Comparison of GIS-based AHP and fuzzy AHP methods for hospital site selection: a case study for Prayagraj City, India

Ashutosh Kumar Tripathi · Sonam Agrawal · Rajan Dev Gupta

Abstract Identification of hospital sites and their ranking is important for the planning and development of any country's health infrastructure. The site selection problem is a typical multi-criteria decision making problem involving multiple stakeholders and their interests. Multi-Criteria Decision Analysis (MCDA) is a promising approach to solve a location-based problem due to the constitution of various criteria involved in decision making. In this research, eleven criterion are chosen which are classified under three main criteria; socio-economic, geographical and environmental. This research aims to identify the appropriate MCDA method for the selection of a new hospital sites. Here, two MCDA methods named Analytical Hierarchy Process (AHP) and Fuzzy AHP (FAHP) are used. Further, Geographical Information System (GIS) based MCDA methodology is proposed in this paper. The results obtained with both AHP and FAHP methods are compared. This comparison is based on criterion rankings, proposed hospital locations and sensitivity analysis. The main difference in results is shown in the result of sensitivity analysis in which constant variation in site ranking is obtained when weight change analysis is performed using AHP. The FAHP result shows only one variation in site ranking after a change in weight from +10 to +20%. The result suggests that FAHP may be a better approach to the hospital site selection problem.

Introduction

Over the period of time, the demand for healthcare facilities has increased exponentially all over the world (Pantzartzis et al., 2017; Velez et al., 2021). Healthcare services play an essential role in the socio-economic development of any nation. The main aim of health services is to fulfill the need of healthcare facilities to all people at all times (Daskin & Dean, 2004; Murad, 2007; Tripathi et al., 2020a). The need for healthcare is more pronounced in urban areas where the population increases continuously due to the migration of people from rural areas that resulted in a

A. K. Tripathi (✉) · S. Agrawal
GIS Cell, Motilal Nehru National Institute of Technology
Allahabad, Prayagraj, Uttar Pradesh 211004, India
e-mail: rgi1551@mnnit.ac.in

S. Agrawal
e-mail: sonam@mnnit.ac.in

R. D. Gupta
Civil Engineering Department, Motilal Nehru National
Institute of Technology Allahabad, Prayagraj,
Uttar Pradesh 211004, India
e-mail: rdg@mnnit.ac.in

disparity of access to such services (Dell'Ovo et al., 2018; Reath et al., 2019; Shahbod et al., 2020). However, healthcare is often ignored by the governments during budget allocation and infrastructure development. The recent outbreak of COVID-19 pandemic has realized several nations about the pathetic condition of their health infrastructure (Jabaris & Ananthalakshmi, 2021; Siddiqui et al., 2020). It has reflected the healthcare reality of nations (Caligiuri et al., 2020; Tripathi et al., 2019). For example, the German government was able to save its citizen more than other European Union countries from COVID-19 because of the larger number of hospitals (Zolfani et al., 2020). The mortality and morbidity of this pandemic have highlighted the importance of healthcare access.

More hospitals are needed to be established to improve the healthcare facility. The very first requirement for this is to select the locations of the opening of new hospitals. Site selection of hospitals is an ill structured problem. It has several stakeholders like doctors, medical staff, patients, pharmaceutical representatives and real estate developers. It requires proper coordination between the city planners, government and health-related policy makers (Ahmed et al., 2016; Kahraman et al., 2019; Miç & Antmen, 2019). Optimal hospital location will help to improve the effectiveness of hospitals' functionality in terms of service provision, delivery and optimization. The selection of undesired locations always leads to a decrease in customer satisfaction and an increase in expenses. Therefore, to meet the need for an adequate healthcare facility, there is a need to plan new optimal hospital sites.

The selection of optimal hospital location depends upon the various criteria. These criteria are heterogeneous in nature and require an optimization method to evaluate them and their effect on each other (Çetinkaya et al., 2016; Erbaş et al., 2018). Therefore, a multidimensional approach to decision making is required that can be fulfilled by the Multi-Criteria Decision Analysis (MCDA) method (Ding et al., 2020; Longaray et al., 2018). Integration of GIS with MCDA can assist the site selection with its spatial extent analysis. This capability helps the planner to make an informative decision on the hospital site selection problem. It will be more appropriate in a situation where the planning instruments do not provide prescriptive guidelines for the decisions. Some studies

have been carried out in the selection of optimal hospital locations. These studies have been carried out by different MCDA methods like AnalyticHierarchy Process (AHP), Fuzzy AHP (FAHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy TOPSIS and Elimination and Choice Expressing Reality (ELECTRE) (Kumar et al., 2016; Rajak & Shaw, 2019; Senvar et al., 2016; Vahidnia et al., 2009).

In light of the above discussion, the establishment of new hospitals is undoubtedly the need of the hour. Site selection for the hospital is a complex decision that needs to be supported by advanced decision making techniques using GIS. Although some studies are found on this topic, there is a need for more elaborated evaluation of hospital site selection parameters and criteria by involving more stakeholders. Also, a comparative analysis between popular MCDA methods, viz, AHP and FAHP, is required to ascertain which method would be best for the hospital site selection. Many site selection researches have been carried out by fuzzy AHP methods without examining whether it will actually make a significant difference in outcome than traditional AHP. Few studies have done a comparative analysis of AHP and FAHP in site selection (Guler & Yomralioglu, 2020; Rajak & Shaw, 2019; Rajasekhar et al., 2019). But these studies are mainly focused on identifying differences in criterion weight, criterion ranking and suitability map, which need to be done extensively in the context of GIS based MCDA. This will help the decision-makers to analyze different perspectives such as criterion weight, criterion ranking, suitability map analysis and identifying the spatial extent of alternative locations. However, no research has found that includes a comparative analysis in hospital site selection. Therefore, it is mandatory to conduct a comparative analysis of the AHP and FAHP approaches for the hospital site selection. This research work is an attempt in this direction.

The main objective of this paper is to compare AHP and FAHP based identification of hospital sites. For this purpose, a four-step method is proposed in this paper. In the first phase, three main-criteria and eleven sub-criteria are determined based on the knowledge of experts and literature survey. The next step involves spatial mapping of criteria using GIS analysis. The third stage is the GIS-based MCDA approach, which involves the prioritization of main-criteria and sub-

criteria using AHP and FAHP. In the final phase, a site suitability map is created to determine the optimal sites for the hospital. Finally, a critical comparison of the AHP and FAHP-based hospital site selection process is performed. This comparison is based on criteria ranking, location of hospital sites and sensitivity analysis.

