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Research Paper

Route alignment planning for a new highway between two cities using Geoinformatics techniques

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ABSTRACT

An attempt has been made to delineate and identify the alignment of a new route between two important cities of north India, Haridwar & Roorkee using Geoinformatics techniques. Geo-engineering parameters like slope, aspect, geology, land use, drainage and soil along with some techno-economical parameters have been used for this purpose. Multi-criteria weight method has been applied. Five weighting methods (AHP - Analytical Hierarchy Process, Rank Sum, Rank Reciprocal, Rank Exponent and Ratio Estimation) were applied simultaneously to eliminate biasness in weight assignment to the input parameters. The results show that AHP method is the best and ratio estimation method is the second best method for identification of optimum route alignment. Few more parameters were used for final selection of optimum route viz., minimum construction cost; minimum number of bridges and culverts on that route; maximum number of settlement within 5 km buffers on both sides of route; maximum number of tourist locations like temples, waterfalls, springs etc. within 5 km buffer zone on both side of route. The proposed route between Roorkee and Haridwar towns is only 29.22 km long (includes a 17.10 km long part of the existing road), the new road required is 12.12 km, while the existing longer route between Roorkee and Haridwar is 33 km (instead of 29.22 km). By using multi-criteria weighted methods of route alignment, a length of approximately 3.78 km can be avoided. It was also observed that slope, land use and drainage parameters are more sensitive for route alignment.

1. Introduction

Highways are part of the infrastructure that makes up the spinal cord of modern society. The alignment of a new road route line should be made carefully after proper considerations, as improper alignment may prove to be costlier and may not be able to fulfill the objectives for which the route line was made (Saxena, 2014). The following aspects also require special attention for aligning routes (i) shortest route, construction and maintenance cost minimum (ii) operational expenses minimum (iii) maximum safety and comfort, aesthetic considerations. It is a complicated task to select best route alignment, due to the consideration and analysis of various data sets. In order to achieve the best results, many variables must be taken into consideration. To overcome such deficiencies, the introduction of Geoinformatics (Remote Sensing, Geographic Information Systems (GIS), Global Positioning Systems (GPS) etc.) techniques has made this quite easy. GIS can easily model these variables and data sets, viz. environment, built-up areas, topography and geological variables (Jha and Schonfeld, 2004). Conventional methods i.e., chain surveying, plane table, compass, leveling etc. take lot of time and are more expensive for extraction of surface profile information required for road alignment (Ning et al., 2014). Topographical maps may not provide sufficient information and up-to-date data. To gather such information by ground survey methods within limited time, funds, man power and technical limitations pose a complex situation for surveyors. If the terrain to be analyzed is highly irregular and detailed data are not available, modern techniques and survey aids contribute most significantly during the reconnaissance and feasibility stage of a route alignment. To overcome these difficulties multi criteria based route alignment approach is used in GIS environment. This technique gives more flexibility and strength for choosing the best possible transport route alignment in the terrain. Some of these survey aids are aerial photographs, satellite imageries, digital terrain model (DTM). Aerial photographs are costly and have restricted uses as well as does not exist for some areas. With the availability of satellite images since 1970's, satellite images remain the most impor-

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tant for route alignment studies in developing countries (Subramani and Nanda, 2012). The specialized section of GIS dealing with hilly areas is known as 3D-GIS, which uses DTM and surface representation techniques to view the terrain and perform various calculations, analysis and graphical representation tasks (Agarwal, 2013). The present study explores and demonstrates the potential of GIS for the optimum route delineation and alignment process. The main objective of this study is to find out any other possible alignment to carry out the preliminary survey for delineating an optimal route alignment between Haridwar and Roorkee, so that the route is the shortest and techno-economical.

2. Study area

The aim of this study is the route alignment planning for a new highway between two cities Haridwar and Roorkee in Uttarakhand state of India. The geographical bounds of the study area are latitude 29.766° N to 29.962° N and longitude 78.05° E to 78.16° E. The study area covers approximately 1000 km^2 and is shown in Fig. 1. The climatic regime of Haridwar and Roorkee falls under the semi-arid type, as influenced by the continental winds during major portion of the year. The summer is very hot and winter is very cold.

3. Methodology and data used

The present study attempts the development of an integrated remote sensing and GIS technique to calculate route alignment between Haridwar and Roorkee. Remote sensing data sets have been used to extract information about geologic and terrain features controlling route alignment. Thematic information from various sources has been used to support remote sensing data interpretation. Appropriate tool to converge this large volume of data into same spatial georeference system for integrated analysis and decision support, is provided by GIS. The flow chart for the approach/methodology followed in this study is depicted in Fig. 2.

A general outline of the methodology (steps) followed in this study has been summarized below:

1. Data input.
2. Pre-processing
3. Digital image processing of remote sensing data sets.
4. Processing of ancillary and field data to generate thematic information.
5. Development of the spatial database.
6. Integrated analysis functions.
7. Computation and simulation of route alignment using GIS.

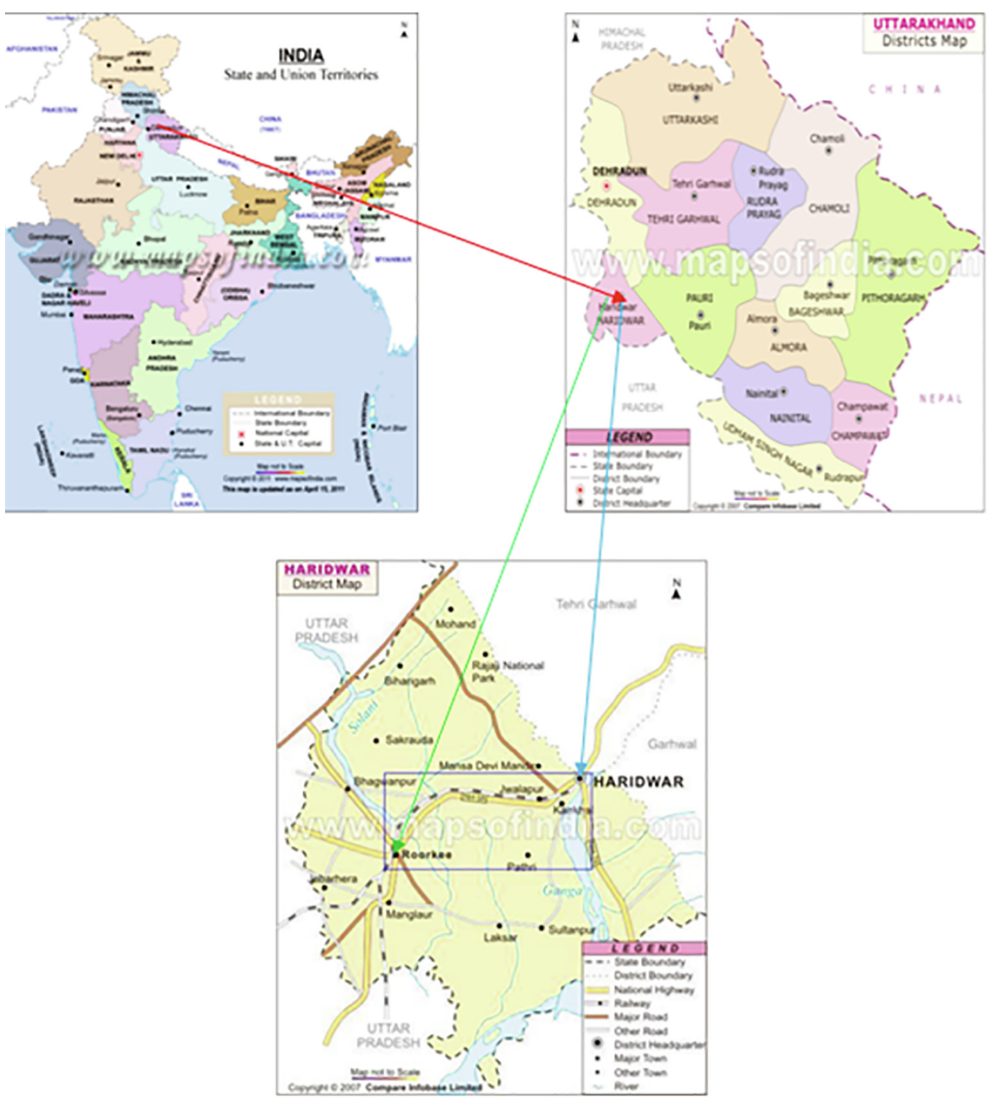

Fig. 1. Location map of study area.

