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ORIGINAL ARTICLE

Fuzzy AHP-based multi-criteria decision-making analysis for route alignment planning using geographic information system (GIS)

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Abstract

An approach for identifying and selecting the route alignment using GIS and fuzzy AHP is developed in the present study. Spatial multi-criteria decision analysis is applied to identify optimal route alignment with the consideration of criteria such as environmental, social, economic and technical spatial datasets. These criteria play a significant role in the identification and selection of optimal route alignment. Fuzzy set theory is used to handle vagueness-type uncertainty in the multi-criteria decision analysis. Fuzzy AHP is introduced to compare the fuzzy criteria for ranking purpose, and fuzzy criteria weights are used to develop relative surface cost maps. The least-cost path (LCP) method is applied to find alternate four route alignments from source to destination by considering several criteria in GIS. The criteria values of each four alignment and weight of each criterion on the basis of maximum priority weight are calculated. The designed four routes are evaluated using priority weight method and fuzzy-AHP method. The selection of optimum route is considered by maximum weight of the alignment. The technical route alignment (alignment 4) is considered as optimum route with weight value 80.38%. The proposed methodology is implemented for a study area, outer region of Allahabad city, India.

Keywords Route alignment planning · Geographic information system (GIS) · Fuzzy-analytic hierarchy process (F-AHP) · Multi-criteria decision analysis (MCDA) · Decision support system (DSS)

JEL Classification C61

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1 Introduction

The decision for optimum route alignment of a road is very complex and challenging problem. Multi-criteria decision analysis is an appropriate tool for solving such problems (Malczewski 2006, 2004, 1999a, b). There are various competing and conflicting criteria for the identification of route alignment, such as technical, economic, social, environment and physical features for the study area (Singh and Singh 2017; Murat et al. 2015; Yakar and Celik 2014; Effat and Hassan 2013; Tae-Ho et al. 2008; Saha et al. 2005; Sadek et al. 1999; Moreb 1996). The physical feature includes topography and land use in the surroundings. For handling these criteria (factors), multi-criteria decision analysis is required (Jankowski 1995; Jankowski and Richard 1994). This process needs high-level accuracy and reliability in the data involved. The effectiveness of decision-making process depends on the quality of data as well as the evaluation method (Goodchild et al. 1992; Carver 1991). The data may have vague and ambiguous information. This means that the uncertainty involved in the data, and it can be handled by fuzzy set theory (Ayag 2014). The decision makers (DMs) face with a variety of alternatives route alignments for the same due to the uncertain information in the data. It is very difficult to select the optimal alignment among the alternatives (Mishra et al. 2014; Kang et al. 2012; Sadeghi-Niaraki et al. 2011; Lee et al. 2009; Jha 2003; Jha and Maji 2007; Cheng and Lee 2006; Kim et al. 2004, 2005; Maji and Jha 2011; Jha and Schonfeld 2004; Jong et al. 2000; Jong and Schonfeld 2003). The hybridization of fuzzy, MCDA and GIS can be used to identify and select optimal route alignment.

Multi-criteria decision analysis methods can be categorized into two parts: One is known as multi-attribute decision analysis (MADA), and other is called multi-objective decision analysis (MODA) (Malczewski 1999a, 1999b; Zanakis et al. 1998; Angulo et al. 2012; Goktepe et al. 2009). If the decision space is continuous, then we use MODA methods such as multiple objective programming. On the other hand, if the decision space is discrete in nature and target is predefined, then MADA methods are used to solve the problems. The attributes are also known as goals, and these attribute may conflict with each other (Malczewski 2000, 2004, 2006, 2015). For the identification and evaluation of route alignment, the most common multi-criteria method is analytic hierarchy process (AHP) which was developed by Thomas L. Saaty in 1980 and it gives a structural basis for the quantification and comparison of decision criteria in a pairwise matrix (Saaty 2008; Saaty 1990). The AHP is used for the decision analysis for the deterministic or certain (without uncertainty) data (Jankowski and Richard 1994). However, during the decision-making process, data may have been incomplete for the considered study area, inherent complexity, uncertainty in the opinions of experts due to the vagueness of the human thought process (Jankowski et al. 2001). The conventional AHP approach may not be able to deal with this vague information. For dealing with the uncertainty, the fuzzy set theory can be integrated with AHP. The resulted framework is known as fuzzy AHP (F-AHP) (Aggarwal and Singh 2013; Boroushaki and Malczewski 2008). It provides a framework for further analysis, and fuzzy membership functions are used to assess criteria. The particular uncertain attribute can be expressed using the fuzzy membership functions, and it provides the degree of membership for an uncertain attribute of interest. Generally, the attribute values are measured in the discrete intervals, but the fuzzy membership values can be expressed related to map classifications to membership values in the interval [0, 1] (Fazlollahtabar et al. 2010). The membership functions are used to standardize criteria maps by assigning to each object a membership degree or non-membership degree each criterion (Jiang and Eastman 2000). Hybridization of fuzzy and AHP provides more flexibility in the assessment and decision analysis. It also retains the advantages of conventional AHP, like the generation of priority vectors, reduction of consistency, hierarchical structure, pairwise comparison and decomposition (Tyagi et al. 2016).

The basic ideal conditions for optimal route alignments are that it should be short, safe, economic, easy and useful. However, it is not possible to satisfy all these conditions in one alignment (Kadiyali 2011). The selected route alignment should be nearest to its ideal conditions. Alignment should be planned with consideration of construction cost, accessibility, length, time and productivity, where cost optimization is the most important factor (Yang et al. 2014; Effat and Hassan 2013; Gonçalves 2010; Jha and Kim 2006; Jha and Schonfeld 2003and Jha and Schonfeld 2003). The factors which affect the construction cost are elevation, slope, land use, road network, rail network, drainage network, industrial area, rural habitations, population density and constraints of the area. Some factors and constraints can also be included as per the requirements. For the selection of optimum route alignment, the following factors and constraints are further taken into the consideration:

a. The elevation along the route side should be minimum, as much as possible.
b. The slope should be kept as minimum as possible, and alignment is safe when slope is considered between 0 and 10%.
c. To avoid acquisition of the costly land, the alignment should not pass within agricultural land.
d. The alignment should be avoided to pass from urban areas for the property destruction and enhancement of compensation costs.
e. The alignment should be avoided to pass from the water body areas like ponds; wells, etc. It will help to reduce construction costs and pollutions of water bodies.
f. The alignment should be avoided to pass from highly dense forests/trees areas for the protection environment.
g. The alignment should be avoided to pass from natural drainage pattern.
h. The alignment should be avoided to pass from the existing roads. It will help to minimize accidental cases.
i. The alignment should be near or pass from industrial areas: Productivity and accessibility of the route have been increased.
j. The alignment should be avoided to pass from rural areas for the property damage and compensation costs.
k. The alignment should be avoided to pass from high population density areas to reduce accidental cases.

l. The alignment should be avoided to pass from disputed areas to avoid delay of construction of a road.

In this paper, a fuzzy-AHP methodology is proposed for identifying and selecting the optimum route alignment. The proposed methodology is applied on a study area, an outer region of Allahabad city, India. Four alternate route alignments are identifying for developing a major road between two locations with the consideration of technical, social, environmental and economic factors (Singh and Singh 2017). The designed alignments connect the Naini and Jhunsi regions in the outer area of Allahabad city, Uttar Pradesh, India. The proposed route could be helpful to control the traffic of Allahabad city, and it will also be useful to decrease the pollution level in the city area.

The remaining part of the paper is organized as follows: In Sect. 2, study area and data processing are discussed. In Sect. 3, fuzzy, fuzzy AHP and proposed methodology are discussed. The proposed methodology is implemented in Sect. 4. Multi-criteria evaluation is done using priority weight method and fuzzy-AHP methods in Sect. 5. Section 6 describes the conclusion.

2 Study area and data

Allahabad district is situated in the northeast region of Uttar Pradesh State of India. The study area is surrounded by latitudes $25^{\circ}25'$ N and $25^{\circ}50'$ N and by longitudes $81^{\circ}75'$ E and $82^{\circ}00'$ E. The population of Allahabad is 1,042,229 as per the 2011 census. It is listed as the 32nd most densely populated city in India. The area of Allahabad city is nearby 65 km^2 and 98 m/340 ft. above sea level. The locations of alignments are connected between source and destination points. The source and destination points are situated in Naini and Jhunsi areas in Allahabad city. In this study area, the 2D coordinate (81.881, 25.365) is used as the source point and (81.952, 25.425) is used as the destination point for designing of route alignments (Fig 1).

2.1 Data and preprocessing

The first basic step of alignment designing and evaluation is preprocessing of spatial datasets. The following datasets are prepared for the development of this model.

(a) A topographic map (63G/15) of Allahabad district with scales of 1:50000 from Survey of India, issued in 2012, is used to extract the land use/land cover feature of the study areas such as road, rail, drainage network and religious places. It is also used to create the source and destination point data, where the alignment is proposed.
(b) LISS-III satellite data with the 23.5-meter spatial resolution were taken from the National Remote Sensing Center (NRSC), India, issued in 2012. LISS-III

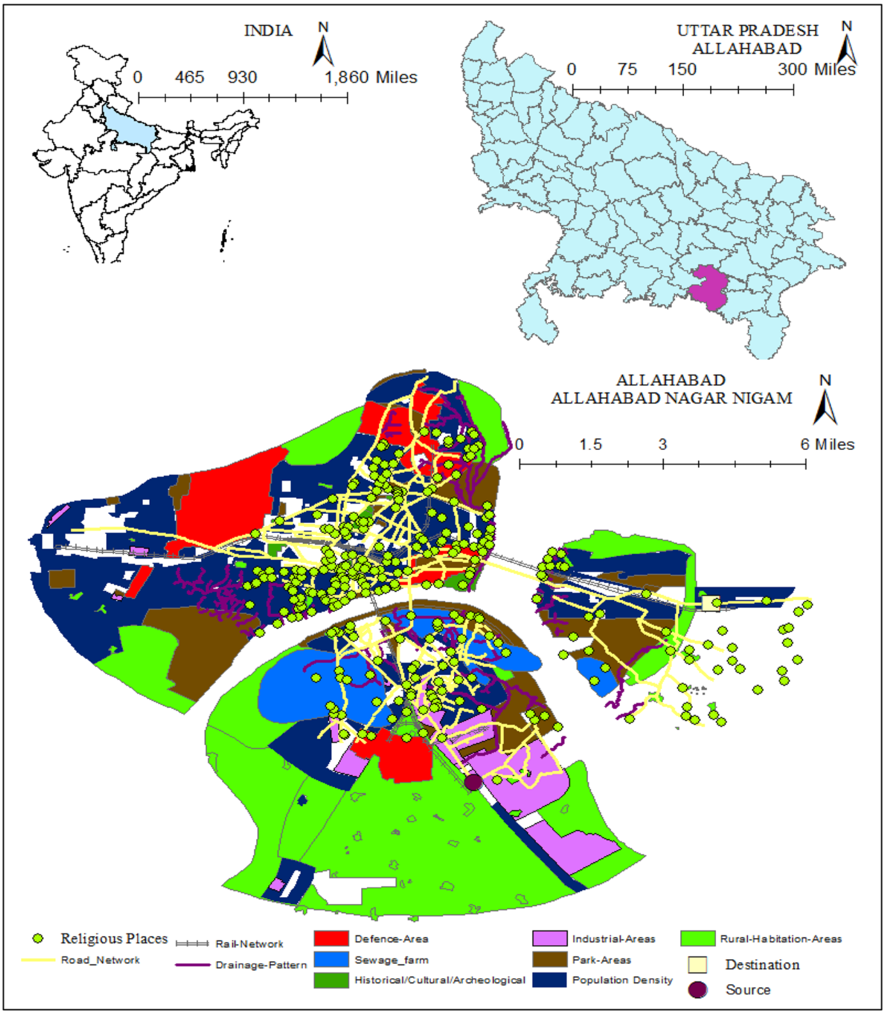


Fig. 1 Study area

satellite image consist four bands (BAND2, BAND3, BAND4 and BAND5) of data separately, combined each band of data into a single RGB raster dataset from multiple bands using composite bands techniques from (ESRI) ArcGIS 10 software. After a composite operation, the land use/land cover (LULC) analysis was performed with the help of supervised classification techniques using the maximum likelihood classifier method. The analysis was carried out using ERDAS IMAGINE 10 software. The LULC map is used to extracting the criteria such as agriculture land, water body, rivers, trees, urban area and sandbank.