Literature review

MCDA technique for site selection

MCDA provides a set of procedures and techniques to solve complex decision-making problems in a hierarchical manner (Malczewski & Rinner, 2015). AHP is one of the most common MCDA methods used for site selection (Saaty, 1977, 1990). It analyzes decision making based on deterministic data values. However, sometimes the data are incomplete and complex. Therefore, experts built different opinions from it due to varying perceptions. This creates ambiguity and uncertainty in the decision space. To deal with such uncertainties, a combination of fuzzy set theory and AHP, known as FAHP, is being introduced (Aggarwal & Singh, 2013). In FAHP, attribute datasets are expressed using a fuzzy membership function that defines the degree of membership value for the interest of the particular attribute.

MCDA technique is frequently used in site selection as it is a multidimensional problem that involves several criteria in decision making. Facility location assessment problems are considered as a critical decision making problem. It is a crucial task for any government to resolve the issue of land acquisition, to avoid undesirable environmental load and to utilize the profitability of the land use (Çetinkaya et al., 2018; Saha & Agrawal, 2020; Soltani et al., 2019). Site selection aided with GIS technology could play a significant role in the creation of a problem-solving environment for spatially referenced data (Maguire, 1991). Although, GIS and MCDA are two different area of research but their integration could benefit the site selection problem in analyzing the spatial decision and evaluating the ranking of different criteria (Feizizadeh et al., 2014; Tripathi et al., 2020b). Site selection studies like railway station (Mateus et al., 2008; Prasertsri & Sangpradid, 2020), fire station (Chaudhary et al., 2016; Nyimbili & Erden, 2020),

solar photovoltaic plant (Garni & Awasthi, 2017; Shorabeh et al., 2019), landfill (Aksoy & San, 2019; Rahmat et al., 2017) and wastewater disposal (Aydi et al., 2016) proves that MCDA could be the best possible model to solve the location based problems.

Hospital site selection is one of the ill structured problem which is faced by the planners, especially for developing countries like India (Kumar et al., 2016; Mishra et al., 2019). A number of research papers focused on the hospital site selection have been found. These literatures offered different procedures for hospital site selection. For example; Kim et al. (2015), Murad (2007), Ramani et al. (2007) and Schuurman et al. (2008) proposed the GIS-based approach for hospital site selection. But, they do not consider the priority of the criterion affecting to the hospital sites and focus only on GIS-based analysis. Therefore, GIS-based MCDA approach is introduced for the hospital site selection that includes the prioritization of affected criterion along with their spatial distribution. This approach is capable of achieving a transparent and analytical decision making environment for hospital site selection. It can consider various factors which cannot be ignored to get a solution closer to reality. These criteria vary with the location of study area (Senvar et al., 2016; Vahidnia et al., 2009). Critical factors that affect the hospital sites are identified through literature review. These factors are population density, land cost, proximity to road, proximity to railway, pollution and distance to other hospital (Dehe & Bamford, 2015; Dell'Ovo et al., 2018; Oppio et al., 2016; Rahimi et al., 2017; Senvar et al., 2016; Vahidnia et al., 2009). In addition to the selection of influential criteria, there is a need to know their relation to each other as well as their impact on overall site suitability.

Recent studies adopted several MCDA techniques such as ELECTRE-TRI, ordered weighted averaging, compromise programming, goal programming and AHP for hospital site suitability. Among them, AHP method is used by several researchers (Ahmed et al., 2016; Dell'Ovo et al., 2018; Hariz et al., 2017; Mishra et al., 2019; Rahimi et al., 2017; Soltani et al., 2019). In AHP, numerical values are used to express expert judgment. Such precise comparisons of decisions may be impossible to determine and can therefore lead to ambiguity in many practical implementations. Therefore, many hospital site selection researches use the more advance FAHP approach (Kumar et al., 2016;

Neisani Samani & Alesheikh, 2019; Rajak & Shaw, 2019; Soltani & Marandi, 2011; Vahidnia et al., 2009).

AHP

AHP is a multi-criteria decision-making approach in which the criteria are organized in a hierarchical structure. In this approach, the relative importance of the criterion is assumed to be based on the AHP scale. This scale is used to direct the decision-maker to construct the Pairwise Comparison Matrix (PCM). The PCM shows whether each element is equally strong, slightly strong, fairly strong, very strong, or absolutely strong than the other elements. These relative intensities are then converted into numerical values, as shown in Table 1.

The following steps are used to identify the criteria weight through the AHP process:

1. From the PCM m = (n*n) for n criteria. Let P_{ij} is the value of the cell located at the ith row and jth column of PCM. Then, the scores entered in P_{ij} and P_{ji} should satisfy the constraint in Eq. (1).

$$P_{ij}.P_{ji} = 1 \tag{1}$$

2. Calculate the Consistency Ratio (CR) based on Eq. (2). This defines whether the formed PCM is consistent or not. If CR is less than 0.1, then it is consistent.

$$CR = \frac{CI}{RI} \tag{2}$$

Here, RI is the Random Index and CI is the Consistent Index, which is calculated using Eq. (3).

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3}$$

Here, λ_{max} is the biggest eigen value of PCM.

3. The normalized matrix is then formed using Eq. (4).

$$\overline{P}_{ij} = \frac{P_{ij}}{\sum\limits_{i=1}^{n} P_{ij}} \tag{4}$$

4. In this step, the average across row entries is calculated to obtain the final weights using Eq. (5).

$$W_i = \frac{\sum\limits_{i=1}^{n} \overline{P}_{ij}}{n} \tag{5}$$

FAHP

Sometimes dissipation or ambiguity problems arise when creating a comparison matrix. It is not always possible to specify crisp values to compare different criteria. Therefore, FAHP is used so that fuzzy crisp values can be assigned. The following is the working procedure of FAHP.