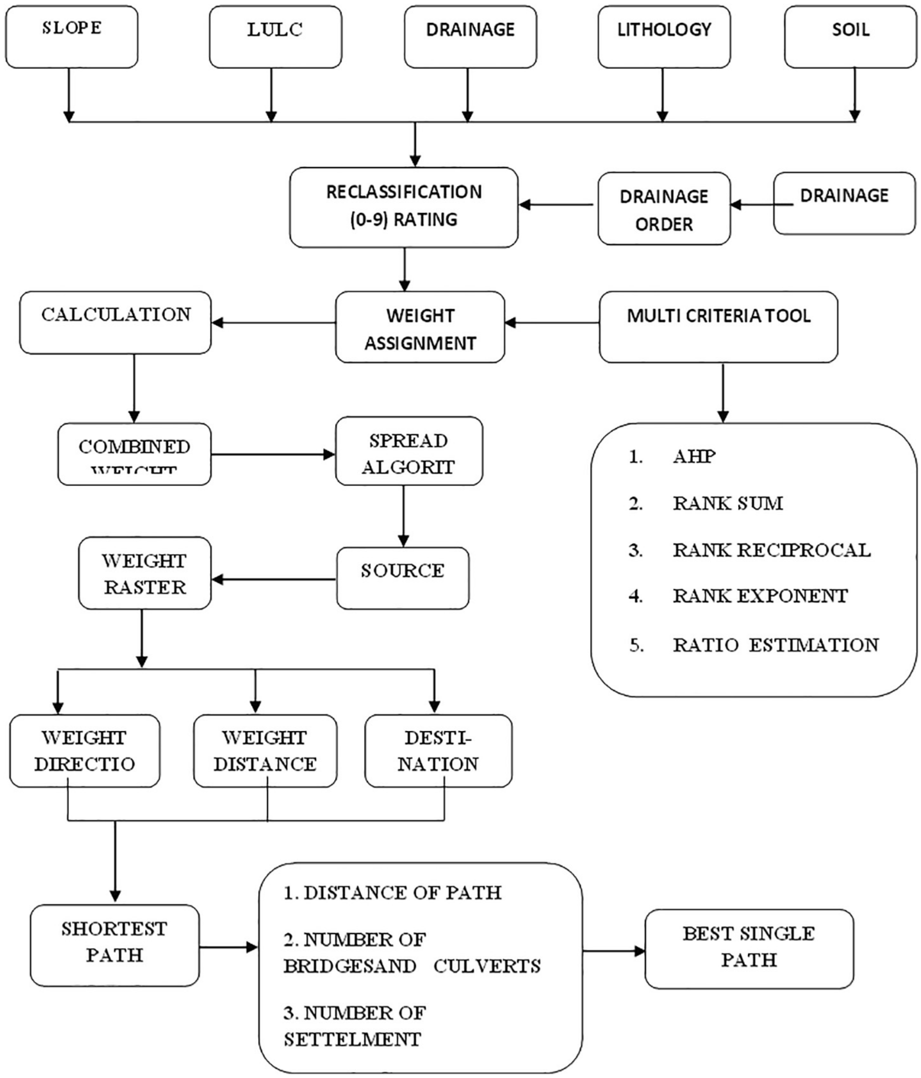

Fig. 2. Flow chart for the overall methodology.

Table 1
Satellite data used for the study.

Satellite	Sensor	Path/Row	Data acquired	Spatial resolution (m)
LANDSAT – 8	Operational Land Imager (OLI)	146/039 (WRS-2 footprints)	26-12-2015	30

8. Virtual GIS.
9. Generation of efficient route as output

Landsat 8 OLI satellite image acquired on 26 December 2015 is used for extracting the ground information in this study. Table 1 shows the characteristics of the satellite data used in the study. Other secondary data like Survey of India (SOI) topographic sheet Nos. 53G/13, 53 K/1 at 1:50,000 scale along with soil map, geology map, population and demographic data also have been used for this study (Table 2). Field data (ground truth data) is also used for training and testing in this study.

Table 2
Ancillary data used for the study.

Data	Data Sources	Scale
Topographical Sheet No. 53G/13, 53 K/1	- Survey of India (SOI)	1:50,000
Maps	- Soil map, NBSSLUP, Nagpur, India - Geology map, Geological Survey of India	1:250,000
Population and Demographic Data	- National Informatics Centre (NIC), Dehradun, India	
Field Data	- From field survey	
IKONOS, QUICKBIRD Satellite Images	www.earth.google.com	

3.1. Thematic data layers preparation

Various terrain/geo-engineering parameters like land use, geology, drainage, slope, aspect have been used for the identification of route alignment for their role in deciding the route. Different thematic layers have been generated for this study in ArcGIS environment.

3.1.1. LULC map

Remote sensing data are used for mapping of land use land cover (LULC) for the study area. Taking into account the spectral characteristics of the satellite images and existing knowledge of land use land cover of the study area, seven LULC categories i.e., road, water body, built up area, forest, river sediments, agricultural land, plantation/manmade forest were respectively identified and derived from satellite image. Maximum likelihood classifier (MLC) is used for the spectral classification of the Landsat images. Overall steps for preparing LULC map from satellite images shown in Fig. 3. The LULC map shown in Fig. 4.

3.1.2. Slope map

The slope map of the region is calculated with the help of digital elevation model (DEM) generated from the Survey of India (SOI) topographic map. Then the slope map has been reclassified. In order to facilitate interpretation and for further use as an input layer in integrated analysis, slope has been classified to 7 classes. The slope map (Fig. 5) suggested that north; west and central parts of the study area show a flat terrain.

3.1.3. Aspect map

Aspect map shows the direction of the slope. The area shows a major two or three trend of slopes. The area shows flatness towards northwest. The regional trend of the slopes is towards westerly direction. In the hilly tracts, local slope direction is in various directions, allowing tributaries from different direction to feed to main channels. Fig. 6 shows aspect map prepared for this study.

3.1.4. Soil map

It consists of three types of soil in the region viz. Tarai soil, Bhabar soil, Young alluvial (Fig. 7). Almost the entire area is covered by ustothents soil. South eastern areas are occupied with palehumults soil while south west areas are occupied with older alluvial soil type.

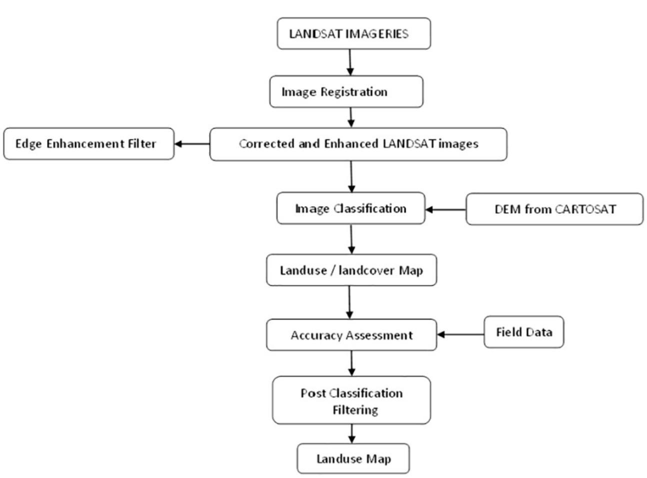

Fig. 3. Methodology for land use land cover map preparation.