(c) High-resolution ASTER DEM satellite data in 14 different bands of the electromagnetic spectrum acquired in 2009, with 30-meter spatial dimension, are used to create and deliberate slope map of study area.
(d) The slope is a very important factor which affects the geometrical design of the route alignment. For every cell, slope tool of ArcGIS is used for the calculation of the maximum rate of change in the surface value of horizontal and vertical directions between a cell and its neighborhood cell. The maximum change in the slope calculates the steepest downhill percentage over the distance between that cell and its eight neighborhood cells (ESRI 2010).

According to Indian Road Congress (IRC), the following are the ranges for the slope criteria:

The range for the flat surface should be 0%–10%, for rolling surface should be 10%–25%, for the mountainous surface should be 25%–60%, and for the steepest surface should be above 60% as shown in Fig. 4 (Kadiyali 2011). In this study, the flat surface is assumed to be the least cost and the steepest surface has the highest cost. The slope of the route alignment should be minimized because flat surface allows the route direct, faster and easy for the traveling (Singh and Singh 2017).

(e) A master plan land use map was taken from Municipal Corporation of Allahabad city. A georeferencing technique is applied on master plan map, and it makes an appropriate map for digitizing and extracting land use/land cover feature of the study area, which is associated with attribute table. Data layers such as cantonment area, park area, archeological area, rural habitation, sewage treatment area, industrial area and the population density are extracted.

Spatial datasets are created in ESRI ArcGIS 10 software and projected to Universal Transverse Marketer (UTM) projection, zone 44 N. Subsequently, all spatial datasets are arranged by geometric, thematic and topology editing of the original datasets. A buffer analysis technique is applied to vector datasets. Data management techniques are used to convert all vector datasets into the raster data format with 23.5-meter spatial dimension. The satellite image, LISS-III and ASTER DEM data are shown in Fig. 2 and 3.

3 Proposed fuzzy-AHP methodology

3.1 Fuzzy sets and fuzzy numbers

Definition 1 Let S be universal set of objects indicated by x, then a fuzzy set $\tilde{A}$ defined on S is characterized by the membership function $\mu_{\tilde{A}} : S \rightarrow [0, 1]$, where $\mu_{\tilde{A}}(x)$ is assigned a real number in the interval [0, 1] for each element $x \in S$ and $\mu_{\tilde{A}}(x)$ shows the grade of membership $x \in \tilde{A}$. A fuzzy set can be interpreted as a set

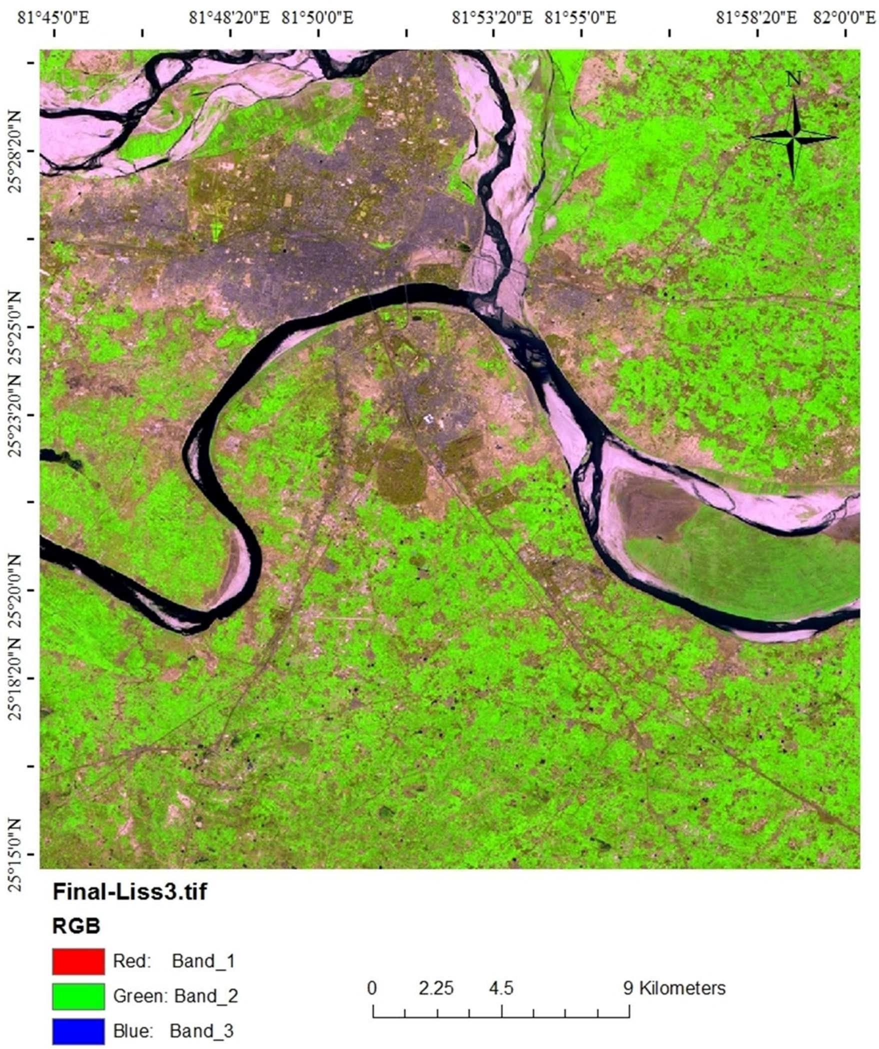


Fig. 2 LISS-III satellite image

of ordered pairs of elements $x \in S$ their membership grades $\mu_{\tilde{A}}(x)$ and it is written as (Zadeh 1978).

$$\tilde{A} = \left\{ \left(x, \mu_{\tilde{A}}(x) \right) | x \in S \right\}$$

Definition 2 Let $\tilde{A}$ be a fuzzy subset defined on S, and it interprets a normal fuzzy set if there exists at least one $x \in S$ such that $\mu_{\tilde{A}} = 1$.

Definition 3 Let $\tilde{A}$ be a fuzzy set defined on S. Then, the support of fuzzy set $\tilde{A}$ is defined as

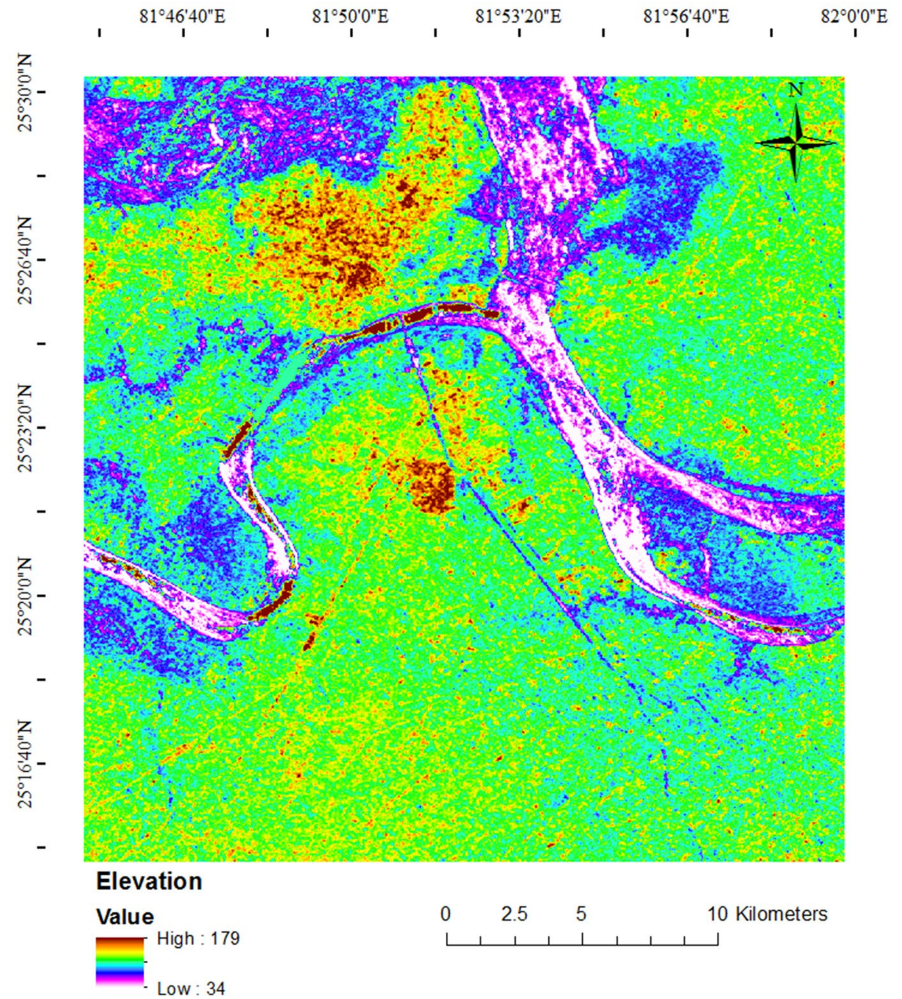


Fig. 3 Digital elevation modeling data

$$\left\{x \in S \middle| \mu_{\tilde{A}}(x)\rangle 0\right\}$$

Definition 4 A fuzzy subset $\tilde{A}$ on S is a convex fuzzy set if and only if $\forall\ x_1, x_2 \in S$ with $\lambda \in [0, 1]$ such that

$$\mu_{\tilde{A}}\left(\lambda x_1 + (1-\lambda)x_2\right) \geq \min\left(\mu_{\tilde{A}}\left(x_1\right), \mu_{\tilde{A}}\left(x_2\right)\right).$$

Definition 5 A fuzzy set $\tilde{A}$ in S with membership function $\mu_A : S \to [0, 1]$ represents a fuzzy number if:

(1) The support of fuzzy set $\tilde{A}$ is bounded.
(2) A fuzzy set $\tilde{A}$ should be convex and normalized fuzzy set.

