Highway alignment connecting Kura town with Gude of Kabo local government area. Slope map and soil map was considered under Technical Theme and Land Use/ Land Cover (LULC) Map only was used as Environmental theme. The grid size of raster map used was of 30m resolution. Two optimal alignment of their respective theme and one additional one from hybrid theme was generated from Least Cost Path Analysis (LCPA). LCPA model was found to be successful on avoiding high slopes, expensive areas, ecologically important zones and fulfilling the overall objectives within the limitation of provided data and criteria [6].

Combination of GIS and MCE in for identifying various route alternatives that link two points of Naini and Jhunsi, two location of outer area of Allahabad city a Least Cost Path Analysis (LCPA) was performed. LCPA was found to be successful in avoiding drainages, religious places, high slopes, minimum road intersection and minimum land use area thus satisfying the optimality condition [7].

Least Cost Path model applied for generation of highway alternatives for linking Taba city, Nekhel and El Shatt was observed passing through gentle slopes and avoiding fault lines, sand dunes and zone of archeological values [5] as shown in fig. 1.

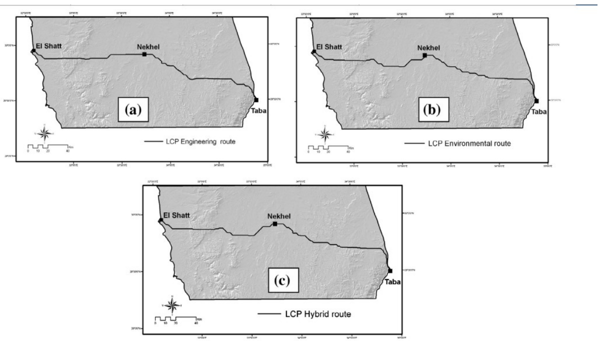

Figure 1: Least Cost Path Alignment from El Shatt-Nekhel-Taba for Engineering, Environmental and Hybrid Route [5]

Slope, Stream Order, Landslide were selected as criteria map for Technical theme, Landcover, Aspect and Protected Areas were selected as criteria maps for Environmental Theme and A hybrid theme proving equal weightage to technical theme and environmental theme was produced. Weightage of criteria under their respective theme was considered equal to generate alignments from the least cost path analysis for connecting two obligatory point of Dupcheshwor Rural Municipality, Nuwakot. Route generated considering all the criteria maps (i.e. from Hybrid Theme) was found to be optimal [8].

2.3 Analytical Hierarchy Process

For Road Network Planning for suitable urban development in Kirtipur Municipality, criteria maps used were Slope, Land Use/Land Cover, Lithology, Existing Roads, Water Bodies and distance from settlement. Weightage to these criteria map was provided on the basis of expert's judgment and validated from AHP for generation of alignment Alternative-1 which was observed to have lesser length, suitable gradient with accessibility, low construction cost and bridge requirement than the proposed road alternative 2 and Road alternative 3 generated with variation of weightage of criteria map [9].

Parameters i.e. Landuse Map, Drainage Order map, Lithology map, Soil Map, Aspect map and Slope map of Uttarakhand Area were assigned weightage based on five (5) different map. The methods used were rank exponent, ratio estimation method, Rank Reciprocal Method, Rank Sum Method, Analytical Hierarchy (AHP) Method. Five highway routes on the study area were generated based on the weightage derived from these methods. The optimum route considered was based in the basis if distance, time and partly to cost comparison (i.e. length of alignment, number of cross drainage structures required, connectivity to habitats and tourist places) and the alignment based on AHP weightage was found to be the best than the alignment produced from other methods [3].

3. Research Methodology

Different criteria maps showing the features of the study area were collected from primary and secondary sources. They are re-classified for the ease of comparison and weights to each criteria map were assigned through Analytical Hierarchy Process (AHP) based on the expert questionnaire survey. Each theme map was generated from the weightage determined and preference theme map was generated providing fifty percentage weightage to the preferred theme and twenty five percentage weightage to each of the remaining two theme map. The preferred theme map, thus generated, undergo cost distance overlay, directional overlay based on the source raster cell and finally Least Cost Path is plotted from the Spatial Analyst tool built in on ArcGIS. On similar fashion other alignment for rest of the preferred themes were generated and Multi-Criteria Analysis of the Alignment was done for ranking these alignments. Flowchart of the methodology is as shown in fig. 2.