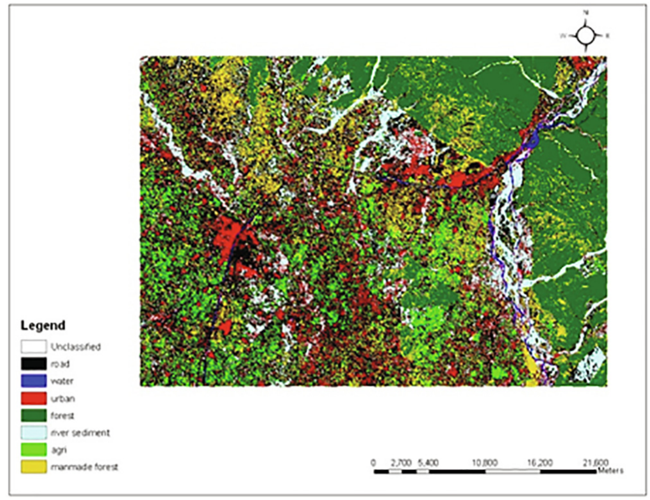

Fig. 4. Land use land cover map of study area.

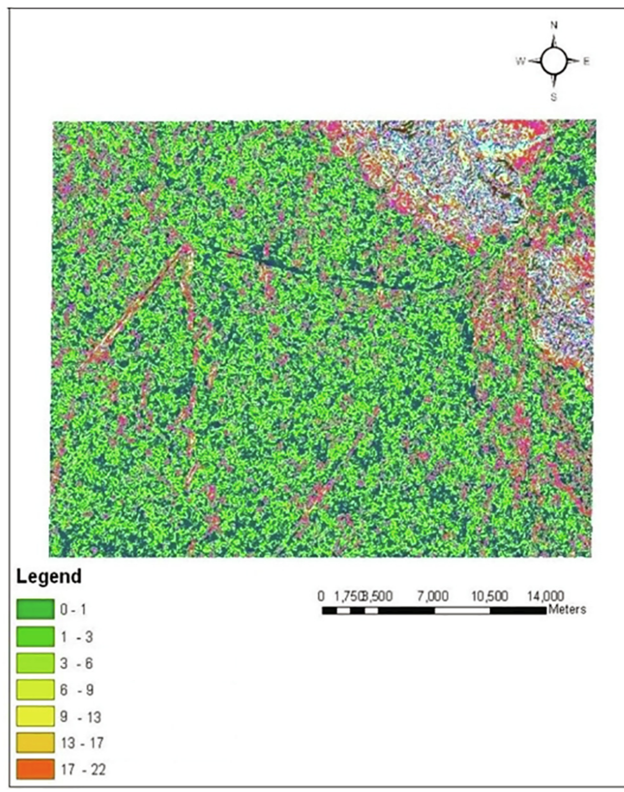

Fig. 5. Slope map of study area.

3.1.5. Geology map

Geological data is very important for identification of alignment of the route, especially in mountainous areas, where ignoring the geology may lead to disruption of route in the form of landslides. The regional geological map has been used as the basic input. The geological map has been digitized and co-registered with respect to other maps. Various lithology like shivalik system, alluvial dun gravel found in the study area have been considered in geology map (Fig. 8).

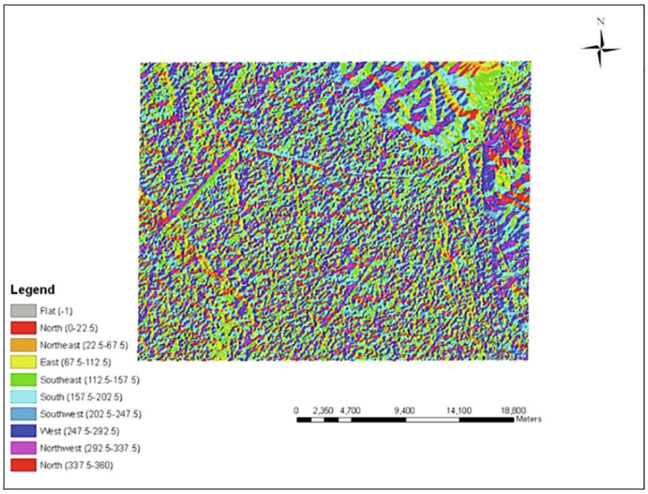

Fig. 6. Aspect map of area, derived from DEM.

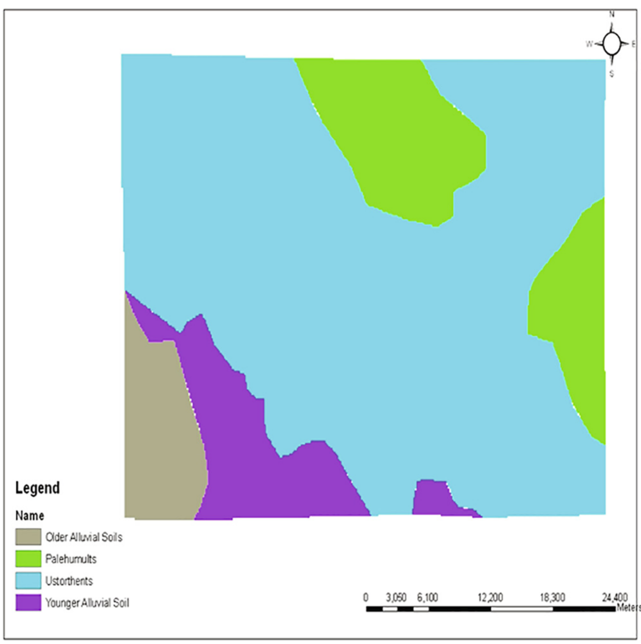

Fig. 7. Soil map of study area (Source: NATMO, 1998).

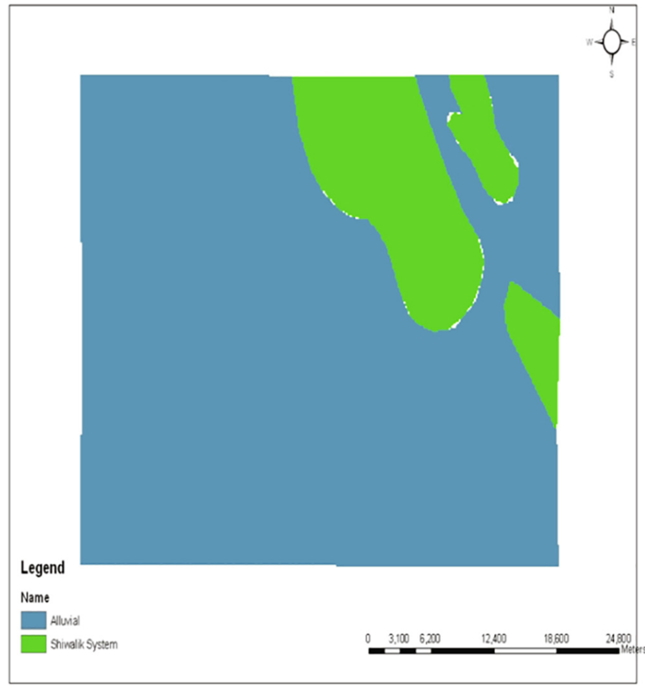

Fig. 8. Geological map of study area.

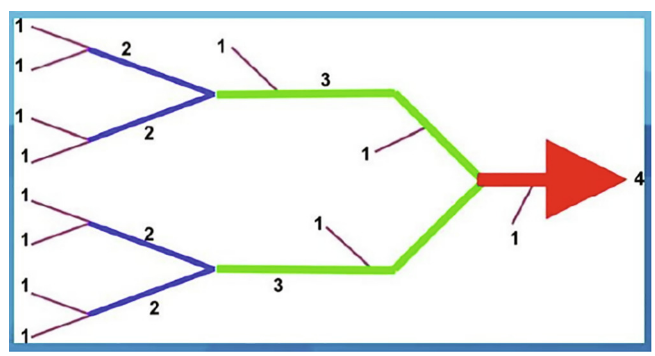

Fig. 9. Drainage order scheme (Strahler, 1964).