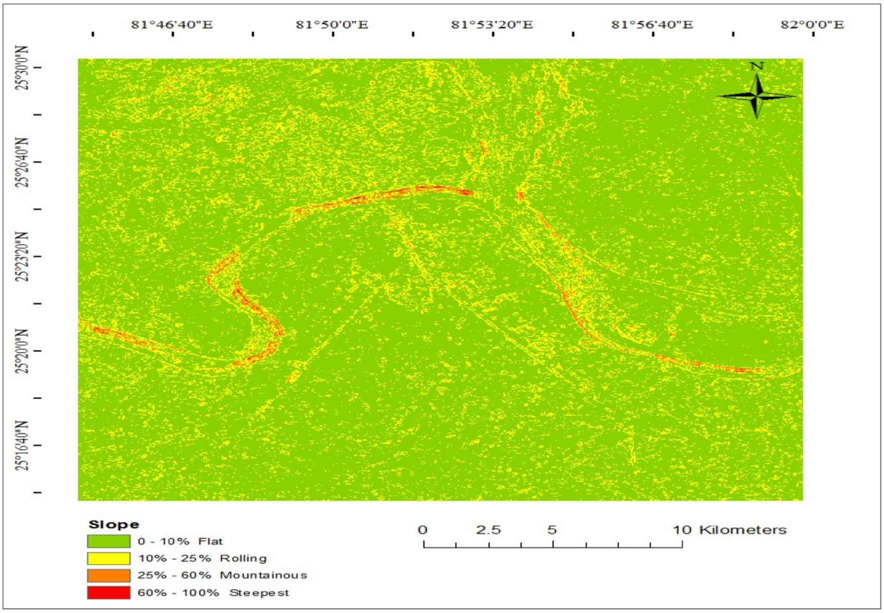


Fig. 4 Slope map of study area

Definition 6 A special case of fuzzy number is a triangular fuzzy number (TFN) $\tilde{N}$ denoted by the triplet $\tilde{N} = \left(a^l, a^m, a^u\right)$with $a^l \le a^m \le a^u$, and it is a fuzzy set if its membership function can be interpreted as (Fig. 4):

$$\mu_{\tilde{N}}(x) = \begin{cases} \frac{x-a^l}{a^m-a^l}, & if, a^l \le x \le a^m \\ \frac{a^u-x}{a^u-a^m}, & if, a^m \le x \le a^u \\ 0, & \text{otherwise} \end{cases}$$

Definition 7 A triangular fuzzy number $\tilde{N} = \left(a^l, a^m, a^u\right)$ is said to be a nonnegative triangular fuzzy number if and only if $a^l \ge 0$, and the set of all these triangular fuzzy numbers is denoted by $TF(R)^+$.

Definition 8 Two triangular fuzzy numbers $\tilde{N} = \left(a^l, a^m, a^u\right)$ and $\tilde{M} = \left(b^l, b^m, b^u\right)$ are said to be equal, $a^l = b^l, a^m = b^m, a^u = b^u$, and it is denoted by $\tilde{N} = \tilde{M}$.

Definition 9 *(Arithmetic of fuzzy numbers)* The basic arithmetic operations for two triangular fuzzy numbers (TFNs) are described by the Zadeh's extension principle, and it may be represented as follows;

Let $\tilde{N} = \left(a^l, a^m, a^u\right)$ and $\tilde{M} = \left(b^l, b^m, a^u\right)$ be two triangular fuzzy numbers and $k \in R$. Define

(1) $$\tilde{N} \oplus \tilde{M} = \left(a^l + b^l, a^m + b^m, a^u + b^u\right)$$

(2)
$$-\tilde{N} = \left(-a^u, -a^m, -a^l\right)$$

(3)
$$\tilde{N} \ominus \tilde{M} = \left(a^l - b^l, a^m - b^m, a^u - b^u\right)$$

(4) For $k \geq 0,\ k\tilde{N} = \left(ka^l, ka^m, ka^u\right)$

(5) For $k \leq 0, k\tilde{N} = \left(ka^u, ka^m, ka^l\right)$

(6) Let $\tilde{N} = \left(a^l, a^m, a^u\right)$ be any arbitrary triangular fuzzy number and $\tilde{M} = \left(b^l, b^m, b^u\right)$ be a nonnegative triangular fuzzy number, then the product of two fuzzy numbers can be defined as:

$$\tilde{N} \otimes \tilde{M} = \begin{cases} \left(a^l b^l, a^m b^m, a^u b^u\right) & if,\ a^l \geq 0 \\ \left(a^l b^u, a^m b^m, a^u b^u\right) & if,\ a^l \leq 0, a^u \geq 0 \\ \left(a^l b^u, a^m b^m, a^u b^l\right) & if,\ a^u < 0 \end{cases}$$

Definition 10 Let $\tilde{N} = \left(a^l, a^m, a^u\right)$ and $\tilde{M} = \left(b^l, b^m, a^u\right)$ be two triangular fuzzy numbers, we say that $\tilde{A}$ is relatively less than $\tilde{B}$ which is denoted by $\tilde{N} \prec \tilde{M}$ if and only if

1. $a^m < b^m$ or
2. $a^m = b^m$ and $(a^u - a^l) > \left(b^u - b^l\right)$ or
3. $a^m = b^m, \left(a^u - a^l\right) = \left(b^u - b^l\right)$ and $a^u + a^l) < \left(b^u + b^l\right)$

Remark 1 It is clear from above that $\tilde{N} = \tilde{M}$ if and only if $a^l < b^l, \left(a^u - a^l\right) = \left(b^u - b^l\right)$ and $\left(a^u + a^l\right) = \left(b^u + b^l\right)$

Remark 2 $\tilde{N} \preccurlyeq \tilde{M}$ if and only if $\tilde{N} \prec \tilde{M}$, or $\tilde{N} = \tilde{M}$.

3.2 Fuzzy AHP

The conventional AHP is inadequate for dealing with the imprecise or vague nature of linguistic assessment (Saaty 1980, 1990, 2008). In fuzzy AHP, common sense linguistic statements can be modeled in the form of fuzzy numbers (Ayag 2014). These triangular fuzzy numbers can be used in the pairwise comparison matrices, and the obtained matrix is called fuzzy pairwise comparison matrix (Chan et al. 2013).

Chang (1996) proposed a method using the triangular fuzzy numbers for the pairwise comparison scale of fuzzy AHP and using the method of synthetic extend analysis to compute the synthetic extend values of the pairwise comparisons (Aggarwal and Singh 2013; Murat et al. 2015).

Step 1 Construction of fuzzy pairwise comparison matrix:

To construct the fuzzy comparison matrix $\tilde{C} = \{\tilde{C}_{ij}\}$ for n criteria or alternatives via pairwise comparison, TFNs are used as follows (Chang 1996; Demirel et al. 2008):

$$\tilde{C} = (\tilde{C}_{ij})_{n\times n} = \begin{bmatrix} N^1_{g1} & N^2_{g1} \dots & N^n_{g1} \\ N^1_{g2} & N^2_{g2} \dots & N^n_{g2} \\ \vdots & \vdots & \vdots \\ N^1_{gn} & N^2_{gn} \dots & N^n_{gn} \end{bmatrix} \tag{1}$$

where $N^j_{gi} = \tilde{C}_{ij} = \left(c^l_{ij}, c^m_{ij}, c^u_{ij}\right)$ is a triangular fuzzy number, and its membership function, $\mu_{\tilde{C}ij}(x)$ or $\mu_{N^j_g i}(x)$, is a continuous function from set of real numbers, R to the closed interval [0, 1].

Step 2 Computation of fuzzy synthetic extent:

The fuzzy synthetic extent with respect to the ith criterion can be calculated as (Chang 1996).

$$S_i = \sum_{j=1}^{n} N^j_{gi} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{n} N^j_{gi}\right]^{-1} \tag{2}$$

This involves the sum of each row of the fuzzy comparison matrix $\tilde{C}$ by fuzzy addition operation of n extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{n} N^j_{gi} = \left(\sum_{j=1}^{n} c^l_{ij}, \sum_{j=1}^{n} c^m_{ij}, \sum_{j=1}^{n} c^u_{ij}\right), i = 1, 2, 3, \dots, n \tag{3}$$

After that, for the computation of $\left[\sum_{i=1}^{n}\sum_{j=1}^{n} N^j_{gi}\right]^{-1}$, fuzzy addition operation on $N^j_{gi}\,(j = 1, 2, 3, \dots n)$ is performed as given below:

$$\sum_{i=1}^{n}\sum_{j=1}^{n} N^j_{gi} = \left(\sum_{i=1}^{n} c^l_{ij}, \sum_{i=1}^{n} c^m_{ij}, \sum_{i=1}^{n} c^u_{ij}\right) \tag{4}$$

And then, compute the inverse vector from Eq. (4), such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} N^j_{gi}\right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} c^u_{ij}}, \frac{1}{\sum_{i=1}^{n} c^m_{ij}}, \frac{1}{\sum_{i=1}^{n} c^l_{ij}}\right] \tag{5}$$

Step 3 Approximation of fuzzy priorities:

To compute the degree of possibility for $S_i \geq S_j$ using the equation as given below:

$$V(S_i \geq S_j) = \operatorname*{Sup}_{y \geq x}[\min(S_i(x), S_j(y)] = \text{height } (S_i \cap S_j) = \mu_S(d) \tag{6}$$

The mathematical formula can be expressed as (Fig. 5)

$$V(S_i \geq S_j) = \begin{cases} 1 & \text{for, } s_i^m \geq s_j^m \\ \frac{s_j^u - s_i^l}{(s_i^u - s_i^m) + (s_j^m - s_j^l)} & \text{for, } s_j^l \leq s_i^u, i, j = 1, 2, \ldots, n; j \neq j \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

where $S_i = (s_i^l, s_i^m, s_i^u)$ and $S_j = (s_j^l, s_j^m, s_j^u)$

Step 4: Finally, priority weight vector $W(w_1, w_2, \ldots, w_n)$ of the fuzzy comparison matrix is computed using the formula

$$w_i = \frac{V(S_i \geq S_j | j = 1, 2, \ldots, n, j \neq i)}{\sum_{k=1}^{n} V(S_k \geq S_j | j = 1, 2, \ldots, n, j \neq k)} \tag{8}$$

For performing a pairwise comparison between fuzzy parameters, first, the decision makers (DMs) have to define linguistic variables for the level of importance (Tyagi et al. 2016). The triangular fuzzy numbers can be used to represent the importance, given in Table 1 (Chang 1996).

Suppose a pair (M_1, M_2) exists such that $M_1 = (m_1, m_2, m_3) \geq M_2 = (m_1', m_2' m_3')$ and $\mu_{M_1(x)} = \mu_{M_2(x)}$, then we have (Chang 1996).$V(M_1 \geq M_2) = 1$.

Since M_1 and M_2 are convex fuzzy number,

$$\begin{cases} V(M_1 \geq M_2) = 1, & \text{if, } m_2 \geq m_2' \\ V(M_1 \geq M_2) = \text{height}(M_1 \cap M_2) = \mu_{M_1(d)}, & \text{Otherwise} \end{cases} \tag{9}$$

where d represents the ordinate of intersection point between μ_{M1} and μ_{M2}. The fuzzy membership value of ordinate d is defined as follows:

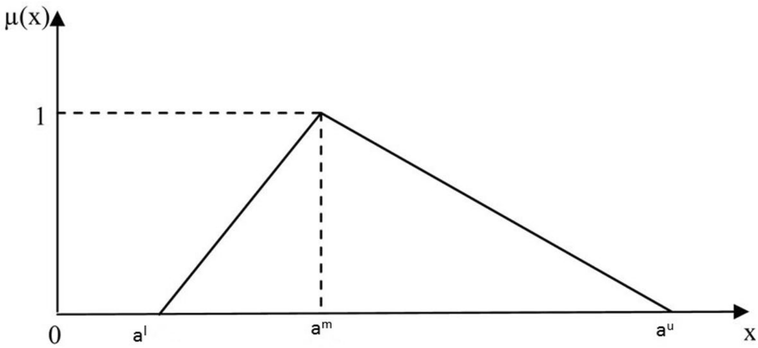


Fig. 5 Membership function for triangular fuzzy number

Table 1 Triangular fuzzy number for linguistic variables used in this study (Vahidnia et al. 2009)

Linguistic importance scale	Triangular fuzzy numbers (TFNs)	Reciprocal scale triangular fuzzy numbers (TFNs)
Equally important	(1, 1, 1)	(1, 1, 1)
Weakly more important	(2/3, 1, 3/2)	(2/3, 1, 3/2)
Strongly more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Absolutely more important	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)

$$V\left(M_1 \geq M_2\right) = \text{height}\left(M_1 \cap M_2\right) = \mu_{M1(d)} = \frac{m_1 - m_3}{\left(m_2^{'} - m_3^{'}\right) + \left(m_2 - m_3\right)} \tag{10}$$

For the comparison of M_1 and M_2, the value of $V\left(M_1 \geq M_2\right)$ first needs to be calculated. The degree of possibility for convex fuzzy number to greater than k convex fuzzy numbers $M_i (i = 1, 2, \ldots, k)$ is defined as follows:

$$V\left(M \geq M_1, M_2, \ldots, M_k\right) = \min\left(V\left(M \geq M_i\right)\right), i = 1, 2, \ldots, k \tag{11}$$

Suppose that

$$W'\left(A_i\right)\min\left(V\left(S_i \geq S_k\right)\right), k = 1, 2, \ldots, n; k \neq i \tag{12}$$

The fuzzy weighted vector can be calculated by:

$$W'\left(A_i\right) = \left[W'\left(A_1\right), W'\left(A_2\right), \ldots, W'\left(A_n\right)\right]^{\mathrm{T}} \tag{13}$$

where $A_i (i = 1, 2, \ldots, n)$ are the n elements. Using the normalization procedure, the normal weighted vector is given by

$$W\left(A_i\right) = \left[W\left(A_1\right), W\left(A_2\right), \ldots, W\left(A_n\right)\right]^{\mathrm{T}} \tag{14}$$

where W is considered to be a non-fuzzy number.