Generation of comparison matrix

In FAHP, a linguistic statement is used to compare the two criteria. These linguistic statements are expressed by the Fuzzy Comparison Ratio Scale, as shown in Table 2. This ratio scale is defined as TFN, namely, a triple with the smallest, most probable and largest possible fuzzy values (Ayağ, 2014). These TFNs are

Table 1 AHP scale (Saaty, 1977)

Linguistic terms	AHP scale Intensity of importance
Equally important	1
Weakly important	3
Strongly important	5
Very strongly important	7
Absolutely important	9
Intermediate values	2, 4, 6, 8

Table 2 FAHP scale (Chang, 1996; Soltani & Marandi, 2011)

Linguistic terms	FAHP scale	
	TFN	Reciprocal TFN
Equally important	(1, 1, 1)	(1, 1, 1)
Weakly important	(2, 3, 4)	(1/4, 1/3, 1/2)
Strongly important	(4, 5, 6)	(1/6, 1/5, 1/4)
Very strongly important	(6, 7, 8)	(1/8, 1/7, 1/6)
Absolutely important	(8, 9, 10)	(1/10, 1/9, 1/8)

used to produce fuzzy PCMs in FAHP (Chan et al., 2013).

The fuzzy PCM $\tilde{C}$ for n criteria or alternatives is defined by Eq. (6) (Chang, 1996; Demirel et al., 2008).

$$
\begin{aligned}
\tilde{C} &= (\tilde{C}_{ij})_{n \times n} \\
&= \begin{bmatrix}
(1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\
(l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\
\vdots & \vdots & \ddots & \vdots \\
(l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1)
\end{bmatrix}
\end{aligned}
$$
(6)

where l, m, u represents the lower, medium and upper bound of the TFN respectively.

$\tilde{C}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $\tilde{C}_{ij}^{-1} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij})$
for i, j = 1,2,……..,n and i $\neq$ j.

Generation of fuzzy weight matrix

Several approaches are available to generate FAHP weights from pairwise comparison matrix. It produces output as a set of fuzzy weights or crisp weights. Geometric mean method (Buckley, 1985), fuzzy logarithmic least-squares method (Wang et al., 2006), and linear goal programming method (Wang & Chin, 2008) are some approaches to produce fuzzy weights from PCM. Extent analysis (Chang, 1996) and fuzzy preference programming based nonlinear method (Mikhailov, 2003) are approaches to produce crisp weights. Chang (1996) proposed an extend analysis method which computes the synthetic extend values of the pairwise comparison (Murat et al., 2015). These synthetic extend values, known as weighted values of all parameters, are also available in the form of TFNs. Fuzzy synthetic extent value for the ith criterion is calculated by the Eq. (7) (Chang, 1996).

$$
\begin{aligned}
\tilde{S}_i &= \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{k=1}^{n} \sum_{j=1}^{n} \tilde{a}_{kj} \right]^{-1} \\
&= \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} l_{kj}} \right)
\end{aligned}
$$
(7)

i = 1,…..,n.

where $\otimes$ denotes the extended multiplication of two fuzzy numbers, j and k are row and column of the corresponding matrix, respectively.

Generation of crisp weight for each criterion

In this step, the approximation of fuzzy priorities is performed. For this purpose, the degree of possibility between two fuzzy synthetic extent values is calculated. The given equation computes the degree of possibility $\tilde{S}_i \geq \tilde{S}_j$.

$$
V(\tilde{S}_i \geq \tilde{S}_j) = \sup_{y \geq x} \left[\min(\tilde{S}_j(x), \tilde{S}_i(y)) \right]
$$

$$
V(\tilde{S}_i \geq \tilde{S}_j) = \begin{cases} 1 & m_i \geq m_j \\ \frac{(u_i - l_j)}{(u_i - m_i) + (m_j - l_j)} & l_j \geq u_i \\ 0 & \text{otherwise} \end{cases}
$$
$$
i, j = 1, ..., n; j \neq i
$$
(8)

where $\tilde{S}_i = (l_i, m_i, u_i)$ and $\tilde{S}_j = (l_j, m_j, u_j)$.

Finally, the estimation of the priority vector $W = (w_1, ..., w_n)^T$ of a comparison matrix is calculated by using Eq. (9).

$$
\frac{V(\tilde{S}_i \geq \tilde{S}_j | j = 1, ..., n; j \neq i)}{\sum_{k=1}^{n} V(\tilde{S}_k \geq \tilde{S}_j | j = 1, ..., n; j \neq k)}, \quad i = 1, ..., n
$$
(9)

The fuzzy weighted vector is calculated by Eq. (10)

$$
W'(A_i) = \left[W'(A_1), W'(A_2), ..., W'(A_n) \right]^T
$$
(10)

where A_i (i = 1, 2,…, n) are the n criteria. The normal weighted vector is calculated using the normalization procedure.

$$
W(A_i) = [W(A_1), W(A_2), ..., W(A_n)]^T
$$
(11)