3.1.6. Drainage map

Drainage is a very important parameter during route alignment because it directly affects the cost of construction. A stream with no tributaries (head water stream) is considered as a first order stream. The confluence of two first order streams on the downstream side produces a second order stream (Strahler, 1964) (Fig. 9). The Ganga is the only perennial river in the area of study. Most of the area has a dendritic drainage pattern, where some area shows trellis drainage. Drainage map (Fig. 10) has been prepared from SOI toposheets and remote sensing data. In this region, the drainage is varying from first to sixth order. In order to calculate drainage density, the area is sub divided into 0.5 km X 0.5 km grid, then, the sum length of stream with each grid has been calculated using ArcGIS software.

3.2. Multi-criteria weight methods

One of the major problems in decision rule development on multi-parameter analysis is the determination of the relative importance of one parameter with respect to the other. The second step therefore involves assignment of weightage to various themes selected, depending upon their importance to route alignment requirements. A number of methods are available to deal with such problems (Mondal et al., 2011). In this study five weighting methods (AHP- Analytical Hierarchy Process method, Rank sum method, Rank reciprocal method, Rank exponent method and Ratio estimation method) are analyzed to find the best path. Different weighting methods were applied simultaneously. These procedures are performed for bias removal in assignment of weights to the input parameters.

3.2.1. Rank sum method

Rank sum is a random sampling variation. It is a non-parametric procedure. Where,

w_j is the normalized weight for the jth criteria
r is the rank position of the criterion
n is the total number of criteria under consideration ($k = 1, 2, \ldots, n$)

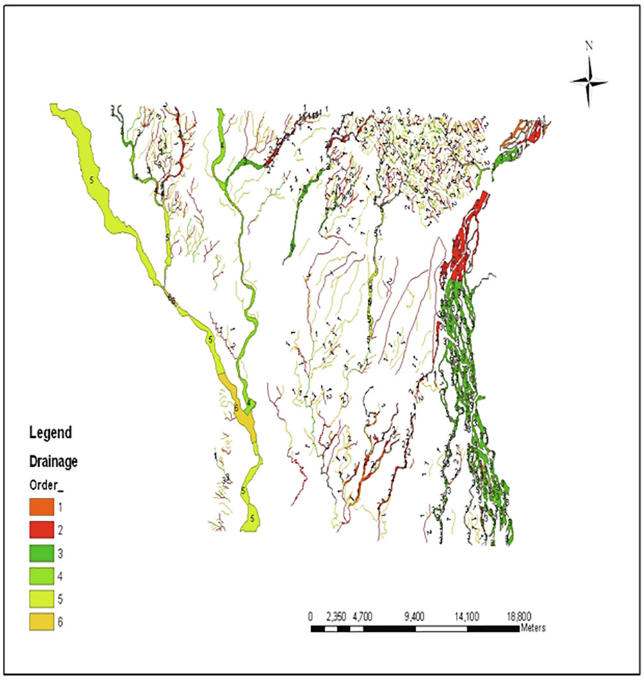

Fig. 10. Drainage map of study area.

Direction map prepared by using rank sum methodis shown in Fig. 11.

3.2.2. Rank reciprocal method

Rank reciprocal weights are derived from the normalized reciprocals of a criterion's rank. Where,

w_j is the normalized weight for the jth criteria
n is the total number of criteria under consideration (k = 1, 2, . . ., n)
r is the rank position of the criterion

Direction map prepared by using rank reciprocal method is shown in Fig. 12.

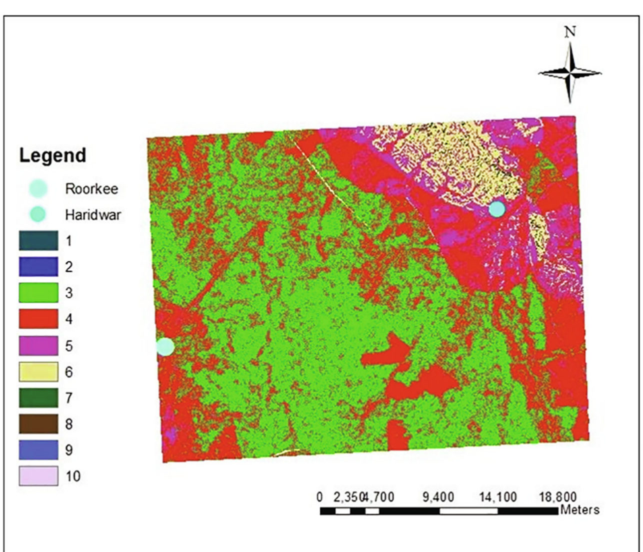

Fig. 11. Direction map by rank sum method.

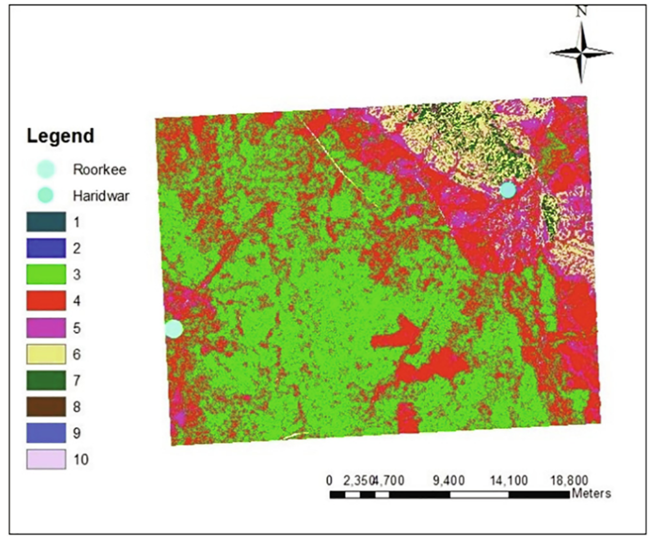

Fig. 12. Direction map by rank reciprocal method.

3.2.3. Rank exponent method

The decision maker is required to specify the weight of the most important criterion on a 0–1 scale. Where,

w_j is the normalized weight for the jth criteria
r is the rank position of the criterion
n is the total number of criteria under consideration (k = 1, 2, . . ., n)

In the above expression, it has been observed that normalized weights get steeper and steeper, as p increases. Direction map prepared by using rank exponent method is shown in Fig. 13.

3.2.4. Ratio estimation method

It starts assigning an arbitrary weight to the most important criterion, as identified by one of the ranking methods. A score of 100 is assigned to the most important criterion and smaller weights are then given to the criteria lower in the order. The procedure is continued until a score is assigned to the least important criterion. Then the score assigned to the least important attribute is taken as an anchor point for calculating the ratios. Direction map prepared by using ratio estimation method is shown in Fig. 14.

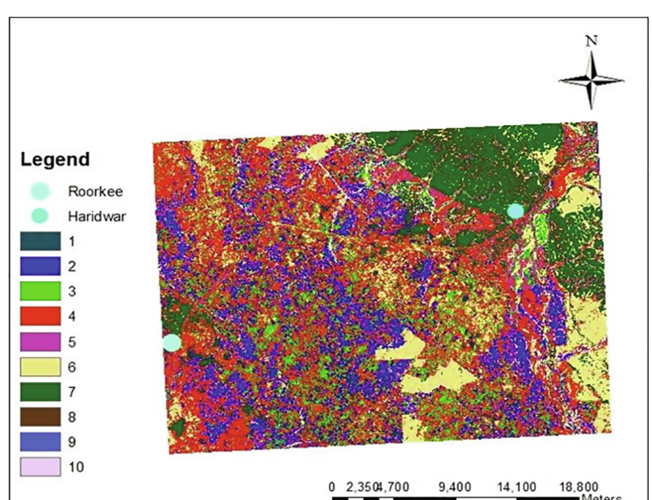

Fig. 13. Direction map by rank exponent method.