3.3 Proposed fuzzy AHP-based intelligent model for route alignment planning

The proposed model is based on GIS and fuzzy AHP (Banai 1993). In this approach, route alignment is designed and evaluated by fuzzy AHP analytical techniques. It involves a collection of data from different sources including remote sensing data, topographic and future land use map of Allahabad city. Preprocessing of data is the first fundamental step in a route alignment decision-making model (Benz et al. 2004). A number of criteria map layers for various factors and constraint which influence the alignment are generated. Evaluation of criteria map can only be compared if the measurement units are same. Because every criterion has collected from different sources, and their own characteristics and extent and each datum of criteria had its own dimension and distribution, it was difficult to directly compare them or include them together in an operational system (Singh and Singh 2017). The process of setting the common platform of each criterion is known as the standardization of criteria (Feizizadeh and Blaschke 2013). Standardization of the criteria maps of attributes is performed in ESRI Spatial Analyst reclassification module. In this process, scale of 0–1 is used for criteria standardization. Reclassification transformation is used to transform the criteria attributes into a cost scale that ranges from 0 to 1, where the value near to 0 is the least cost and 1 is the highest cost. The criteria are categorized based on available environmental, social, economic and technical factors and calculate each criteria weight using fuzzy-AHP method. A surface cost analysis method is applied for generation of weighted relative surface cost maps with the integration of cost criteria weights, cost criteria maps and constraints maps into GIS environment (Yanar and Akyürek 2006). This relative surface cost maps are followed by computation of accumulated cost distance maps and cost direction maps with the help of cost distance analysis method. Subsequently, the four least-cost paths are generated from the integration of cost distance maps and cost direction maps using cost path algorithm. This least-cost path is converted into polyline features for optimum route alignment designing. A polyline feature is helpful for calculation of criteria values as mentioned in Table 6. The flowchart of the proposed fuzzy AHP-based methodology is given in Fig. 6. The proposed methodology can be summarized in the following steps:

Step 1 Preparation of cost criteria and constraints maps using fuzzy member function.
Step 2 Calculate weights of the cost criteria using fuzzy-AHP method as mentioned in Tables 2, 3, 4 and 5.
Step 3 Generate weighted relative cost surface map from cost criteria maps and weights of cost criteria using fuzzy overlay techniques.
Step 4 Generate cost distance and cost direction analysis maps for each relative surface cost maps.
Step 5 Apply cost path algorithm for each cost distance and cost direction map.
Step 6 Generate the cost path alignment from source to destination points.
Step 7 Convert each path alignment into polyline features.
Step 8 Apply buffer analysis on each polyline features.
Step 9 Apply fuzzy-AHP method to evaluate proposed four alignments.
Step 10 Identification of optimum alignment on the basis of the data obtained in step 9.
Step 11 If the decision maker satisfied with the proposed alignment, then STOP, otherwise reevaluate the proposed alignments.

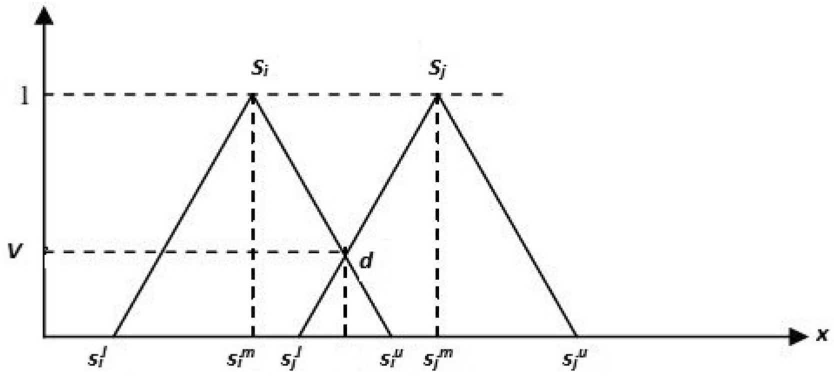


Fig. 6 The degree of possibility V (Vahidnia et al. 2009)

Table 2 Weight calculations for technical cost theme

	Flat	Rolling	Mountainous	Steepest	Weights
Flat	(1, 1, 1)	(0.67, 1, 1.5)	(0.29, 0.33, 0.4)	(0.22, 0.25, 0.29)	0.23
Rolling	(0.67, 1, 1.5)	(1, 1, 1)	(0.4, 0.5, 0.67)	(0.22, 0.25, 0.29)	0.26
Mountainous	(2.5, 3, 3.5)	(1.5, 2, 2.5)	(1, 1, 1)	(0.29, 0.33, 0.4)	0.26
Steepest	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(2.5, 3, 3.5)	(1, 1, 1)	0.26

4 Implementation of proposed methodology

4.1 Preparation of cost criteria and constraint maps

The first fundamental steps in intelligent decision making for route alignment planning using fuzzy-AHP approach is the generation of fuzzy cost criteria maps (DellÁcqua 2012). Twelve cost criteria map layers for the study area, viz. drainage network, road, rail, agriculture land, industrial area, urban area, rural habitation, population density, water body, trees, river and sandbank, are generated using GIS and remote sensing techniques (Benz et al. 2004). The criteria used in this study are as follows:

(i) *Drainage network* Drainage network consideration is important for a number of culvert cost estimation at the construction time. If the route alignment crosses the drainage network, the culvert is required. A 100-meter buffer was created around the drainage network. An area nearby drainage network is costlier than area away from drainage network.

(ii) *Road network* Road network is crucial to route selection process. If route alignment area is the overlay on existing roads, it could be less expensive area than that away from existing roads area. A 20-meter buffer area was created around existing roads side.

Table 3 Weight calculations for the economic cost theme

	Roads	Railway	Drainage	Agriculture	Industrial	River	Weights
Roads	(1, 1, 1)	(0.29, 0.33, 0.4)	(0.4, 0.5, 0.67)	(0.22,0.25,0.29)	(0.67, 1, 1.5)	(0.22,0.25,0.29)	0.10
Railway	(2.5, 3, 3.5)	(1, 1, 1)	(1.5, 2, 2.5)	(0.29, 0.33, 0.4)	(3.5, 4, 4.5)	(0.22,0.25,0.29)	0.10
Drainage	(1.5, 2, 2.5)	(0.4, 0.5, 0.67)	(1, 1, 1)	(0.29, 0.34, 0.4)	(0.67, 1, 1.5)	(0.22,0.25,0.29)	0.26
Agriculture	(3.5, 4, 4.5)	(2.5, 3, 3.5)	(2.5, 3, 3.5)	(1, 1, 1)	(3.5, 4, 4.5)	(0.29, 0.33, 0.4)	0.14
Industrial	(0.67, 1, 1.5)	(0.22,0.25,0.29)	(0.67, 1, 1.5)	(0.22,0.25,0.29)	(1, 1, 1)	(0.22,0.25,0.29)	0.15
River	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)	(1, 1, 1)	0.26

Table 4 Weight calculations for the social cost theme

	Urban area	Rural habitation	Population density	Weights
Urban area	(1, 1, 1)	(3.5, 4, 4.5)	(2.5, 3, 3.5)	0.34
Rural habitation	(0.23,0.25,0.29)	(1, 1, 1)	(0.67, 1, 1.5)	0.32
Population density	(0.29, 0.34, 0.4)	(0.67, 1, 1.5)	(1, 1, 1)	0.34

Table 5 Weight calculations for the environmental cost theme

	Water body	Trees	Sand bank	Weights
Water body	(1, 1, 1)	(0.67, 1, 1.5)	(1.5, 2, 2.5)	0.46
Trees	(0.67, 1, 1.5)	(1, 1, 1)	(0.67, 1, 1.5)	0.33
Sand bank	(0.4, 0.5, 0.67)	(0.67, 1, 1.5)	(1, 1, 1)	0.21

(iii) *Railway* Railway line consideration is important for estimation of a construction cost. If the route alignment crosses the railway line, underpass or overpass bridge is required. A 200-meter buffer was created around the railway network. An area nearby railway network is costlier than area away from railway network.

(iv) *Agriculture land* The alignment of roads should be decided so that costly agricultural land is avoided for the acquisition of the land. Agriculture land is crucial to route selection process. The crossing of agriculture land is high cost than that of other areas.

(v) *Industrial area* Acquiring industrial area land is less expensive than other areas. An alignment passes through the industrial area is easy. The land for acquiring in such areas is less expensive.

(vi) *Urban area* The urban area is an important criterion in selecting a route alignment due to issues of fundamental stability. In order to reduce both construction cost and compensation cost. Alignment that passes through the urban area is highly costlier.

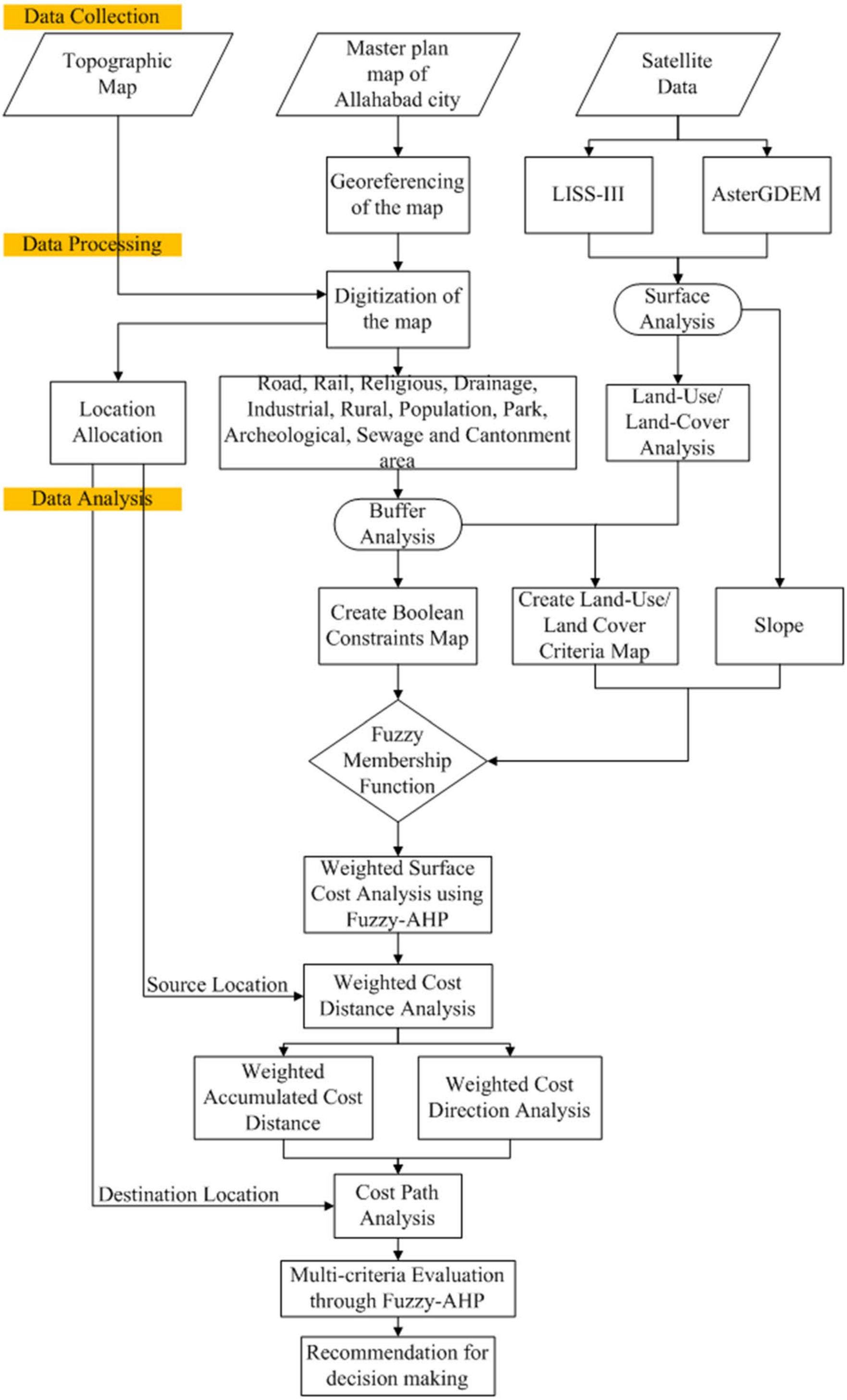
(vii) *Rural habitation* Rural habitation area exists in the study area. Such area should not be crossed by the alignment. A protection buffer zone of 500 meters around rural habitation is created.