3.1 Study Area

The study area lies on lesser Himalayan region in Gandaki Province . It passes through two district namely Lamjung at the east and Kaski at the west. Madhya Nepal municipality, Madi Rural Municipality and Pokhara Metropolitan city are the local level governing body extending the study area. Number of the small dispersed villages and deciduous forest are found to the north and dense settlement to the south in Pokhara valley. Major hydrology of this region is the catchment area of Begnas Lake, Seti Gandaki, Bijaypur river and Madi River.

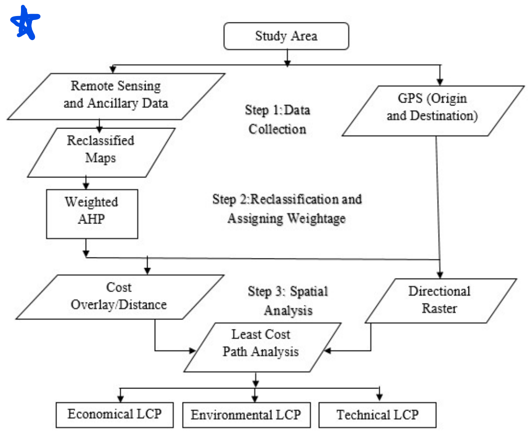

Figure 2: Flowchart of Methodology

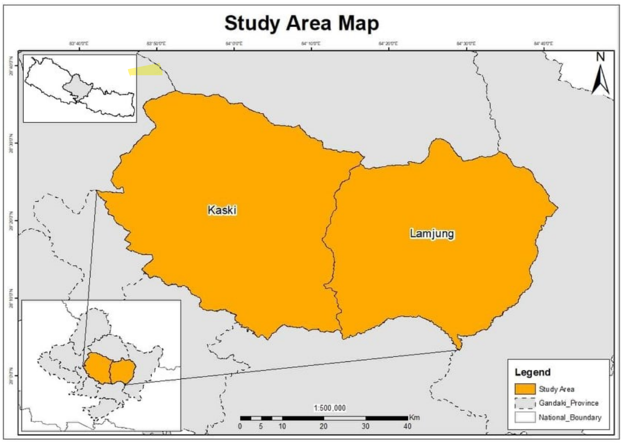

Figure 3: Map of Study Area

3.2 Data Collection

Remote sensing data are collected from USGS, sentinal-2 image and Copernicus. Ancillary data are collected from survey department, soilgrids.org and NAST. And finally origin and destination co-ordinates were recorded from the field visit. Slope map and aspect map were prepared from remote sensing data. Land Use Land Cover(LULC) map, soil map, existing roads, drainage map, conservation map, geological map, protectorate map, archaeological map were ancillary data. Origin and destination raster data were taken from field observation.

3.3 Criteria Definition and Standardization

Rock types, soil, slope and aspect criteria are categorized under technical theme, drainage, land cover and existing roads are classified under economical theme and proximity to stream and water bodies, conservation area and human settlement area is categorized under Environmental theme. The

Table 1: Comparison Scale for AHP rating.

AHP Scale of Importance for pairwise comparison	Numeric Rating	Reciprocal
Extreme Importance	9	1/9
Very strong to extremely	8	1/8
Very strong Importance	7	1/7
Strongly to very strong	6	1/6
Strong Importance	5	1/5
Moderately to Strong	4	1/4
Moderate Importance	3	1/3
Equally to Moderately	2	1/2
Equal Importance	1	1

measuring units are made uniform through the standardization technique, and the scores lose their dimension along with their measurement unit. ArcGIS geoprocessing tool" Reclassify" is used. Numeric scale value with varying scale range taken from Literature review and expert opinions are further normalized to the common scale range between 0-1 using the equation 1 [10].

$$NV = \frac{CV - Min.Value}{Max.Value - Min.Value} \tag{1}$$

Where,
NV= Normalized Value
CV= Cell Value / Pixel value of that particular cell
Maximum Value= Maximum pixel value on selected raster
Minimum. Value = Minimum cell value on selected raster.