Materials

Study area

Prayagraj city, formerly known as Allahabad city, is one the biggest cities in the State of Uttar Pradesh (U.P.) of India. It has been selected as Smart City by Ministry of Housing and Urban Affairs (MoHUA), Government of India (GoI) in 2015. The Smart Cities Mission is an innovative and new initiative by the GoI to drive economic growth and improve the quality of life of people by providing core
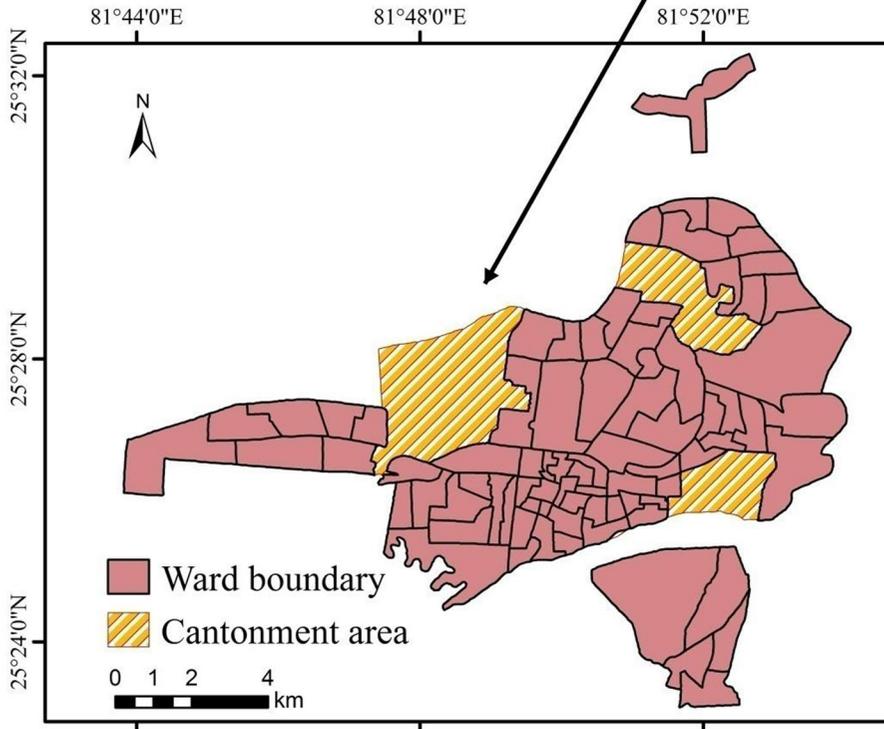
Map of India
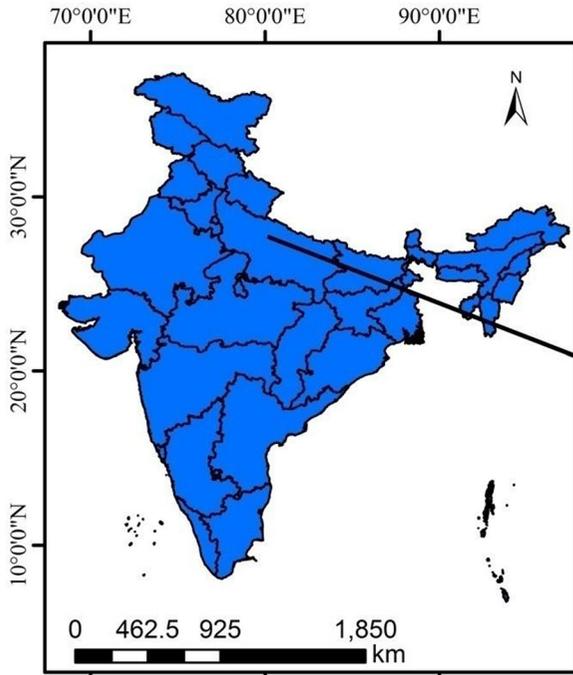
District Boundary Map of Uttar Pradesh
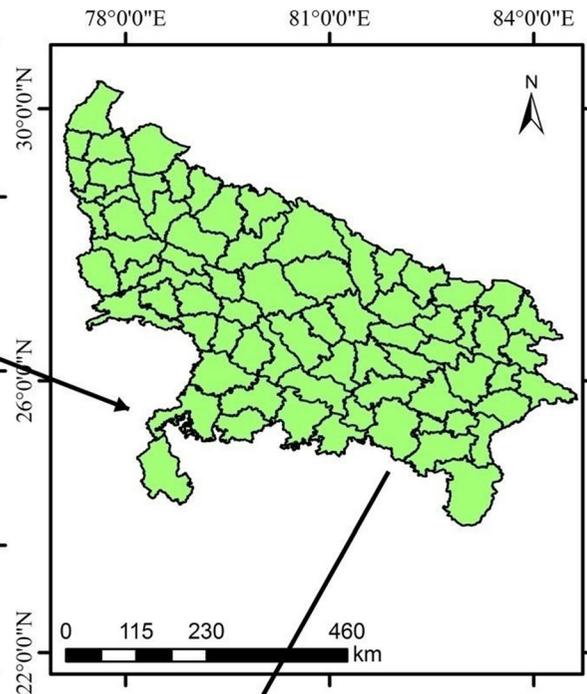
Ward Boundary Map of Prayagraj City

◀**Fig. 1** Study area

infrastructure and harnessing technology to enable the local area development and create smart outcomes for the citizens. Prayagraj city has rapidly evolved in the last three decades due to the urbanization process and there is a need to provide a clean, inclusive and sustainable environment for the development in the city with technological intervention. Due to this, Prayagraj city is selected as the study area for the present work.

Prayagraj city is located in the north-central region of the state of U.P., India and falls in the administrative boundary of Prayagraj district (Fig. 1). The area of Prayagraj city is about 76.29 km^2. The total population of the city is 1,112,544. Prayagraj city has 20% of the

district population and 80% of the total urban population. The population density of city is 157 person per hectare. According to Prayagraj Municipal Corporation, the city is divided into 80 wards. Ward 76 has the highest population of 25,256 person and ward 78 has the highest population density of 1115 person per hectare.