(viii) *Population density* A population density criterion is an important consideration for accessibility measurement.

(ix) *Water body* A water body is considered some small reservoirs such as ponds, wells, etc. Crossing such protectorate is considered a highly costlier.

(x) *Trees* The alignment of roads should be decided so that costly dense forests/trees are avoided for the acquisition of the land.

(xi) *River* A river map has been extracted with the help of attribute table of land use/land-cover map in ArcGIS. The river map has been used to estimate the cost of bridge construction, if required, during the route alignment construction phase.


Data Collection
Topographic Map
Master plan map of Allahabad city
Satellite Data
Georeferencing of the map
LISS-III
AsterGDEM
Data Processing
Digitization of the map
Surface Analysis
Location Allocation
Road, Rail, Religious, Drainage, Industrial, Rural, Population, Park, Archeological, Sewage and Cantonment area
Land-Use/ Land-Cover Analysis
Data Analysis
Buffer Analysis
Create Boolean Constraints Map
Create Land-Use/ Land Cover Criteria Map
Slope
Fuzzy Membership Function
Weighted Surface Cost Analysis using Fuzzy-AHP
Source Location
Weighted Cost Distance Analysis
Weighted Accumulated Cost Distance
Weighted Cost Direction Analysis
Destination Location
Cost Path Analysis
Multi-criteria Evaluation through Fuzzy-AHP
Recommendation for decision making

◂**Fig. 7** Flowchart of the proposed fuzzy AHP-based intelligent decision-making model for route alignment planning

(xii) *Sandbank* A sandbank area has been extracted with the help of attribute table of land use/land cover map in ArcGIS. The sandbank area has been used to analyze the flood/natural drainage area which affects the alignment of roads. It is considered as criteria map for proper planning of route alignment (Fig 7).

(xiii) *Constraint areas* The areas such as park and government, archeological, sewage, cantonment and religious are considered as constraint areas. A 200-meter buffer was created around each constraint areas. The constraint area was converted into Boolean maps, each Boolean map was combined, and finally, a constraint map was generated as shown in Fig. 8.

4.2 Cost criteria weights using fuzzy AHP

The attribute factors are represented in terms of map layers in the GIS database and attribute values for each pixel that occurred in raster format (Kiker et al. 2005; Eastman 1999). The fuzzy AHP is a structured tool for the quantification, comparison and analysis of the complex decisions situations when the data are represented by the fuzzy numbers (Comes et al. 2013; Hill et al. 2005). In fuzzy-AHP method, first, the decision problem decomposes into the hierarchy of subproblems (Demirel et al. 2008). Then expertise is used for the evaluation of the relative importance of various fuzzy criteria using the pairwise comparisons matrix as mentioned in Tables 2, 3, 4 and 5 (Malczewski 2000; Eastman et al. 1995). The weights of each criterion as mentioned in Tables 2, 3, 4 and 5 are used for creation of weighted relative surface cost maps (Fig 9).

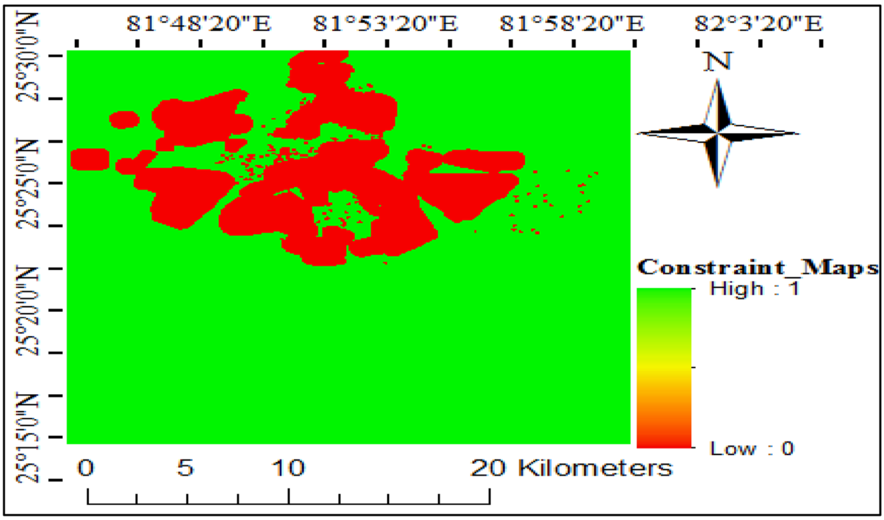


Fig. 8 Constraint maps

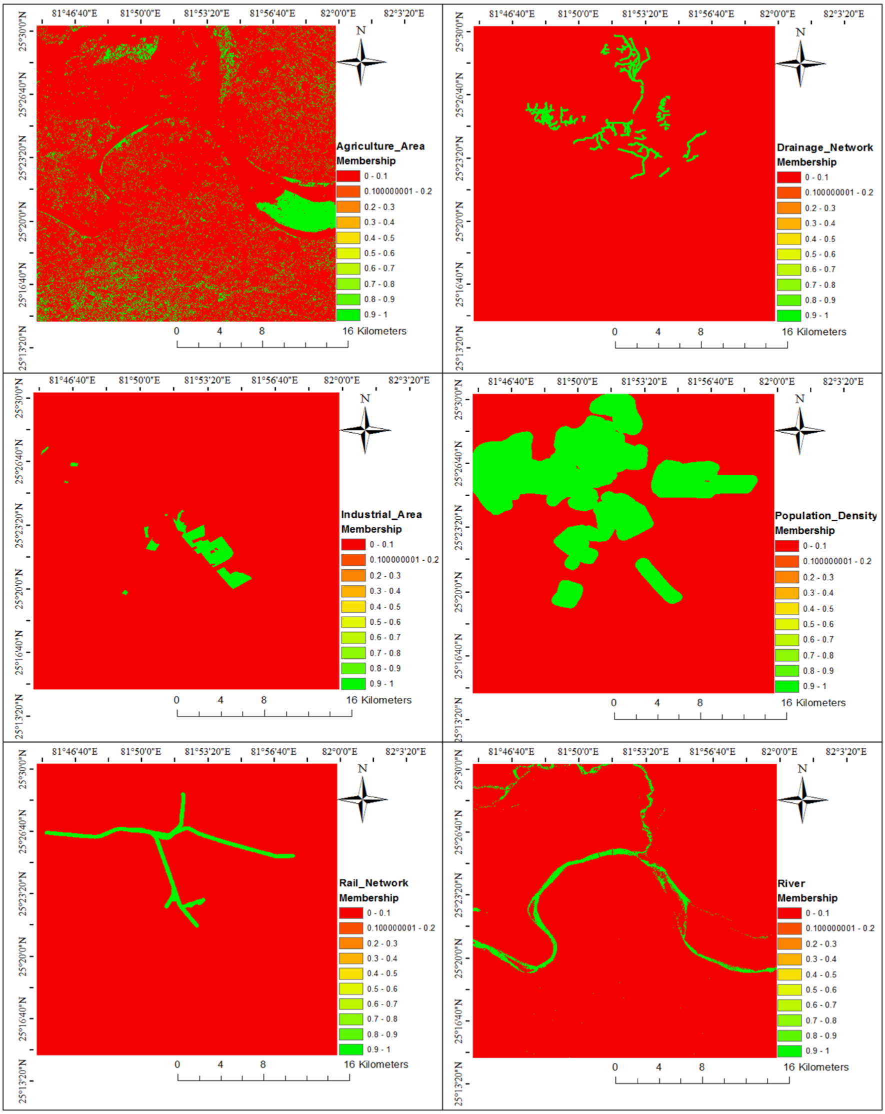


Fig. 9 Cost criteria maps with fuzzy membership values

4.3 Weighted relative cost surface analysis

In decision-making process of route alignment, planning, cost analysis and evaluation are required. To create a cost surface map, all the criteria maps are transformed into a common measurement scale such as 0–1, with 1 being the highest cost and near to 0 being the least cost (Feizizadeh and Blaschke 2013). The transform operation is performed in ArcGIS (ESRI) with the fuzzy membership

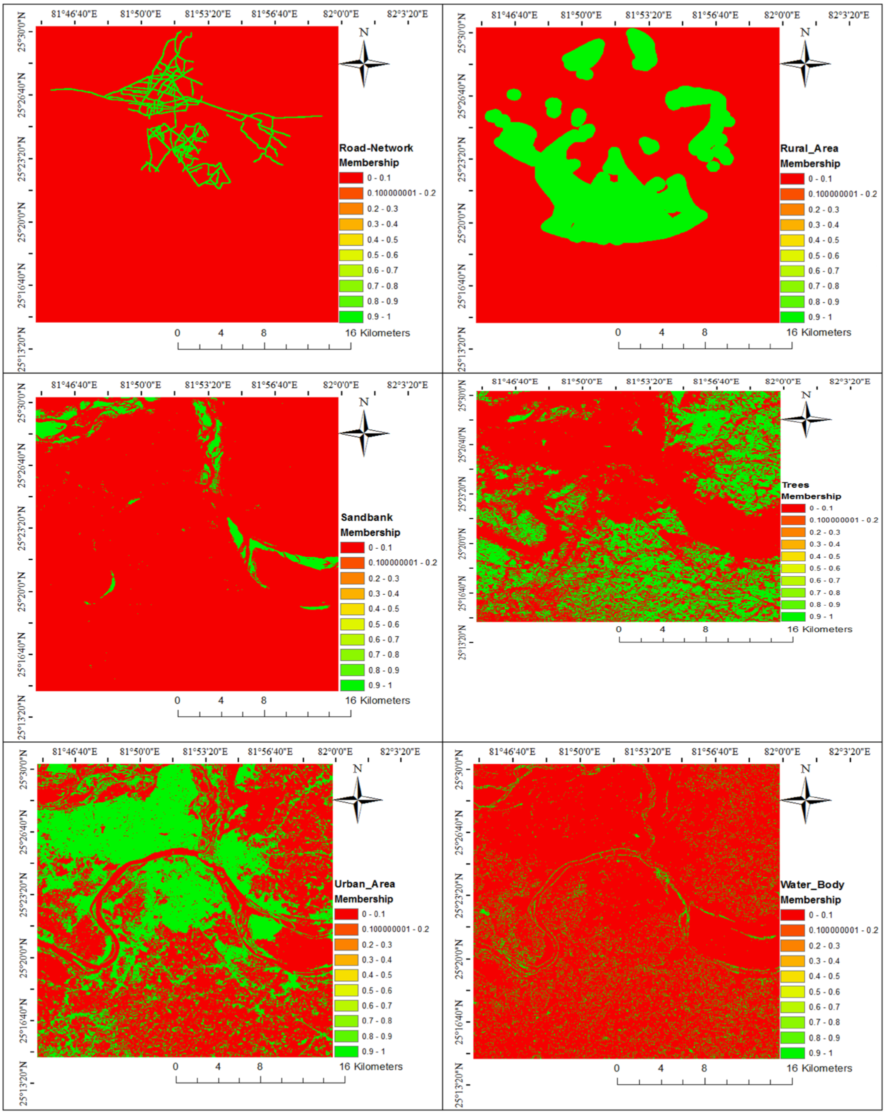


Fig. 9 (continued)

of spatial analysis tool. This is one of the most common approaches for intelligent decision making of multi-criteria problems (Voogd 1983). The relative cost surface map is defined as a raster map, where the value of each pixel represents the estimated relative cost of route alignment and construction through the pixel (Malczewski and Rinner 2015; Eastman et al. 1995). The value of each cell in the cost criteria map represents the cost per unit distance of crossing that cell (which does not include the physical distance traveled as a measurement) (Singh and