3.4 Analytical Hierarchy Process

AHP provides a structural basis for quantifying the comparison of decision elements and criteria in a pairwise fashion. This kind of comparison greatly reduces complexity and enhances the simplicity of decision making. AHP was originally developed by (Saaty, 1980) and relative rating of two criteria's are measured in the scale of 1 to 9 as shown in Table 1.

The AHP aids in capturing both subjective and objective components of a decision making. The weights for each criterion is calculated from comparative matrix of criteria. Consistency Index is then calculated, and if it falls within a 10% threshold weight range, calculated weight is acceptable. Flowchart for carrying out AHP is as shown in fig. 4.

The calculation of weightage from AHP is done with the aid of AHP Excel template with multiple inputs prepared for windows operating system for Microsoft Excel version of 2013. This template can judge maximum ten criteria and twenty respondents [11].

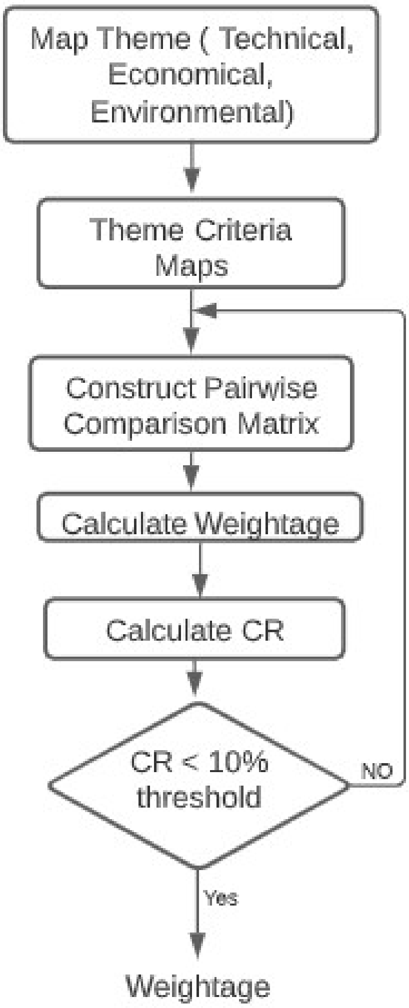

Figure 4: Flow Chart for conducting Analytical Hierarchy Process (AHP)

3.5 Spatial Analysis

The first step in the spatial analysis was the creation of the source and the destination raster of the proposed route. The different maps of the criteria were overlaid base on the weighted influence from the AHP result to give a cost raster overlay. Combined cost surface for preferred theme is created using Weighted Sum geo processing tool by giving 0.5 weightage to preferred theme and 0.25 weightage each to other two themes [4] as in equation 2.

Mathematically,
Prefered Theme Combined Cost

$$Surface = \sum(0.5*PT)+(0.25*NPT1)+(0.25*NPT2) \quad (2)$$

Where,

PT- Preferred Theme Cost Surface
NPT1- First Not preferred Theme Cost Surface
NPT2- Second Not Preferred Theme Cost Surface

Cost Distance Function that is based on Djikstra Algorithm is available in Spatial Analyst Module The function takes the cost raster and calculates a value for each cell in the output cost weighted raster that is the accumulated least cost of getting from that cell to the nearest source. The cost distance raster shows the least accumulated cost of each cell to the nearest source, but it does not decide as which way to go to get there. The direction raster function available in Spatial Analyst Module provide a road map, identifying the route to take from any cell, along the least cost path, back to the nearest source. Least Cost Path Analysis function is then applied to generate alignment. Illustration of calculation of Least Cost Path is shown in fig. 5 .