As per the Ministry of Urban Development (MoUD) report, Prayagraj city has 37 dispensaries (1 for every 15,000 person), 15 small hospitals (1 for every 45,000–1 lakh person) and 12 multi-specialty hospitals (1 for every 1 lakh person). As per norms, there should be 162 dispensaries, 54 small hospitals and 24 multi-specialty hospitals. As per GoI's latest National Family Health Survey (2015–16) just 7.1% of district households are covered by health insurance or related schemes. There are some key health
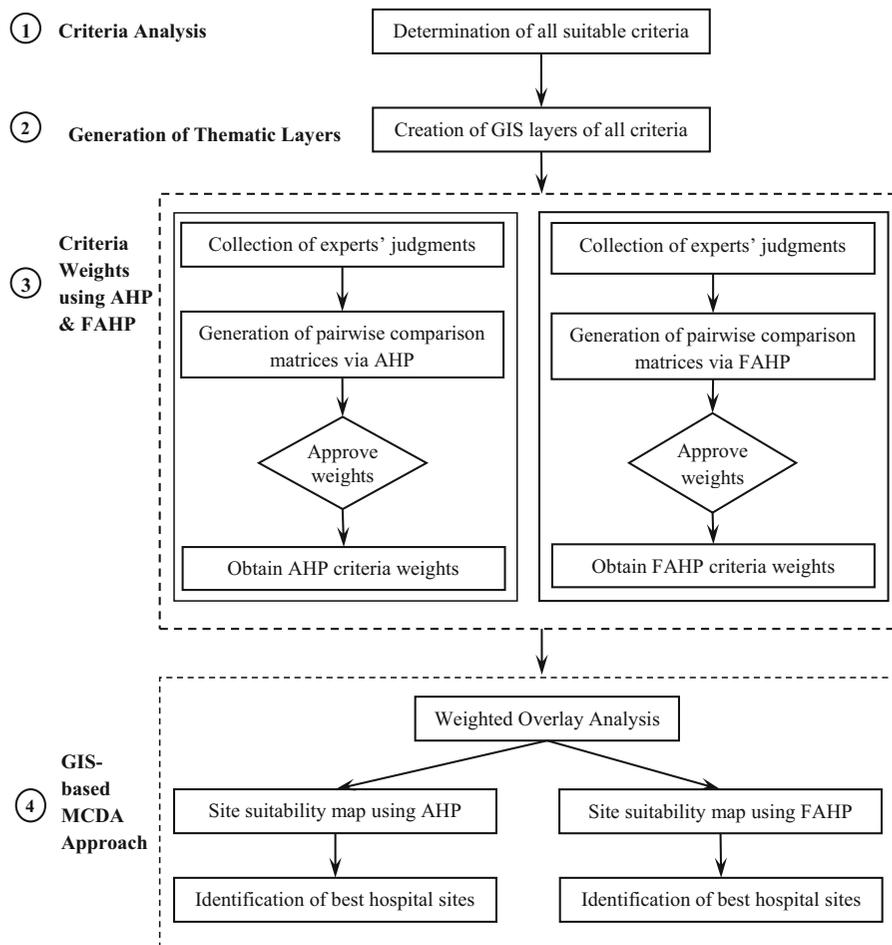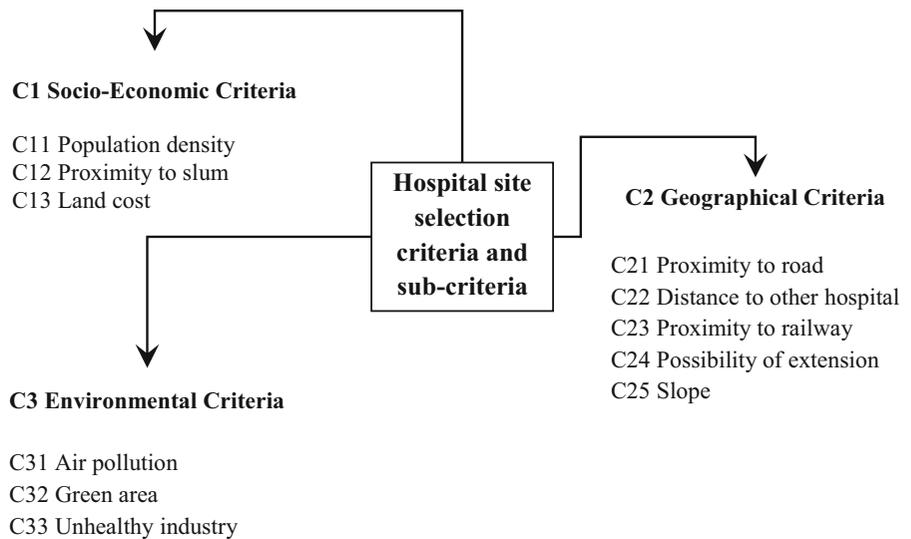

Fig. 2 Methodology to compare and analysis of GIS-based AHP and FAHP for Hospital Site Selection

Table 3 Description of the evaluation criterion

S. No.	Criteria	Definition	Vahidnia et al., 2009	Dehe & Bamford, 2015	Senvar et al., 2016	Rahimi et al., 2017	Ovo et al., 2018,	Şahin et al., 2019	Soltani & Marandi, 2011	Ramani et al., 2007
1	Population density	Hospital site should be near to the high population zones	√	√		√	√	√	√	
2	Proximity to slum	Hospital site should be near to the slum location								√
3	Land cost	Hospital site should be preferably located on low land cost area	√	√	√					
4	Proximity to road	Hospital site should be near to the main road for transportation	√	√	√	√	√		√	√
5	Distance to other hospital	New hospital site should not be very far from the already available hospital							√	√
6	Proximity to railway	Hospital site should be near to the railway for transportation		√	√	√	√			
7	Possibility of extension	Hospital site should be located in abandoned areas where urban expansion is possible in the future		√	√	√				
8	Slope	Hospital site should be located in flat area (not greater than 7%)							√	√
9	Air pollution	Hospital site should be far from where air quality index is higher, i.e., air pollution is high	√			√		√	√	√
10	Green area	Hospital site should be near to dense vegetation like trees or forest				√				
11	Unhealthy industry	Hospital site should be far from the industrial area				√				

indicators in this survey that can highlight the need of the hospitals in the study area. In the urban area, just 37.9% of children whose age is 12–23 months got fully immunized. This immunization includes BCG, measles, three doses of polio vaccine and three doses of DPT vaccine. The anemia condition of children and women is also alarming. In the urban region, 60.7% children and 55.5% of women are anemic. Lifestyle diseases are also getting rampant in the urban population. Among the adults of age 15–49 years, 9.5% are suffering from a higher level of blood sugar while 16.7 are having hypertension. Therefore, new hospitals must be established around the city to fulfill the healthcare requirement of people.

Fig. 3 Criteria hierarchy
for hospital site selection

C1 Socio-Economic Criteria

C11 Population density
C12 Proximity to slum
C13 Land cost

**Hospital site
selection
criteria and
sub-criteria**

C2 Geographical Criteria

C21 Proximity to road
C22 Distance to other hospital
C23 Proximity to railway
C24 Possibility of extension
C25 Slope

C3 Environmental Criteria

C31 Air pollution
C32 Green area
C33 Unhealthy industry

Data used

To perform the spatial mapping of criteria different type of datasets are collected from different sources. The Survey of India (SOI) is a government agency that is authorized for the distribution of topographic maps in India. A topographic map with Open Series Map number G44P15 is collected from SOI. This topographic map is at the scale of 1:50,000 with WGS-84 datum and UTM projection system. The administrative boundary of Prayagraj city is extracted from the ward boundary map, which is downloaded from the Prayagraj Nagar Nigam website (http://allahabadmc.gov.in/). This map is available at 1:40,233 scale. Here, digitization is performed to create the ward boundary layer of Prayagraj. The geographic location (latitude and longitude) of each hospital is collected using the handheld Global Positioning System (GPS) receiver from the field survey. Field survey is performed using Trimble Juno 3B handheld GPS with 2–5 m real-time accuracy. Air pollution data is collected from the U.P. Pollution Control Board. Population data is collected from the Census-2011 registry. Slum data is collected from the MoHUA, Government of India. Prayagraj Development Authority (PDA) provides the land cost information of the Prayagraj city.