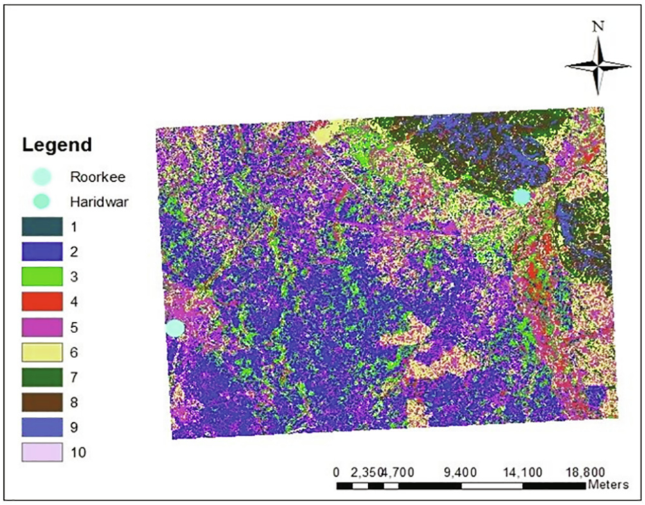

Fig. 14. Direction map by ratio estimation method.

3.2.5. AHP - Analytical Hierarchy Process methodv

In the present study, Saaty's AHP method (Saaty, 1980) has also been chosen; this allows for scaling of weights of parameters by constructing a pairwise comparison matrix. The pairwise comparison of parameters results into the "importance matrix" which was generated at a scale of 10, based on Saaty's guidelines (Eastman, 1997). In the development of pairwise comparison matrix, each factor is assigned a weight based on its significance relative to other factor. Two factors are compared at a time in terms of their relative importance to the given objective and then module calculates a set of weights that give a consistency ratio. The weights derived from the pairwise comparison matrix are displayed in the Table 3, along with the weights derived from other methods. Higher the weight, more important the factor becomes in determining the suitability for the objective. Employing Saaty's AHP, the importance matrix was derived to calculate the individual theme weight, reflecting the contribution of the factor towards best path identification. Direction map prepared by using AHP method is shown in Fig. 15.

3.3. Identification of optimum route alignment

Further keeping the geo-environmental concern of the area, the following constraints have been used for more accurate route alignment planning: (i) Avoiding the buildup area in the region (ii) Avoiding wet land, higher order drainage, forest for new route. (iii) Preferring barren land, alluvial dun gravel in lithology, bhabar as the soil type. More constraints can be defined according to scope of the project for future study. Through the utilization of knowledge based user preferences, unit weights were assigned to the subunits of each theme. Tables 4a–4f, correspond to land use land cover, slope, aspect, soil, geology and drainage respectively. Once the weightage of all the subunits were decided, the ArcGIS Spatial Module was utilized to create weight map (Figs. 11–15). The

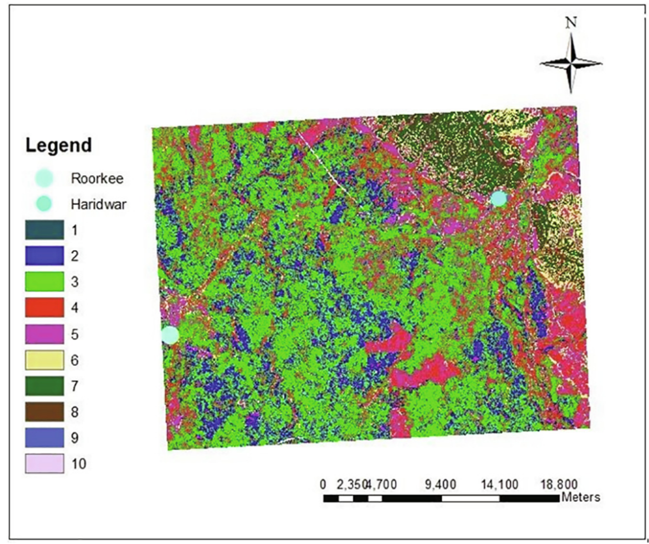

Fig. 15. Direction map by AHP method.

Table 4a
Route alignment land use parameter and its rating (weight).

Parameter	LULC Class	Rating
Land Use Land Cover	Agriculture	3
	Road	5
	Water	7
	Urban	6
	Forest	9
	River sediments	7
	Manmade forest	4

Table 4b
Route alignment slope parameter and its rating (weight).

Parameter	Slope Class (in Degree)	Rating
Slope	0–1	0
	1–3	2
	3–6	4
	6–9	6
	9–13	7
	13–17	8
	>17	9

weighted parameters were aggregated in GIS to develop the cumulative index (Table 5). Cumulative weight maps were generated using following formula:

$$\text{Combined Weight Map} = \sum_{i=1}^{n} \text{Weight} \times \text{Reclassified Grid}$$

Mapwhere i = Number of parameters from 1 to n.

Cumulative weight map finds cumulative weight of pixels from the source. It works on the principle of spread algorithm, cumulative weight of pixels from the source. The spread algorithm works

Table 3
Calculated weights using multicriteria weighted methods.

Parameter	Rank Sum	Rank Reciprocal	Rank Exponent	Ratio Estimation	AHP
Slope	28.57	41.00	19.6	22.61	40.00
LULC	23.80	21.00	18.73	20.64	28.80
Drainage	19.04	13.00	17.72	18.46	13.9
Lithology	14.28	10.90	16.49	15.99	9.60
Soil	9.52	8.10	14.90	13.05	5.00
Aspect	4.76	6.00	12.53	9.23	2.70

Table 4c
Route alignment aspect parameter and its rating (weight).

Parameter	Aspect Class	Rating
Aspect	Flat (−1)	10
	North (0–22.5)	9
	Northeast (22.5–67.5)	8
	East (67.5–112.5)	7
	Southeast (112.5–157.5)	6
	South (157.5–202.5)	5
	Southwest (202.5–247.5)	4
	West (247.5–292.5)	3
	Northwest (292.5–337.5)	2
	North (337.5–360)	1

Table 4d
Route alignment soil parameter and its rating (weight).

Parameter	Sub Class	Rating
Soil	Ustorthents	5
	Palehumutts	4
	Older alluvial	2
	Younger alluvial	3

Table 4e
Route alignment geology parameter and its rating (weight).

Parameter	Sub Class	Rating
Geology	Alluvial	2
	Shiwalik system	4

Table 4f
Route alignment drainage parameter and its rating (weight).

Parameter	Sub class	Rating
Drainage	1st order	1
	2	2
	3	5
	4	6
	5	6
	6	7
	No drainage	0

on accumulated weight surface; the path is traced by the following two equations:

$$CC_{(o,pi)} = \frac{(c_o + c_{pi})}{2}\mu + cc_o \quad (1)$$

where, i = 2, 4, 5, 7 direct neighbor

$$CC_{(o,p_i)} = \frac{(c_o + c_{Pi})}{2}(SQRT2)\mu + cc_o \quad (2)$$

where, i = 1, 3, 6, 8 diagonal neighbors, CC (O,P_i) is the accumulated weight from cell O to P_i, C_o and Cp_i are the weights for moving between the individual cells, μ represents cell width, CC_o is the accumulated weight at cell o.

The shortest path (Fig. 16a–e) from source point to destination was calculated using cost weighted distance function and direction

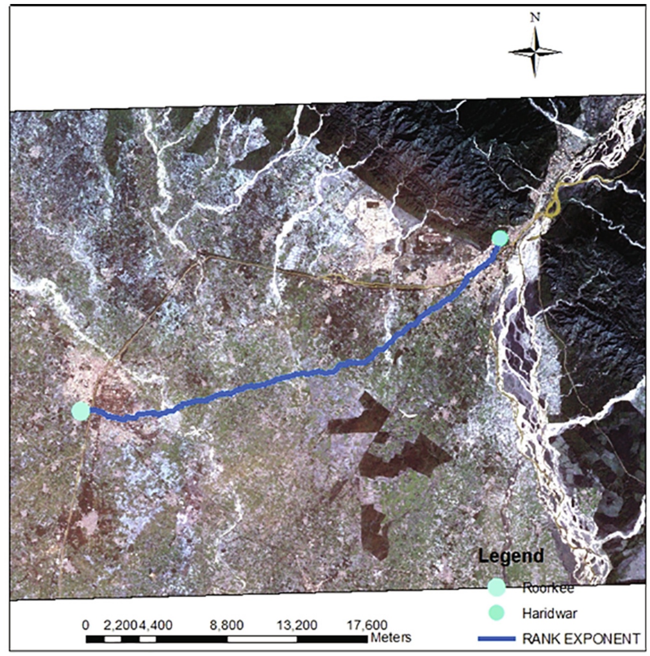

Fig. 16. a:Route alignment with rank exponent method. b:Route alignment with ratio estimation method. c:Route alignment with rank reciprocal method. d:Route alignment with rank sum method. e:Route alignment with AHP method.