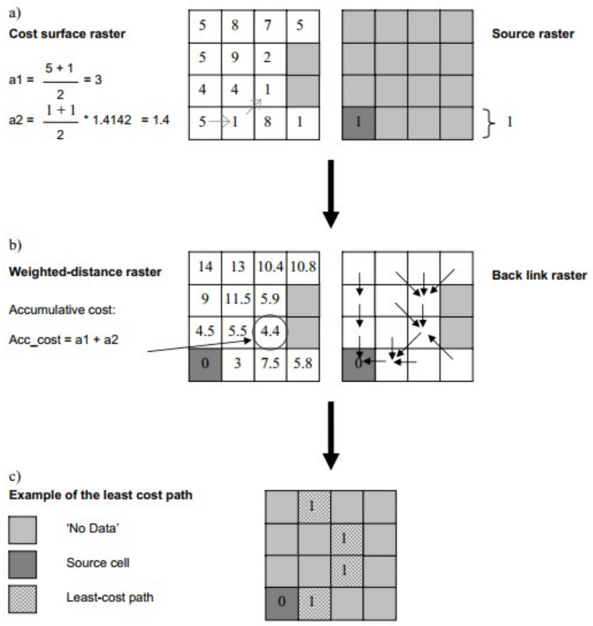

Figure 5: Illustration of Calculating Least Cost Path [12]

4. Analysis and Results

Maps from data collection are further preprocessed to be reclassified on a quantifiable scale for their easy comparison. An assigned least value represents the most preferable choice (least cost) whereas highest value is the least preferable (highest cost). Then weightage for criteria map under their respective theme (engineering, Economical and technical) were

Table 2: Buffer Distance for Stream Order.

Strahler stream order	Distance in buffer tool (m)
1st	3
2nd	6
3rd	12
4th	25
5th	37
6th	50

determined from Analytical Hierarchical Process (AHP). Road network data were buffered to their respective right of way (RoW) as per NRS-2070 and NRRS-2071 and rasterized. Stream orders were buffered and rasterized as per the table 2 [4].

4.1 Reclassification of Map

Different criteria Maps are reclassified to the range accordingly with the table 3 and respective cost is assigned. Reclassification is followed by normalization for further execution.

4.2 Weightage Assignment from AHP

Expert Questionnaire Survey was conducted for assigning weightage of each criteria maps under their respective theme. The consistency ratio of each theme is within 0.1 limit so our calculation satisfies the condition of AHP. Weightage of criteria maps under their umbrella theme is as shown in Table 4, 5 and 6.

4.2.1 Technical Theme

Table 4: Weightage of Criteria under Technical Theme.

Criteria	Weight
Minimize construction through hard and tough rocks	23.10%
Maximize construction through suitable soils	24.50%
Maximize construction through gentle and mild slope	37.40%
Minimize north facing to avoid moist, cold and dampness	15.00%

4.2.2 Economical Theme

Table 5: Weightage of Criteria under Economical Theme.

Criteria	Weight
Minimize destruction of Settlement and Agricultural Land	33.9%
Minimize cross drainage structure construction avoiding higher stream order	27.3%
Maximize upgrading of already existing tracks and roads.	38.8%

Table 3: Cost of Criteria Range.

S.N.	Criteria Maps	Range	Cost
1	Slope [13]	0-3	1
		3-5	2
		5-8	3
		8-10	4
		10-15	5
		15-18	6
		18-20	7
		20-25	8
		>25	9
2	Aspect [3]	North west (292.5-337.5)	2
		West (247.5-292.5)	3
		South West (202.5-247.5)	4
		South(157.5-202.5)	5
		South East (112.5-157.5)	6
		East(67.5-112.5)	7
		North East (22.5-67.5)	8
		North (0-22.5)	9
		North(337.5-360)	1
3	Rock Types	Fluvial Non Calcareous	5
		Gneiss, Migmatite	2
		Quartzite	1
		Slate, Phyllite	4
4	Land Cover [13]	Settlement, Water Bodies and Snow	9
		Agriculture	6
		Natural Vegetation	4
		Barren Land	1
5	Drainage Order [3]	No drainage	0
		First Order	1
		Second Order	2
		Third Order	5
		Fourth Order	6
		Fifth Order	6
		Sixth Order or more	7
6	Existing Road Types [9]	Highway	1
		Feeder Roads	3
		District Roads	5
		Village Roads	7
		No Road	9
7	Proximity to Agricultural Area (Distance in m) [13]	0-100	9
		100-200	6
		200-300	3
		>300	1
8	Proximity to water Bodies (Distance in m) [4]	0-100	5
		100-200	4
		200-350	3
		350-500	2
		>500	1
9	Proximity to Conservation Area (Distance in m)[4]	0-100	5
		100-200	4
		200-300	3
		300-500	2
		>500	1
10	Proximity to Human Settlement [9]	<100	9
		100-300	2
		300-500	5
		500-1000	7
		1000-1500	8
		>1500	9