A multispectral image is also collected to create the Land Use/Land Cover (LULC) map of the Prayagraj city. Here, the Sentinel-2A satellite image, acquired on April 4, 2019, is downloaded from the Copernicus programme of the European Space Agency (ESA) website. This multispectral image has a spatial resolution of 10 m for band 2 (blue), band 3 (green), band 4 (red) and band 8 (near infrared). Image preprocessing and layer stacking is performed to obtain a composite image. The LULC map is then generated by applying the supervised classification technique. The ASTER DEM data, acquired on October 17th, 2011 with 30 m resolution, is downloaded from the USGS website. It helps to generate the slope map of the study area.

Methodology

The flowchart of the proposed methodology is given in Fig. 2. It is a four-step process, which includes: (1) criterion analysis, (2) GIS analysis, (3) MCDA methods, and (4) GIS-based MCDA analysis. A detailed description of this method is given below.

Criteria analysis

The first phase involves the analysis and evaluation of criteria that affect the location of the hospital. For this, a board of experts and academicians is created. Experts are local administrators working in various hospitals in the Prayagraj city while academicians are the researchers working in the health service domain. In this research, hospital site selection criteria are evaluated based on the expert's and academician's knowledge and from literature survey. From the relevant literature, it is founded that the criteria used

Table 4 Spatial data and its associated spatial analysis tool

	Criteria	Sub-criteria	Source	Analysis
C11	Socio-Economic	Population density	Census 2011	Normalization
C12		Proximity to slum	MoHUA, Government of India	Euclidean distance
C13		Land cost	Prayagraj Development Authority	Interpolation (IDW)
C21	Geographic	Proximity to road	SOI topographic map	Euclidean distance
C22		Distance to other hospital	Field survey	Euclidean distance
C23		Proximity to railway	SOI topographic map	Euclidean distance
C24		Possibility of extension	ESA	Euclidean distance
C25		Slope	USGS	Slope
C31	Environmental	Air pollution	U.P. Pollution Control Board	Interpolation (IDW)
C32		Green area	ESA	Euclidean distance
C33		Unhealthy industry	SOI topographic map	Euclidean distance
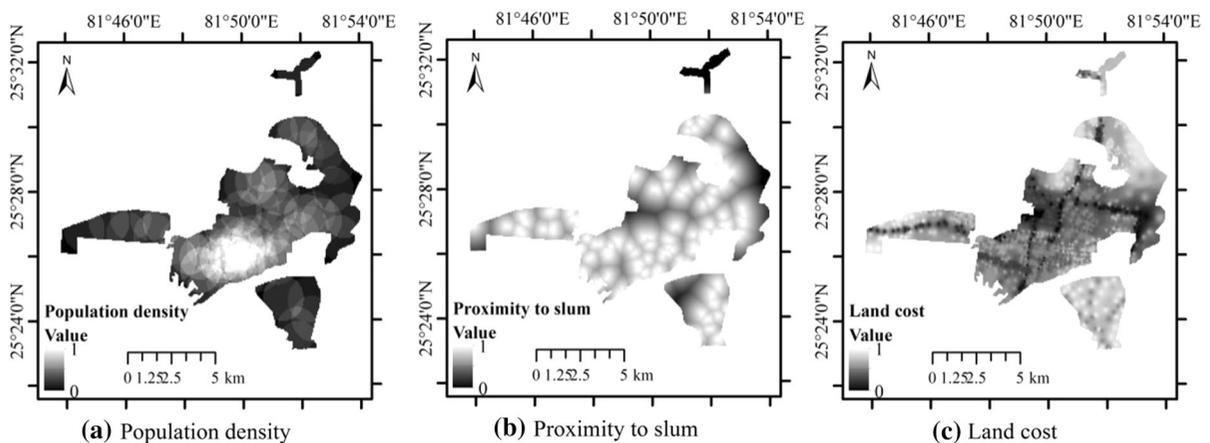
Fig. 4 Thematic layer map of socio-economic criteria

for site selection vary in different literature. Table 3 lists all the criteria along with their brief descriptions and the authors who evaluate them in their studies. A total of eleven criteria have been identified for this research. Population density, land cost, accessibility (proximity to road and railway), and possibility of extension have been selected by several researchers. However, air pollution, green area and unhealthy industry norms have also been pointed out as important criteria by some researchers. In very few researches, slope and urban slum population are considered for hospital site selection. These are included in this research as the role of these criteria was found to be very important for the selected study area.