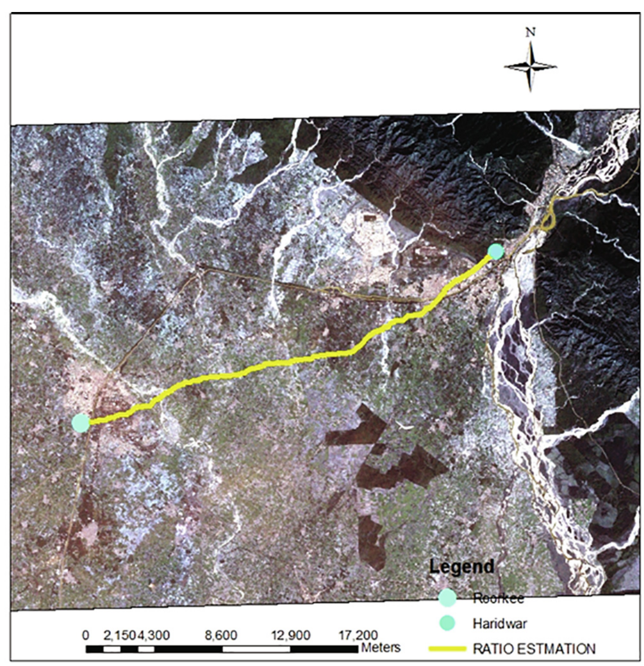

Fig. 16 (*continued*)

Table 5
Route alignment multi-criteria weight equation.

Method	Equation used
Rank Exponent	[Slope × 19.6 + Landuse × 18.73 + Drainage Order × 17.72 + Lithology × 16.49 + Soil × 14.9 + Aspect × 12.53]
Ratio Estimation	[Slope × 22.61 + Landuse × 20.64 + Drainage Order × 18.46 + Lithology × 15.99 + Soil × 13.05 + Aspect × 9.23]
Rank Reciprocal	[Slope × 41 + Landuse × 21 + Drainage Order × 13 + Lithology × 11 + Soil × 8 + Aspect × 6]
Rank Sum	[Slope × 28.57 + Landuse × 23.80 + Drainage Order × 19.04 + Lithology × 14.28 + Soil × 9.52 + Aspect × 4.76]
AHP	[Slope × 40.00 + Landuse × 28.8 + Drainage Order × 13.9 + Lithology × 9.6 + Soil × 5 + Aspect × 2.7]

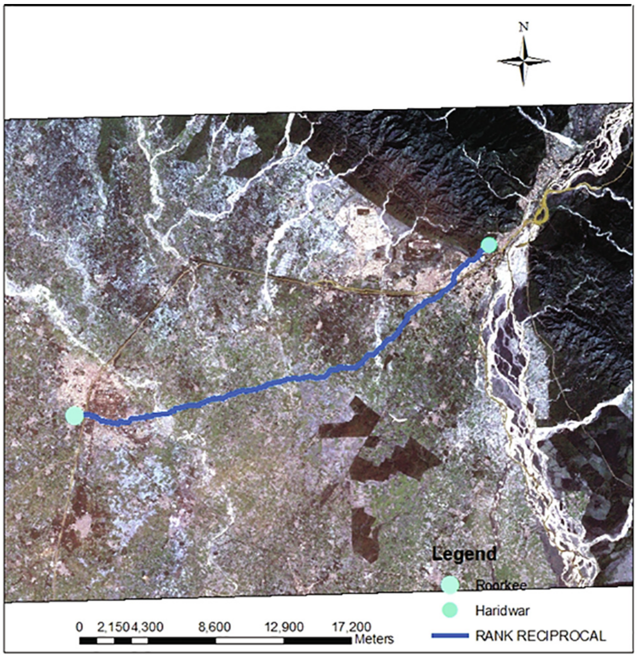

Fig. 16 (*continued*)

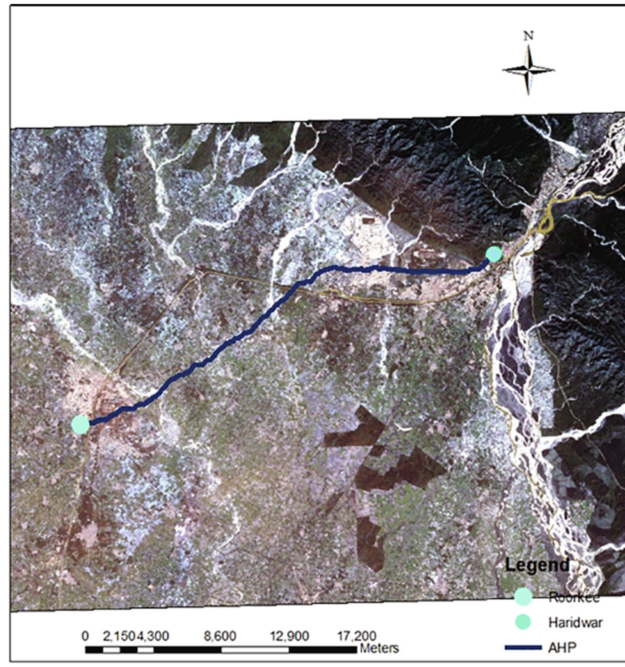

Fig. 16 (*continued*)

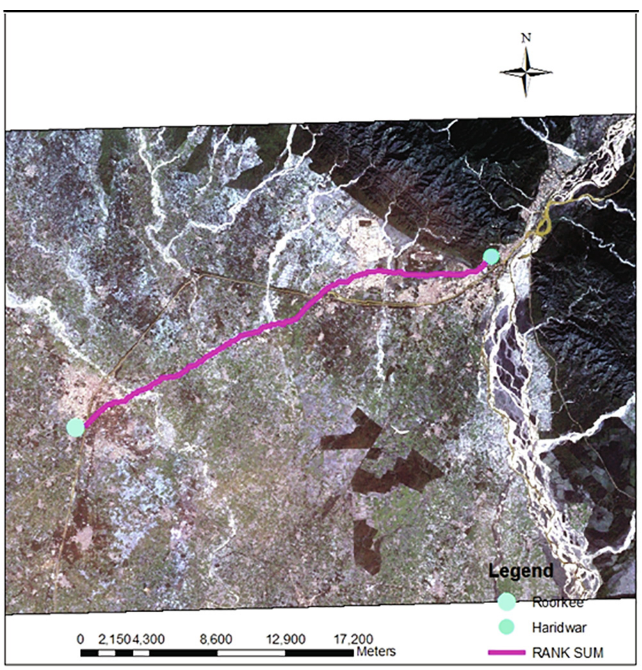

Fig. 16 (*continued*)

function in Spatial Analyst Module of ArcGIS. Overlay analysis in ArcGIS environment has been carried out by applying probability weighted approach. The overlay analysis performs a linear combination of weights of each thematic map with respect to cost effective shortest path. The final selection of best path or optimum route was carried out based on parameters like minimum construction cost (Winter, 2002); minimum number of bridges and culverts on that route; maximum number of settlement within 5 km buffers on both sides of route; maximum number of tourist locations like temples, waterfalls, springs etc. within 5 km buffer zone on both side of route.