4.2.3 Environmental Theme

Table 6: Weightage of Criteria under Environmental Theme.

Criteria	Weight
Minimize Proximity to Agricultural Land	20.60%
Minimize Proximity to Stream and Water Bodies	15.1%
Minimize Proximity to Conservation Area	29.5%
Minimize proximity to residential areas.	34.8%

4.3 Weighted Cost Overlay

Thus normalized map is then assigned weightage obtained previously overlaid from AHP using Weighted Overlay function to generate the respective theme map as shown in fig. 6, 7 and 8.

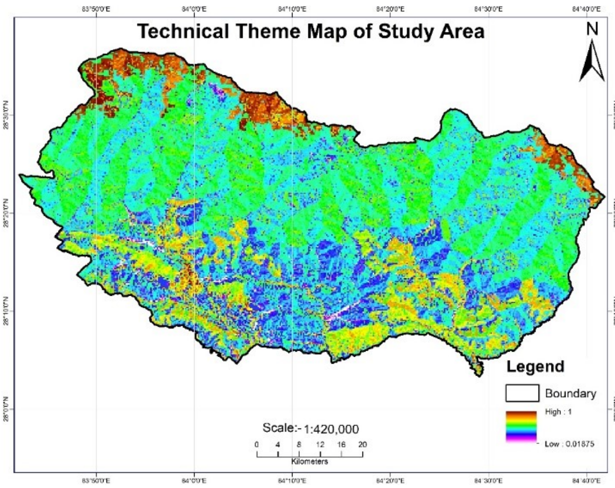

Figure 6: Technical Theme Map.

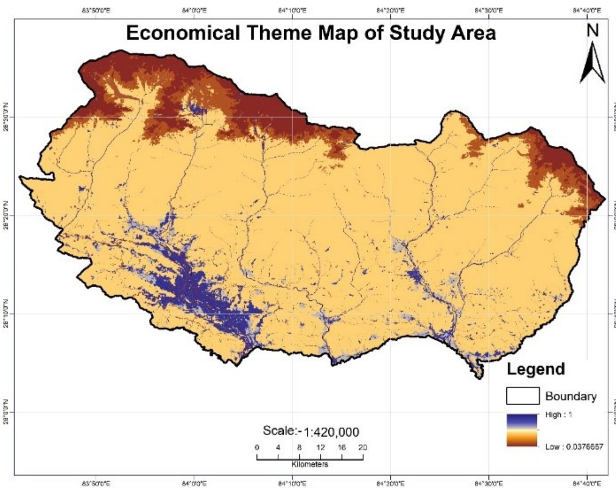

Figure 7: Economical Theme Map.