All these criteria are aggregated hierarchically at two levels: main-criteria and sub-criteria. The hierarchical structure of all eleven criteria is shown in Fig. 3. All eleven criteria are grouped into three main criteria viz., socio-economic, geographical and environmental. The socio-economic criterion considers the social and economic factors that are related to human health. Geographical criterion examines access to health facilities. The environmental criterion helps in locating the places where less pollution and more vegetation is around the hospital.
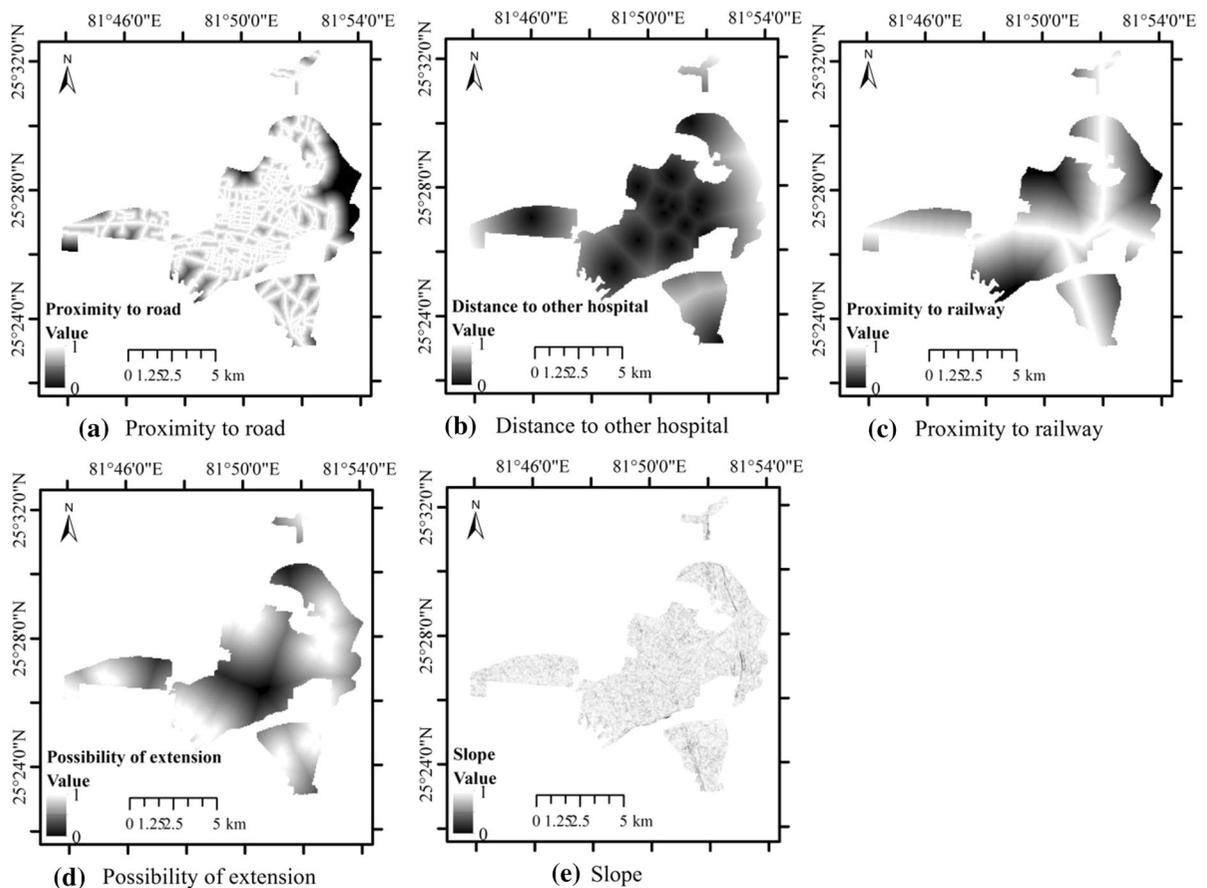
Fig. 5 Thematic layer map of geographical criteria

Generation of thematic layers

Spatially referenced criterion provides more detail and visual information that helps decision-makers to make decisions effectively and quickly. This step analyzes the spatial extent of each criterion. It aggregates different geospatial layers to create suitability maps. As different forms of criterion data such as satellite images, topographic maps and field data are collected, different GIS operations such as euclidean distance, slope, interpolation, etc., are needed to create the thematic layer of each criterion. Table 4 presents all the criteria for creating thematic layers with their sources and spatial operations performed on them.

Since most of the data used in this study are in vector format, they need to be converted to raster format. The Raster Calculator and Reclassify GIS tools are used to perform this conversion. This process helps in extracting useful information from the

converted file. Here, to maintain the integrity of the measurement, the ranges defined in the thematic layer are normalized in a scale from 0 to 1. Pixel value 1 denotes the most suitable area for hospital sites and is indicated by white color on the map. The pixel value 0 depicts an area unsuitable for hospital sites and is shown by black color on the map. This helps experts to make critical comparisons among each criterion and to rank the identified alternative sites. The construction of normalized thematic layer maps of each criterion corresponding to all sub-criteria is described below.

Thematic layer map of socio-economic criteria

The thematic map of socio-economic criteria is shown in Fig. 4.

Population density Population density should be examined to determine population distribution around
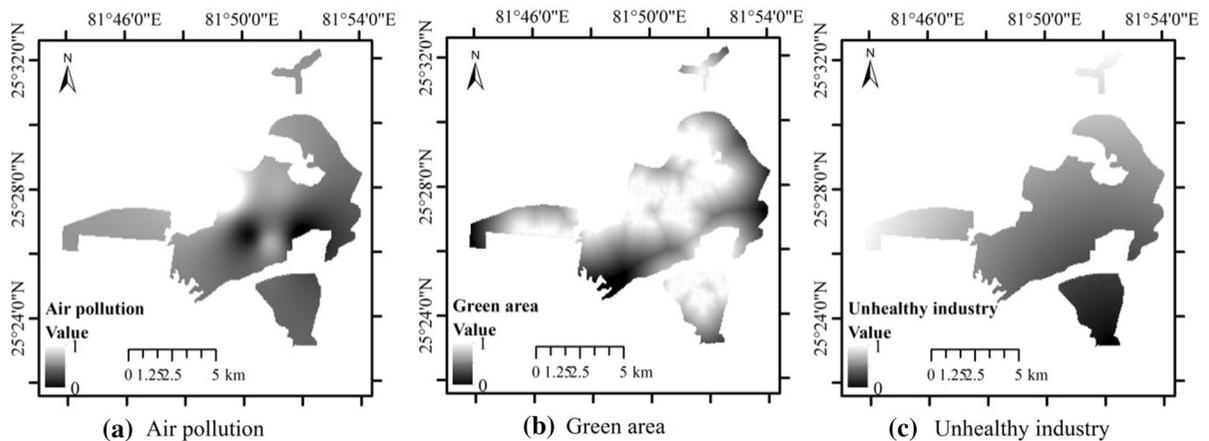
Fig. 6 Thematic layer map of environmental criteria

the city. Hospitals should be located in such a way that more and more population gets the benefit of health services at the nearest possible location. Figure 4a shows the population density criteria map. In this map, higher population density wards are given a higher score than the wards with lower population density.

Proximity to slum area   The slum area is recognized as a highly populated area located in deteriorating infrastructure. There is a high need for health services in the slum and fringe areas as health and sanitation conditions in these areas are generally poor. Figure 4b represents the slum area map where higher scores are given to the slum areas.

Land cost   The value of land is an essential parameter in deciding the location of hospital sites. It somehow directly reflected the cost of health care services. The land cost map is shown in Fig. 4c. Higher score is given to the land with lower cost as it is economical to build new hospitals over there.

Thematic layer map of geographical criteria

The thematic map of geographical criteria is shown in Fig. 5.

Proximity to road   Effective transport facilities in terms of access positively affect hospital sites. It benefits those who were in need of health services. It is important to build a new hospital near the streets. In view of this, a high priority has been given to nearby

road areas. Figure 5a shows the proximity to road map where higher priority is given to the pixels near to the roads.