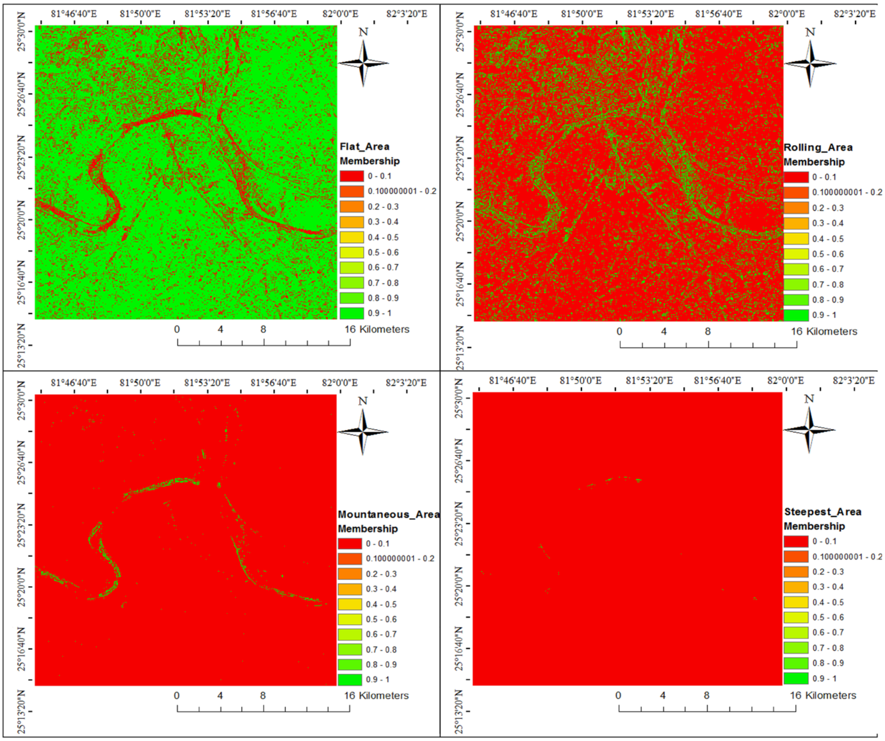


Fig. 9 (continued)

Singh 2017; Yakar and Celik 2014; Yanar and Akyürek 2006; Xu and Lathrop 1994). The cost is cumulative, having inputs from various data layers (Yildirim et al. 2006; Sadek et al. 1999).

The relative cost surface is generated with the help of fuzzy overlay analysis (FOA) tool in ArcGIS (ESRI) software. Relative cost for this analysis is identified and classified into 4 different themes, viz. technical, social, economic and environmental cost surface raster (Singh and Singh 2017).

$$\text{Relative Cost Surface } = \sum w_i x_i \times \prod c_j, \text{with} \sum w_i = 1 \tag{15}$$

where w_i = weights assigned to each criterion. x_i = factors score (cells). c_j = constraint maps. $\sum$ = sum of weighted factors. $\prod$ = product of constraints.

Using Eq. (15), the following four different viewpoints of relative cost surface maps are created as shown in Fig. 10.

Technical cost = ([Cost of Flat area * 0.23] + [Cost of Rolling area * 0.26] + [Cost of Mountainous area * 0.26] + [Cost of Steepest area * 0.26]) * ([Parks and government area] * [Archeological area] * [Sewage plant area] * [Cantonment area] * [Religious places]).

Social cost = ([Cost of Rural habitation * 0.34] + [Cost of Population * 0.32] + [Cost of Urban area * 0.34]) * ([Parks and government area] *

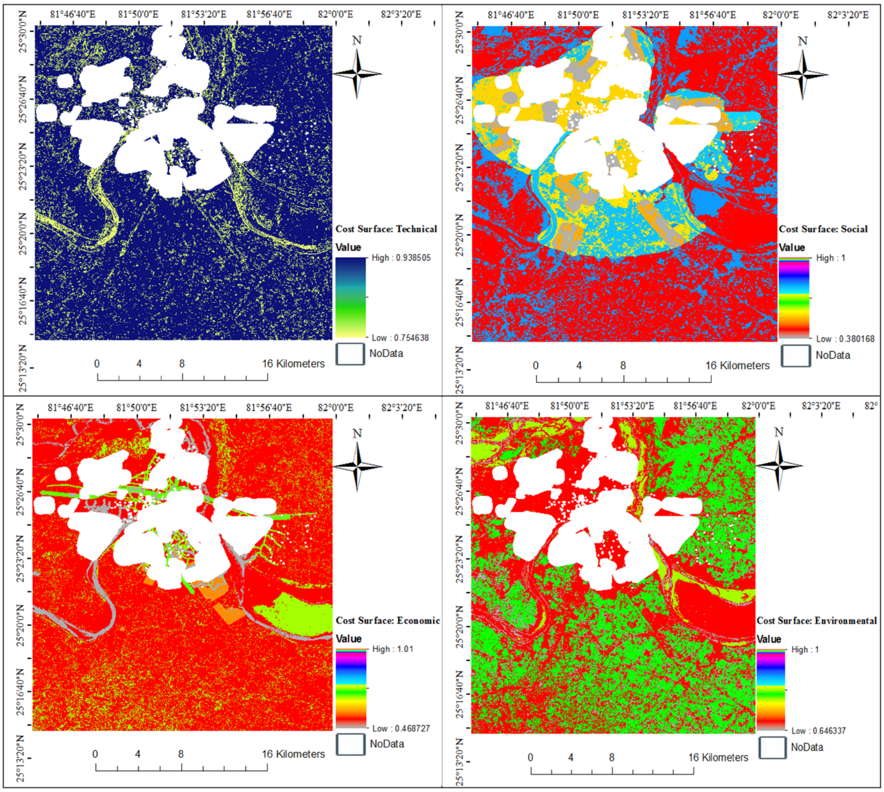


Fig. 10 Relative cost surface analysis maps

[Archeological area] * [Sewage plant area] * [Cantonment area] * [Religious places]).

Economical cost = ([Cost of Road Network * 0.10] + [Cost of Railway * 0.10] + [Cost of Drainage * 0.26] + [Cost of Agriculture * 0.14] + [Cost of Industrial * 0.15] + [Cost of River * 0.26]) * ([Parks and government area] * [Archeological area] * [Sewage plant area] * [Cantonment area] * [Religious places]).

Environmental cost = ([Cost of Sand bank area * 0.21] + [Cost of Trees * 0.33] + [Cost of water body area * 0.46]) * ([Parks and government area] * [Archeological area] * [Sewage plant area] * [Cantonment area] * [Religious places]).

4.4 Cost distance analysis

4.4.1 Weighted cost distance analysis map

Cost distance algorithm requires source locations and weighted relative cost surface map as input. Cost distance analysis determines the shortest weighted distance (or accumulated cost distance) from each cell to the closest source location (Douglas 1994; Xu and Lathrop 1994). Cost distance analysis contains distance in cost units, not in geographic units. The computation of a weighted or accumulated cost distance maps are based on the neighborhood relationship concept in a grid-based model. Each cell in a raster or grid-based model is represented as a network node (Atkinson et al. 2005; Collischonn and Pilar 2000). The cost distance algorithm is based on graph theory techniques where each cell is considered as a node and each node is connected to its adjacent nodes by multiple links. Every link is associated with impedance values (Yu et al. 2003; Carver 1991).

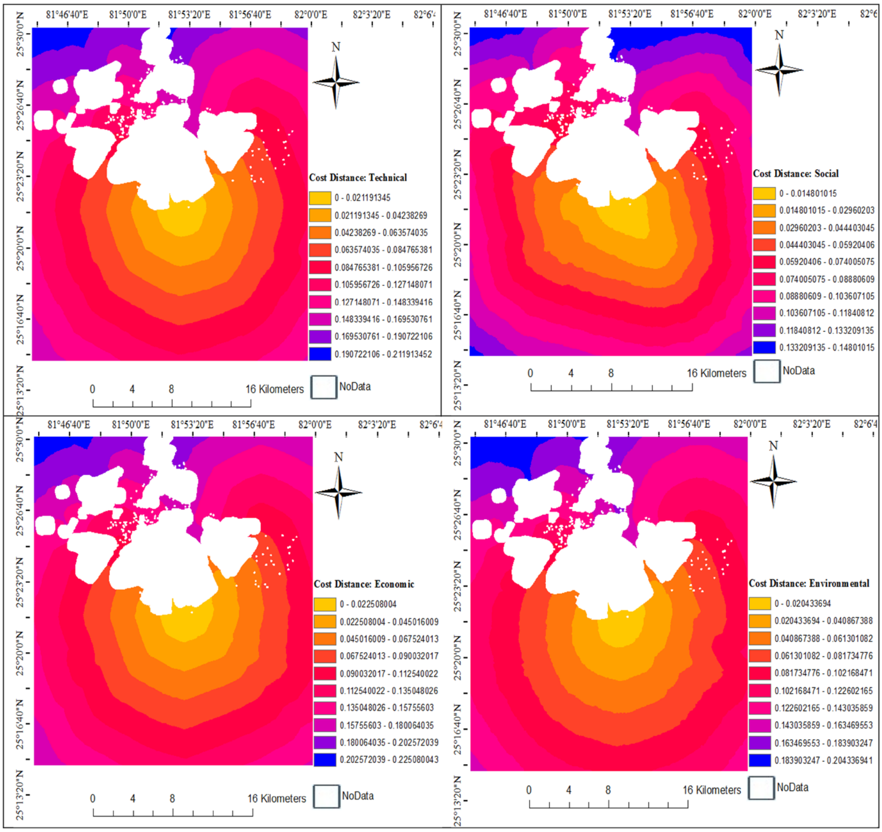


Fig. 11 Cost distance analysis maps

Weighted cost distance maps or accumulated cost distance maps are shown in Fig. 11.

4.4.2 Weighted cost direction analysis map

Cost direction analysis algorithm for determining the back link raster assigns a value to each cell. The value 0 is reserved for source cells. The values 1–8 encode the direction in a clockwise manner starting from the right. This process is done for every cell in the output back link raster, producing output rasters, the direction to travel from every cell in the cost distance raster back to the source (Douglas 1994; Xu and Lathrop 1994).