4.4 Weighted Cost Overlay for Preferred Theme

The fifty percentage weightage is given to the map of preferred theme and twenty five percentage weightage

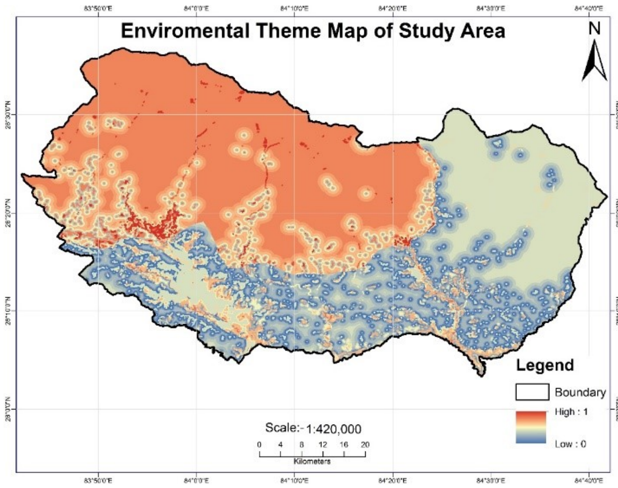

Figure 8: Environmental Theme Map.

each to the remaining two theme. These maps are merged together with weighted overlay tool in ArcGIS to generate the map. This step generates three maps i.e. technical theme preferred map, economical theme preferred map and environmental theme preferred map.

4.5 Cost Distance and Backlink Functions

Cost Distance spatial analyst tool in ArcGIS was used to generate the respective cost distance map for three different theme preference cases as shown in the fig. 9. The directional map of travelling to the source for the three different theme preference cases was prepared using back link raster spatial analyst tool.

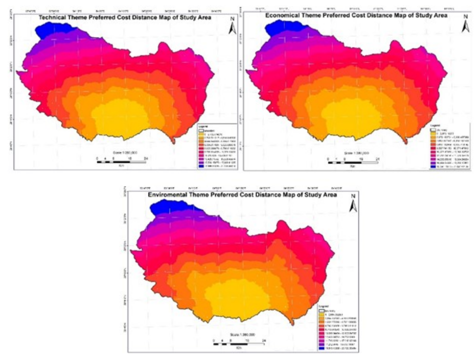

Figure 9: Cost Distance Map of Preferred Themes

Figure 9: Cost Distance Map of Preferred Themes.

4.6 Least Cost Path (LCP) Analysis

Previously prepared cost distance maps and directional raster map for the preferred themes along with the destination raster were used as an input on Least Cost spatial analyst tool for generation of alignment from origin to destination based on the theme preferred. Three (3) alignments of respective preferred theme are shown in the fig.10.

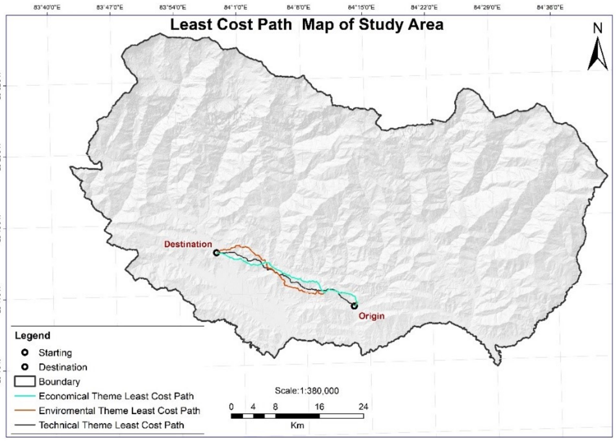

Figure 10: Least Cost Path Alignments.

Conclusion

The purpose of this research work was to develop a model to find out the optimal route from three different prospect under preference. Use of GIS on this regard helps to incorporate ground information for spatial analysis. This study suggested that technical theme when preferred have total roadway length of 32.62 km, economic theme when preferred have the total roadway length of 33.36 km and Environmental theme with the total roadway length of 36.17 km. . Thus, Three (3) optimal alignments were generated from cost surfaces of their respective themes and among those optimal routes, shortest route is obtained from the technical theme under preference.

Recommendations

Further research can be done using other associated criteria maps for the alignment selection procedure. In addition this approach of using GIS and LCP can be used to avoid the vulnerable areas within the study area like landslide areas, swamps, geological discontinuities, flooding areas etc. in the planning stage itself. Best alternatives among the alternative can also be purposed through Multicriteria Analysis (MCA) instead of considering roadway length only as only evaluation criteria. This approach is suitable during early planning stage and further detailed studies and field investigation are suggested before final decision making on alignment selection.

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