4. Results and discussions

In this study five methods of route alignment (AHP - Analytical Hierarchy Process method, Rank sum method, Rank reciprocal method, Rank exponent method and Ratio estimation method) are analyzed to find the best path. Five routes are identified using multi-criteria weighted methods (Fig. 16a–e). Based on total length of road and the new road needed, the AHP was observed to be the best method out of the five methods, followed by ratio estimation method for identification of optimum route alignment (Fig. 17, Table 6). In the AHP method, the total length of road is 29.22 km

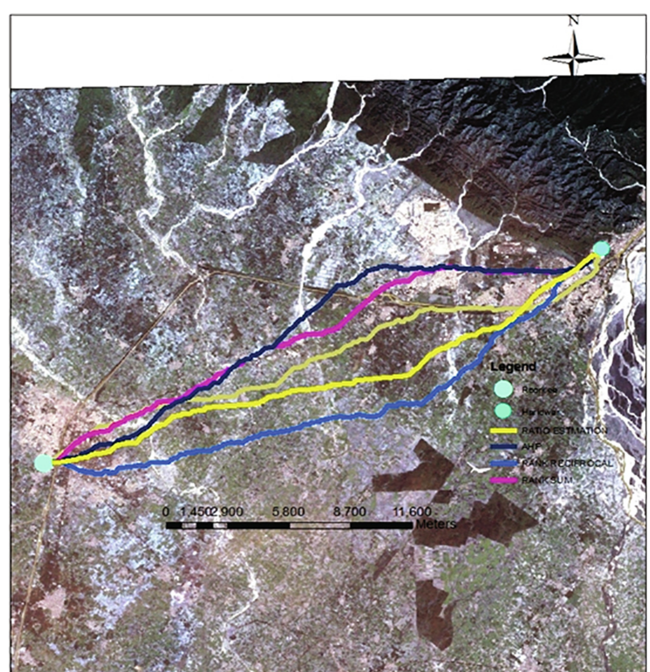

Fig. 17. Final route by five methods overlaid on the satellite image.

Table 6
Length comparison of five methods.

Route	Method	Total length (km) (i)	Existing road (km) (ii)	Road needed (km) (i-ii)
1	Rank exponent	33.21	14.33	18.88
2	Ratio estimation	30.78	17.43	13.35
3	Rank reciprocal	32.45	14.73	17.72
4	Rank sum	32.79	15.43	17.36
5	AHP	29.22	17.10	12.12

Table 7
Habitations within 5 km buffer zone of all five routes.

Buffer (km)	Rank exponent	Ratio estimation	Rank reciprocal	Rank sum	AHP
<1	10	8	11	13	13
1–2	9	10	17	7	5
2–3	6	6	10	4	6
3–4	7	12	12	13	10
4–5	12	7	11	7	17
Total	44	43	61	44	51

including 12.12 km new road needed to be constructed; while in ratio estimation method the total length of road is 30.78 km including 13.35 km new road needed to be constructed. The optimum route was finally selected based on the length of route, number of bridges and culverts along the route, connectivity to other habitations and tourist places, like springs, waterfalls and temples within 5 km buffer on both sides of the route. In general, criteria for comparison of routes include distance, cost and time of travelling from point of origin to destination and direct transport cost (by one or more modes of transport routes). The information related to the cost and time elements should be as detailed as possible, for comprehensive analysis. Our consideration analysis is limited to distance, time, and partly to cost comparison. For direct transport route, among these methods, AHP method gives the optimized route.

The route derived from the AHP method is implemented with a buffer ranging from 1 km to 5 km. The descriptions of the various habitations coming within the buffer are shows in Fig. 19 and Table 7 & Appendix A. Starting with the road network centerline layer, the buffer width of 1–5 km is added as a field to the attribute table to calculate each individual segment of the road. The buffer width is according to the requirement. GIS is used to create a buffer around the centerlines of the aligned route. This road buffer layer is converted to raster format. Buffers with distances 1–5 kms are shown in Fig. 18 which are implemented on the route derived by the AHP method. The proposed route extends from Roorkee to Haridwar via Mayapur, Kankhal and Jwalapur. On this proposed route, various temples lie which is important because pilgrims visit these temples (Table 8).

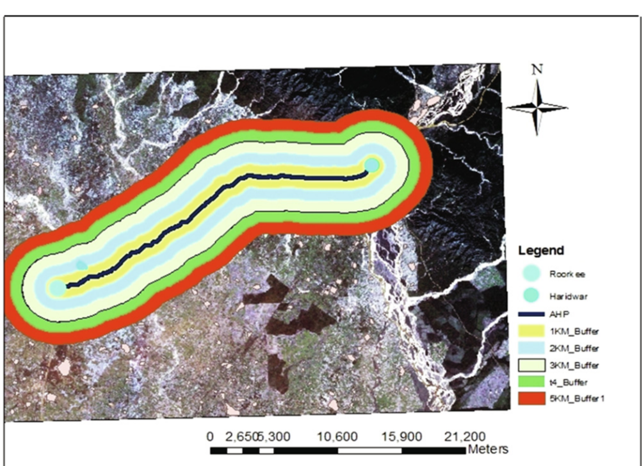

Fig. 18. Number of habitations within 5 km buffer zone of best route identified by AHP method.

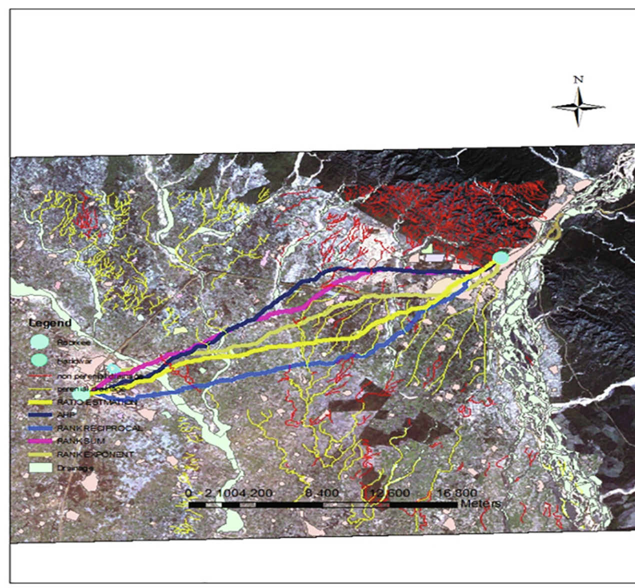

Fig. 19. Drainage intersection by the five routes.

The advantage of the evaluating drainage intersection with the proposed routes are shows in Fig. 19 & Table 9a–9c, 10. The length of proposed route between Roorkee and Haridwar towns is only 29.22 km. This includes a 17.10 km long part of the existing road, which is common with the proposed alignment. Therefore, the new road required is 12.12 km, while the existing longer route between Roorkee and Haridwar is 33 km (instead of 29.22 km). By using multi-criteria weighted methods of route alignment, a length of approximately 3.78 km can be avoided where 17.10 km of existing route will be used. It was observed that slope, land use and drainage parameters are more sensitive for route alignment (in that order), as compared to other parameters considered in the study.

Table 8
Temples within 5 km buffer zones.

Buffer distance (km)	Rank exponent (route 1)	Ratio estimation (route 2)	Rank reciprocal (route 3)	Rank sum (route 4)	AHP (route 5)
<1	6	5	3	2	4
1–2	0	2	4	3	3
2–3	3	4	5	4	0
3–4	2	3	2	0	2
4–5	4	4	0	2	4
Total	15	17	14	11	13

Table 9a
Comparison of routes on the basis of intersection with 1st to 4th order drainages.

Method	Length of intersection with 1st to 4th order drainage (m)
Rank exponent	210
Ratio estimation	215
Rank reciprocal	279
Rank sum	210
AHP	192

Table 9b
Comparison of routes on the basis of intersection with 5th to 7th order drainages.

Method	Length of intersection with 5th to 7th order drainage (m)
Rank exponent	115
Ratio estimation	125
Rank reciprocal	125
Rank sum	135
AHP	103

Therefore these input parameters are required to be derived with higher accuracy.

5. Conclusions

In the present study, optimal route between Roorkee and Haridwar towns has been obtained by using multi-criteria weighted methods of route alignment, i.e., AHP, Rank Sum, Rank Reciprocal, Rank Exponent, Ratio Estimation. Different geo-engineering as well as techno-economical parameters have been considered in GIS environment. It has been observed that AHP provided the best results followed by ratio estimation method. The proposed route between Roorkee and Haridwar is only 29.22 km long including a 17.10 km long part of the existing road. The new road required is 12.12 km. Thus, a length of approx. 3.78 km can be reduced by using multi-criteria weighted methods of route alignment, since the existing route between Roorkee and Haridwar is 33 km. It was also observed that slope, land use and drainage parameters

Table 9c
Comparison of routes on the basis of drainage intersection.