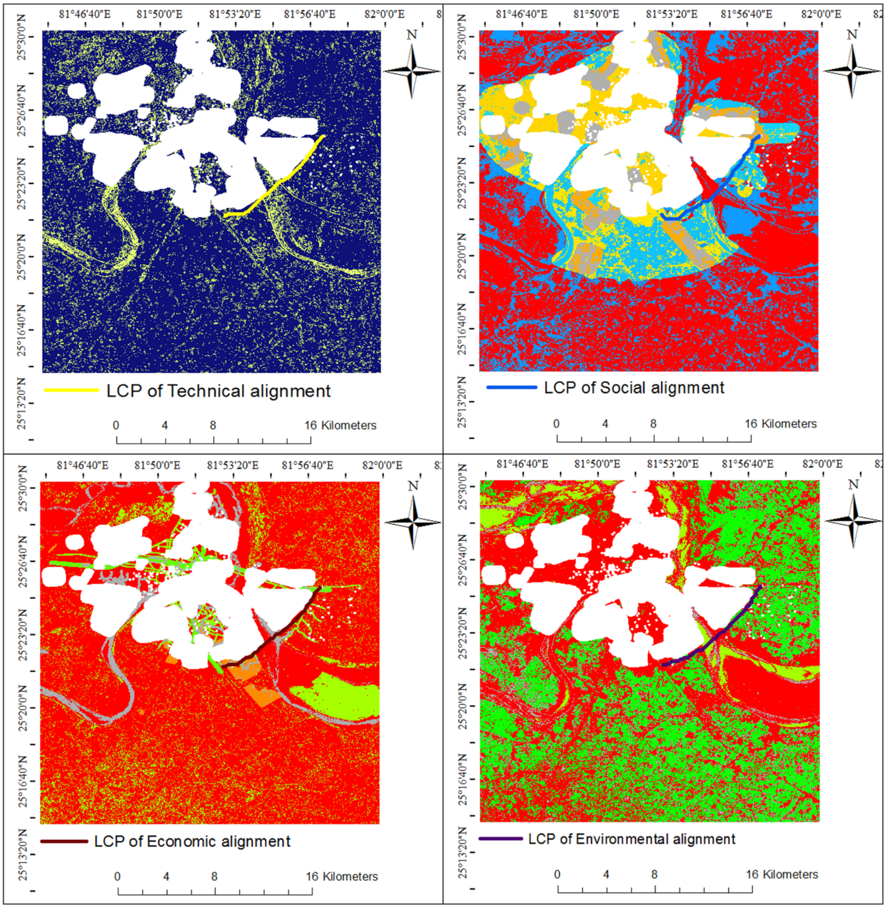


Fig. 12 Least-cost path modeled routes

4.5 Cost path algorithms

Cost path algorithm generated the least-cost path from a destination to source locations (Douglas 1994). The cost of a path between source and destination is the sum of the costs of the edges on that path. The cost path algorithm requires that costs always be positive, so there is no benefit in passing through a node more than once. In this algorithm, the eight neighbors of a cell are evaluated and the path moves to the cell with the smallest accumulated value (Yakar and Celik 2014; Effat and Hassan 2013; Gonçalves 2010; Yu et al. 2003; Xu and Lathrop 1994). The algorithm repeats itself until the source and destination points are connected (Collischonn and Pilar 2000). The complete path represents the smallest sum of cell values between two locations as shown in Fig. 12.

5 Evaluation and selection of optimal alignments

5.1 Evaluation using priority weight

Least-cost path determines a thin layer of route alignment, which is raster dataset. Least-cost path route alignment is applicable when the thin layer of alignment converted into raster data to polyline features. Identification of optimum route alignment in decision-making model using GIS and fuzzy AHP is used to simultaneously minimize the alignment impact area of economic, environmental, social, technical preserved land and construction cost. The criteria and factor maps are obtained from the study area, and the two-dimensional location coordinates are used as the source point (81.881, 25.365) and destination point (81.952, 25.425) for the design of the route alignments. The proposed alignments are basically designed and planned for a typical 6-lane road; the 60 m of the right of way area will be required (Kadiyali 2011). For the designing 6-lane road, create (60 meters) proximity analysis along the alignments using spatial analysis function of ArcGIS software. Multi-criteria such as area of land use, maximum slope %, length of alignments, no. of rail network intersections, no. of road intersections, no. of drainage pattern intersections, no. of constraints area intersections and sum of cost path are all important for the identification of optimum route alignments. It is helpful for quantitative-based analysis to calculate the value of criteria along the alignments as shown in Table 6.

The numbers of rail, road, drainage, constraints area intersection are calculated with the help of overlay techniques in ArcGIS software. The length of the alignments is calculated with the help of calculate geometry tool in ArcGIS software. Clip method is used to extract the intersection area of land use within the 60-meter buffer of each alignment and then calculate the area of land use using cell resolution and total number of pixel along the alignments with field calculator tool in ArcGIS software. Maximum priority weight is assigned for each criteria layer. The total sum of priority weight values is not exceeding above 100%. Every suggested alignment has contained criteria values and % weight. A criterion has assigned maximum weights which satisfy optimum condition and calculate relative weight of each alignment using mathematical process. Calculate the sum of the weight of each

Table 6 Route alignment selection criteria

Multi-criteria	Maximum priority weights for each criterion (%)	Social route alignment (alignment 1)		Environmental route alignment (alignment 2)		Economical route alignment (alignment 3)		Technical route alignment (alignment 4)	
		Criteria values	%	Criteria values	%	Criteria values	%	Criteria values	%
Area of land use (ha)									
River		7		6		5		5	
Water body		11		10		8		8	
Sandbank		9		12		10		10	
Urban area		67		27		41		47	
Trees		31		62		50		46	
Agriculture land		7		9		8		8	
Industrial area		32		32		32		28	
Rural area		12		6		20		25	
Population density area		5		3		4		4	
Total area	20	181.00	18.45	167.00	20	178.00	18.76	181.00	18.45
Max. slope %	5	3.64	5	4.02	4.53	4.11	4.43	4.11	4.43
Length of alignments (km)	20	11	18.18	11	18.18	10	20	10	20
No. of rail network intersections	5	1	5	1	5	1	5	1	5
No. of road intersections	5	6	4.17	8	3.13	6	4.17	5	5
No. of drainage pattern intersections	5	1	5	1	5	3	1.67	2	2.5
No. of constraints area Intersections	5	Nil	5	Nil	5	Nil	5	Nil	5
Sum of cost path	20	26.18	19.25	28.32	17.80	31.23	16.14	25.20	20
Total sum of weight	100		80.05		78.64		75.17		80.38

Table 7 Pairwise comparison matrix of all criteria

	Agriculture cost	Drainage cost	Industrial cost	Railway cost	Trees cost	Urban area cost	Water body cost	Sand bank cost	River cost	Rural area cost	Road cost	Population cost	Priority weights
Agriculture cost	(1, 1, 1)	(2.5, 3, 3.5)	(3.5, 4, 4.5)	(2.5, 3, 3.5)	(1.5, 2, 2.5)	(.29, .33, .4)	(1.5, 2, 2.5)	(.29, .33, .4)	(.22, .25, .29)	(.67, 1, 1.5)	(3.5, 4, 4.5)	(.67, 1, 1.5)	0.05
Drainage cost	(.29, .33, .4)	(1, 1, 1)	(.67, 1, 1.5)	(.29, .33, .4)	(.67, 1, 1.5)	(.22, .25, .29)	(.67, 1, 1.5)	(.4, .5, .67)	(.22, .25, .29)	(.22, .25, .29)	(.67, 1, 1.5)	(.4, .5, .67)	0.07
Industrial cost	(.22, .25, .29)	(.67, 1, 1.5)	(1, 1, 1)	(.22, .25, .29)	(.67, 1, 1.5)	(.22, .25, .29)	(.67, 1, 1.5)	(.67, 1, 1.5)	(3.5, 4, 4.5)	(.29, .33, .4)	(.67, 1, 1.5)	(.67, 1, 1.5)	0.07
Railway cost	(.29, .33, .4)	(2.5, 3, 3.5)	(3.5, 4, 4.5)	(1, 1, 1)	(3.5, 4, 4.5)	(.22, .25, .29)	(1.5, 2, 2.5)	(.67, 1, 1.5)	(3.5, 4, 4.5)	(.29, .33, .4)	(.67, 1, 1.5)	(.67, 1, 1.5)	0.05
Trees cost	(.4, .5, .67)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.22, .25, .29)	(1, 1, 1)	(.22, .25, .29)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.22, .25, .29)	(.22, .25, .29)	(.67, 1, 1.5)	(.4, .5, .67)	0.08
Urban area cost	(2.5, 3, 3.5)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(1, 1, 1)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(.67, 1, 1.5)	(3.5, 4, 4.5)	(.67, 1, 1.5)	(1.5, 2, 2.5)	0.2
Water body cost	(.4, .5, .67)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.4, .5, .67)	(.67, 1, 1.5)	(.22, .25, .29)	(1, 1, 1)	(3.5, 4, 4.5)	(.22, .25, .29)	(.22, .25, .29)	(.67, 1, 1.5)	(.4, .5, .67)	0.03
Sand bank cost	(2.5, 3, 3.5)	(1.5, 2, 2.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.22, .25, .29)	(.22, .25, .29)	(1, 1, 1)	(.22, .25, .29)	(.22, .25, .29)	(.67, 1, 1.5)	(.29, .33, .4)	0.03
River cost	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(.22, .25, .29)	(.22, .25, .29)	(3.5, 4, 4.5)	(.67, 1, 1.5)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(1, 1, 1)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	0.2
Rural area cost	(.67, 1, 1.5)	(3.5, 4, 4.5)	(2.5, 3, 3.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)	(.22, .25, .29)	(3.5, 4, 4.5)	(3.5, 4, 4.5)	(.22, .25, .29)	(1, 1, 1)	(3.5, 4, 4.5)	(.67, 1, 1.5)	0.14
Road cost	(.22, .25, .29)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.22, .25, .29)	(.22, .25, .29)	(1, 1, 1)	(.67, 1, 1.5)	0.03
Population cost	(.67, 1, 1.5)	(1.5, 2, 2.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(1.5, 2, 2.5)	(.4, .5, .67)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(.22, .25, .29)	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	0.05

Table 8 Pairwise comparison matrix for calculation of weights for the evaluation of alternative route alignments

Agriculture cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Drainage cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Economical route	(1, 1, 1)	(.29, .33, .4)	(.29, .33, .4)	(.67, 1, 1.5)	.03	Economical route	(1, 1, 1)	(1, 1, 1)	(1.5, 2, 2.5)	(.67, 1, 1.5)	.31
Environmental route	(2.5, 3, 3.5)	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	.38	Environmental route	(1, 1, 1)	(1, 1, 1)	(1.5, 2, 2.5)	(.67, 1, 1.5)	.31
Social route	(2.5, 3, 3.5)	(.67, 1, 1.5)	(1, 1, 1)	(1.5, 2, 2.5)	.47	Social route	(.4, .5, .67)	(.4, .5, .67)	(1, 1, 1)	(.67, 1, 1.5)	.13
Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(.4, .5, .67)	(1, 1, 1)	.12	Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	.25
Industrial cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Rail route cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Economical route	(1, 1, 1)	(.67, 1, 1.5)	(2.5, 3, 3.5)	(.67, 1, 1.5)	.38	Economical route	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	.23
Environmental route	(.67, 1, 1.5)	(1, 1, 1)	(.67, 1, 1.5)	(.4, .5, .67)	.11	Environmental route	(.67, 1, 1.5)	(1, 1, 1)	(.67, 1, 1.5)	(.29, .33, .4)	.16
Social route	(.29, .33, .4)	(.67, 1, 1.5)	(1, 1, 1)	(.29, .33, .4)	.03	Social route	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	(.67, 1, 1.5)	.23
Technical route	(.67, 1, 1.5)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(1, 1, 1)	.48	Technical route	(.67, 1, 1.5)	(2.5, 3, 3.5)	(.67, 1, 1.5)	(1, 1, 1)	.37
Trees cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Urban area cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Economical route	(1, 1, 1)	(1.5, 2, 2.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	.28	Economical route	(1, 1, 1)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(.67, 1, 1.5)	.48
Environmental route	(.4, .5, .67)	(1, 1, 1)	(.67, 1, 1.5)	(.29, .33, .4)	.16	Environmental route	(.4, .5, .67)	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	.11

Table 8 (continued)

Agriculture cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Drainage cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Social route	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	(.4, .5, .67)	.13	Social route	(.29, .33, .4)	(.67, 1, 1.5)	(1, 1, 1)	(.29, .33, .4)	.03
Technical route	(.67, 1, 1.5)	(2.5, 3, 3.5)	(1.5, 2, 2.5)	(1, 1, 1)	.43	Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(2.5, 3, 3.5)	(1, 1, 1)	.38
Water body cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Sand bank cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Economical route	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	.23	Economical route	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	.25
Environmental route	(.67, 1, 1.5)	(1, 1, 1)	(.4, .5, .67)	(.29, .33, .4)	.07	Environmental route	(.67, 1, 1.5)	(1, 1, 1)	(1.5, 2, 2.5)	(.67, 1, 1.5)	.30
Social route	(.67, 1, 1.5)	(1.5, 2, 2.5)	(1, 1, 1)	(.67, 1, 1.5)	.31	Social route	(.67, 1, 1.5)	(.4, .5, .67)	(1, 1, 1)	(.4, .5, .67)	.16
Technical route	(.67, 1, 1.5)	(2.5, 3, 3.5)	(.67, 1, 1.5)	(1, 1, 1)	.39	Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(1.5, 2, 2.5)	(1, 1, 1)	.30
River cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Rural area cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Economical route	(1, 1, 1)	(.4, .5, .67)	(.67, 1, 1.5)	(.67, 1, 1.5)	.21	Economical route	(1, 1, 1)	(.29, .33, .4)	(.67, 1, 1.5)	(.67, 1, 1.5)	.12
Environmental route	(1.5, 2, 2.5)	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	.30	Environmental route	(2.5, 3, 3.5)	(1, 1, 1)	(1.5, 2, 2.5)	(.67, 1, 1.5)	.50
Social route	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	(.67, 1, 1.5)	.24	Social route	(.67, 1, 1.5)	(.4, .5, .67)	(1, 1, 1)	(.67, 1, 1.5)	.15
Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	.24	Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	.23

Table 8 (continued)

Agriculture cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Drainage cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Road network cost	Economical route	Environmental route	Social route	Technical route	Priority weights	Population cost	Economical route	Environmental route	Social route	Technical route	Priority weights
Economical route	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	.25	Economical route	(1, 1, 1)	(.4, .5, .67)	(.67, 1, 1.5)	(.67, 1, 1.5)	.21
Environmental route	(.67, 1, 1.5)	(1, 1, 1)	(1.5, 2, 2.5)	(.67, 1, 1.5)	.30	Environmental route	(1.5, 2, 2.5)	(1, 1, 1)	(.67, 1, 1.5)	(.67, 1, 1.5)	.30
Social route	(.67, 1, 1.5)	(.4, .5, .67)	(1, 1, 1)	(.4, .5, .67)	.16	Social route	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	(.67, 1, 1.5)	.24
Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(1.5, 2, 2.5)	(1, 1, 1)	.30	Technical route	(.67, 1, 1.5)	(.67, 1, 1.5)	(.67, 1, 1.5)	(1, 1, 1)	.24

Table 9 Analysis of testing the weights of the evaluation criteria on ranking of the four alternative route alignments

	Agriculture cost (.05)	Drainage cost (.07)	Industrial cost (.07)	Railway cost (.05)	Trees cost (.08)	Urban area cost (.20)	Water body cost (.03)	Sand bank cost (.03)	River cost (.20)	Rural area cost (.14)	Road cost (.03)	Population cost (.05)	Priority weights
Economical route	.03	.31	.38	.23	.28	.48	.23	.25	.21	.12	.25	.21	0.2709
Environmental route	.38	.31	.11	.16	.16	.11	.07	.30	.30	.50	.30	.30	0.2563
Social route	.47	.13	.03	.23	.13	.03	.31	.16	.24	.15	.16	.24	0.1625
Technical route	.12	.25	.48	.37	.43	.38	.39	.30	.24	.23	.30	.24	0.3079
Total weight													0.9976

alignment and evaluate which alignment is optimum alignment. A sum of weight which is near to sum of maximum priority weights is the optimum route alignment. A technical route is near to sum of maximum priority weights, so we could determine that alignment 4 is the optimum alignment. All the criteria values and weights are computed as shown in Table 6.

5.2 Evaluation using fuzzy AHP

Table 6 shows that alignment that contains the highest weight is the optimum route alignment. For validation of the above result, a fuzzy-AHP evaluation technique is used. Uncertainty and vagueness can be effectively handled in fuzzy-AHP method (Fazlollahtabar et al. 2010). Twelve cost criteria are included in this research, and it is very difficult to simultaneously compare all criteria. Fuzzy-AHP method is used to compare all criteria simultaneously and evaluate each criterion with alternatives (Pahlavani and Delavar 2014; Sadeghi-Niaraki et al. 2011; Sadek et al. 1999). A pairwise comparison weight matrix is created using fuzzy-AHP method for all criteria, and weight has been assigned as shown in Table 7. A weight matrix is created for each alternative corresponding to each criterion as shown in Table 8. Calculate the priority weight of each alternative, and an alternative which contains the highest weight is optimum route alignment as shown in Table 9. The optimization process is done by quantitative-based (weight percent) and fuzzy-AHP method as shown in Tables 6 and 9; both provide the same optimization route alignment (Hill et al. 2005). A field survey has also been done and verifies the result for an optimum route as obtained in Table 6; route does not cross constraints area and does not affect the highest cost area within the optimum alignment. Some point locations and road intersections data have been collected through GPS and exported data into ESRI file format with the help of Pathfinder software as shown in Fig. 7.

There are 4 suggested routes; the technical route is optimum route alignment. The following discussions are made about the technical route:

(1) Each alignment has contained different land use values. The technical route contains maximum land use values; the degree of compensation for any acquired land and cost values of any land use criteria can be determined.
(2) Each alignment has contained different slope values. The technical route has contained maximum slope percentage value, so we can observe that cost value of this alignment is highest than that of other three routes.
(3) An equal number of the rail network is intersected by every alignment. One overpass construction cost of bridge is considered.
(4) If the length of alignment is minimum, the construction, maintenance and vehicle operating costs are minimum. Technical alignment has contained minimum length.
(5) The technical route contains minimum road intersection, so we can consider that the possibility of accidental cases and intersection points would be comparatively minimum than in other three routes.

(6) In technical route, construction of two culvert and two intersections are proposed for the natural drainage in the study area.
(7) The technical route contains nil value of constraints area, so the delay of construction cost and resettlement cost is removed.
(8) In cost path analysis, the attribute table of each alignment contains the average cost of alignment and the total number of pixel. So we can estimate the total construction cost of alignment. The technical route is considered to have minimum cost other than three routes.

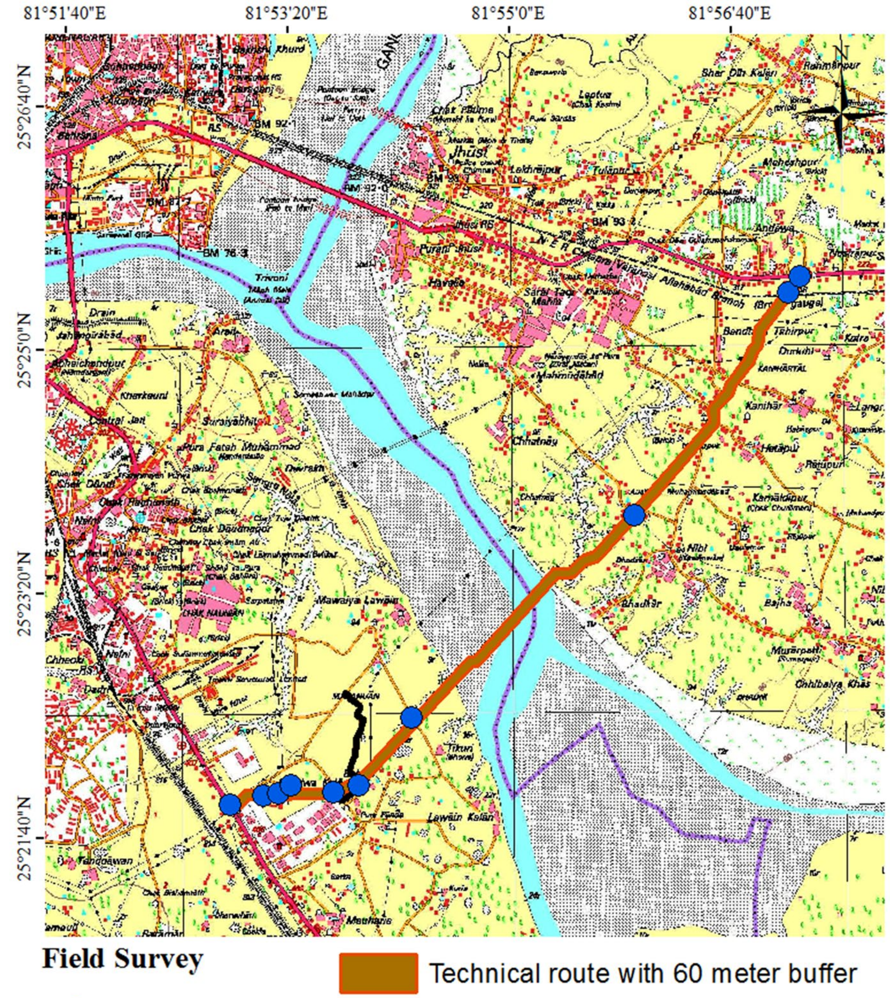


Fig. 13 Field survey along the optimum route (technical route)

6 Conclusions

This study presents a methodology with the combination of GIS and fuzzy AHP for identification, evaluation and selection of a route alignment. The proposed methodology is applied on the case study of outer region Allahabad city, India, to connect source point Naini and destination point Jhunsi situated in the outer region of Allahabad city. The following are the conclusions made for this study:

1. Four alternative route alignments are being proposed for avoiding constraints area. All four alignments are evaluated using fuzzy AHP, and an optimum route alignment is selected with minimum effect on drainage, religious places, high slopes, roads intersection and land use areas. The objective of the optimum condition is almost satisfied in this study within the given criteria and constraints.
2. A different perspective of analysis such as social, environmental economical and technical surface cost is used to generate four alternatives, and it is useful to combine all twelve criteria. The least cost path analysis (LCPA) with the integration of GIS and fuzzy AHP is successfully implemented for the identification of optimum route from the source point to destination point.
3. This study develops a most appropriate method for the selection of optimum route alignment, and further studies can be suggested for this method by changing the additional factors and constraints for any study area. This study can be applied not only for the normal terrain but also for another terrain like hilly area.
4. It is concluded that the proposed intelligent methodology based on GIS and fuzzy AHP is useful for solving the practical problems where the data are having the uncertain information.
5. The proposed intelligent fuzzy-AHP model is validated through the field survey of the study area according to multi-criteria values in Table 6, like road, rail constraint area and drainage intersections, shown in Fig. 13.

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