Drainage order	Rank exponent (route 1)	Ratio estimation (route 2)	Rank reciprocal (route 3)	Rank sum (route 4)	AHP (route 5)
1st	6	12	10	8	7
2nd	4	5	7	9	4
3rd	5	4	6	5	4
4th	3	2	4	3	2
5th	0	0	0	0	0
6th	2	2	1	2	2
Total	20	25	28	27	19

Table 10
Drainage for bridges and culverts by AHP method,change in kilometers.

	Drainage order	Type of construction	Longitude	Latitude
0	Starting point of source (Roorkee)		**7753′00″E**	**29 52′00″N**
7.24	6	Bridge	77° 57′ 28.59″	29° 53′ 39.13″
9.15	6	Bridge	77° 57′ 24.17″	29° 53′ 47.06″
10.25	1	Culvert	77° 58′ 11.49″	29° 54′ 03.06″
10.75	3	Bridge	77° 59′ 16.43″	29° 54′ 04.27″
11.21	2	Bridge	78° 00′ 28.06″	29° 54′ 26.38″
11.71	1	Culvert	78° 01′ 00.98″	29° 54′ 37.86″
12.12	2	Bridge	78° 02′ 17.02″	29° 55′ 11.29″
13.42	1	Culvert	78° 02′ 52.86″	29° 55′ 15.72″
14.98	1	Culvert	78° 02′ 48.14″	29° 55′ 28.85″
17.40	2	Bridge	78° 04′ 40.72″	29° 55′ 08.20″
17.80	1	Culvert	78° 06′ 00.82″	29° 55′ 01.87″
22.10	3	Bridge	78° 06′ 12.00″	29° 55′ 08.76″
22.89	2	Bridge	78° 06′ 43.29″	29° 55′ 17.75″
24.79	1	Culvert	78° 07′ 03.52″	29° 55′ 26.10″
25.76	3	Bridge	78° 07′ 16.28″	29°55′ 33.36″
26.10	1	Culvert	78° 09′ 25.28″	29° 55′ 48.94″
27.85	4	Bridge	78° 09′ 25.28″	29° 56′ 24.28″
28.10	4	Bridge	78° 09′ 52.07″	29° 56′ 43.79″
28.40	3	Bridge	78° 10′ 31.49″	29° 57′ 28.27″
29.22	**End of optimum route (Haridwar)**		**78° 16′ 00″**	**29° 96′ 00″**

Source of Data: Field visit& digital data analysis.

are more sensitive for route alignment. The proposed methodology with suitable modifications can be applied for other applications related to alignment, like water pipelines, electrical cables etc. Rules specific to the terrain type may be developed for the improvement of route alignment in various hilly regions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Location of habitation within 5 km buffer zone (By AHP method)

Sl. No.	Habitation	Population	Longitude	Latitude	Buffer Distance from Route (km)
1	Jaswale	1500	77° 56′ 19.34″	29° 53′ 51.94″	<2
2	Bedpur	1000	77° 56′ 48″	29° 54′ 16.95″	<3
3	Madhapur	5500	77° 54′ 49.71″	29°54′ 27.83″	<3
4	Patanjali	5000	77 °59′ 45.45″	29° 54′ 06.03″	<1
5	Bharatpur	1600	77° 23′ 45.67″	29° 53′ 18.20″	<2
6	Ibrahimpur	2300	77° 32′ 34.89″	29° 54′ 64.3″	<4
7	Salempur	1500	77° 55′ 52.12″	29° 53′ 23.54″	<5
8	Bahadrabad	15,000	78° 02′ 16.08″	29° 55′ 10.21″	<1
9	Kota Muradnagar	2000	77° 55′ 08.36″	29° 50′ 17.92″	<5
10	Kalan	5000	77° 54′ 01.83″	29° 50′ 18.06″	<4
11	Chandipur	1000	77° 56′ 17.51″	29° 52′ 22.25″	<3
12	Rasulpur	1500	77° 56′ 25.02″	29° 52′ 59.27″	<2
13	Santarsah	2500	77° 55′ 22.13″	29° 54′ 08.97″	<3
14	Bahadurpursaini	5000	77° 54′ 50.31″	29° 54′ 28.27″	<3
15	Badheri	4000	77° 59′ 15.42″	29° 55′ 16.10″	<4
16	Kanahpur	5000	77° 58′ 39.47″	29° 55′ 48.88″	<5
17	Gumanwala	2000	77° 58′ 01.08″	29° 54′ 33.54″	<2
18	Kayanpur	1500	77° 58′ 25.94″	29° 54′ 05.54″	<1
19	Piranpur	500	78° 00′ 24.16″	29° 55′ 21.73″	<2
20	Moldaspur		78°54′18.36″	29° 54′ 68″	<3
21	Kamalpur	5000	77° 58′ 25.75″	29° 52′ 52.78″	<5
22	Ahamadpur	800	77° 58′ 51.62″	29° 53′ 31.77″	<2
23	Alipur	1500	78° 06′ 41.95″	29° 53′ 27.85″	<4
24	Kishanpur	9500	78° 02′ 08.71″	29° 54′ 10.22″	<3
25	Ibhahimpur	3000	78° 07′ 09.43″	29° 54′ 12.54″	<3
26	Roshanabad	4000	77° 56′ 34.54″	29° 55′ 55.56″	<5
27	Begampur	1700	78° 02′ 56.56″	29° 54′ 33.98″	<5
28	Salehpur	2500	78° 06′ 45.56″	29° 53′ 23.45″	<4
29	Muqarrabpur	900	77° 55′ 25.77″	29° 53′ 26.74″	<5
30	PiranKaliar	2000	77° 56′ 02.66″	29° 55′ 24.75″	<4
31	Ranipurrao	8000	78° 46′ 17.54″	29° 52′ 40.76″	<1
32	State Bank Colony	3000	78° 59′ 43.19″	29° 53′ 59.7″	<2
33	Jwalapur	20,000	78° 06′ 28.35″	29° 55′ 31.75″	<1
34	Ranipur	2000	77° 54′ 47.74″	29° 56′ 15.86″	<1
35	Vetanary hospital	1200	78° 03′ 27.45″	29° 52′ 25.22″	<2
36	Dhandhera	5000	78° 01′ 06.35″	29° 55′ 21.29″	<4
37	COER college	5000	77° 59′ 17.42″	29° 53′ 58.02″	<1
38	HakimpurTurra	3000	78° 04′ 02.45″	29° 53′ 55.37″	<5
39	Padirgujjar	2500	77° 49′ 18.64″	29° 53′ 33.00″	<3
40	Sheikh	3500	78° 00′ 43.82″	29° 51′ 57.36″	<4
41	Mahawapur	1400	77° 57′ 28.39″	29° 58′ 04.97″	<1
42	Kellenpuri	1000	78° 07′ 36.07″	29° 53′ 46.31″	<3
43	Dandheri	6500	77° 59′ 50.30″	29° 57′ 16.43″	<4
44	Jamalpur	1200	78° 03′ 27.29″	29° 55′ 39.69″	<4
45	Jagatpur	15,000	78° 08′ 13.3″	29° 55′ 01.47″	<5
46	Devpura	10,000	78° 08′ 53.42″	29° 56′ 28.27″	<3
47	Hiranwala	12,000	78° 10′ 28.79″	29° 55′ 03″	<4
48	Sitapur	3000	77° 51′ 16.66″	29° 54′ 08.72″	<3
49	BHEL township	15,000	78° 02′ 34.90″	29° 58′ 07.35″	<2
50	Delna	2500	77° 47′ 27.20″	29° 50′ 32.10″	<2
51	Hetampur	3000	78° 04′ 02.45″	29° 58′ 07.35″	<5

Source of Data: Field visit & digital data analysis.

The authors whose names are listed in this manuscript entitled by “Route Alignment Planning for a New Highway between Two Cities using Geoinformatics Techniques” submitted to “The Egyptian Journal of Remote Sensing and Space Sciences”, certify that they do not have any kinds of conflict of interests.

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