Distance to other hospital   It is important to assess the availability of existing hospitals. New hospitals should be constructed from existing hospitals so that health services are well distributed around the city. Distance to other hospital map is shown in Fig. 5b in which higher priority is assigned to the area away from the existing hospitals.

Proximity to railway   This is another important criterion for the selection of a hospital site. People living away from urban areas sometimes travel via railways. Due to this, the area near the railway is given more priority than the area away from the railway. The proximity to railway map is shown in Fig. 5c.

Possibility of extension   Since most of the land within the city is already occupied, it is difficult to acquire land within the city to build a new hospital or to expand an existing one. Keeping this criterion in mind, the open area is given a higher priority than the built-up area. Figure 5d shows the possibility of extension map.

Slope   The slope of the land may contribute to checking the site of the hospital. Flat or low slope areas are better for building a hospital. Figure 5e shows the slope map, where higher scores are given to the lower slope areas.

Table 5 Normalized weight of main and sub-criteria

Criteria	AHP			FAHP					
	Local weights	Global weights	Ranking	Fuzzy synthetic extent			Local weights	Global weights	Ranking
				Lower	Middle	Upper			
C1	0.300			0.183	0.301	0.479	0.289		
C2	0.419			0.281	0.419	0.602	0.461		
C3	0.281			0.192	0.280	0.443	0.249		
Sub-criteria									
C11	0.535	0.161	1	0.241	0.521	1.031	0.530	0.153	3
C12	0.288	0.086	6	0.150	0.308	0.629	0.342	0.099	5
C13	0.177	0.053	9	0.105	0.170	0.353	0.128	0.037	8
C21	0.306	0.128	3	0.152	0.299	0.569	0.369	0.170	2
C22	0.336	0.141	2	0.169	0.328	0.606	0.396	0.182	1
C23	0.156	0.065	7	0.103	0.183	0.332	0.209	0.097	6
C24	0.101	0.042	10	0.055	0.089	0.174	0.009	0.004	11
C25	0.101	0.042	11	0.059	0.101	0.179	0.018	0.008	10
C31	0.438	0.123	4	0.268	0.459	0.741	0.534	0.133	4
C32	0.349	0.098	5	0.216	0.329	0.504	0.344	0.086	7
C33	0.213	0.060	8	0.147	0.213	0.340	0.121	0.030	9

Thematic layer map of environmental criteria

The thematic map of environmental criteria is shown in Fig. 6.

Air pollution It is very important to consider air pollution for the selection of a hospital site because it exerts extreme influence around the place in which people live and the hospital is located. If the air pollution around the hospital is high, it will affect the health of patients. Therefore, a lower priority level is
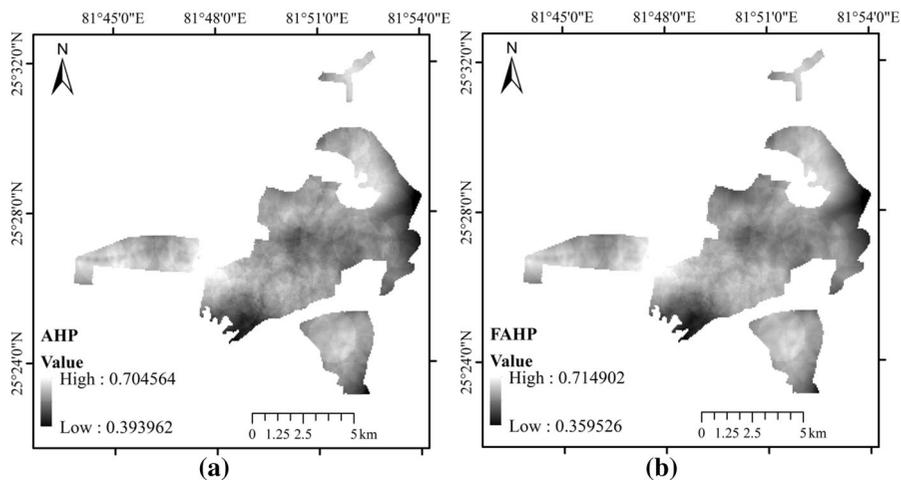

Fig. 7 Final suitability map of hospital site selection for the Prayagraj city **a** normalized suitability map of AHP **b** normalized suitability map of FAHP

given to the area where the air quality index is higher. Figure 6a represents the air pollution map of the study area.

Green area Surrounding of the hospital plays a crucial role in providing effective healthcare services to the patients. Green area must be present at the hospital sites. Due to this, a higher priority is given to the location near to the green area. Figure 6b represents the green area map of the study area.

Unhealthy industry The industrial sector negatively affects hospital patients due to various types of pollutants, such as wastewater, disposals and hazardous waste. To minimize its impact, the new hospital should be located away from the industrial area. Figure 6c represents the unhealthy industry map of the study area.

Criteria weights using AHP & FAHP

In this step, criteria weights are calculated based on the above definition of AHP and FAHP. For this purpose, expert opinions are considered to assign the weight using the scale given in Tables 1 and 2. To determine the relative importance of each criterion, the opinions of experts are obtained in linguistic terms. It is further transformed and evaluated on a nine-point scale for both AHP and FAHP (Tables 1, 2). In this study, experts from hospital planning authority are taken for

their judgment for the site selection of the hospital. The final score of the relative weight is calculated by applying the geometric mean to the expert judgments. The geometric mean method was given by Saaty (1990) and Dyer and Forman (1992) to integrate individual judgments. This will help to generate the PCM for criteria and sub-criteria. After this, the weight is calculated by AHP and FAHP methods. Finally, the overall normalized weight of each sub-criterion is calculated by multiplying the individual weight of sub-criteria with the weight of the corresponding criteria (Chang, 1996). Table 5 shows the calculated priority weights and ranking of each sub-criteria in AHP and FAHP.

GIS-based MCDA approach

This step involves GIS-based MCDA analysis to obtain the final suitability map. This is done by implementing a weighted linear combination (WLC) operation. In this operation, more than one attributes or criteria along with its weight are taken into consideration. Each criterion is transformed into a GIS layer and described by its pixel values. The overall suitability map is generated by using Eq. 12. This formula evaluates the suitability of each pixel based on standardized score and normalized weight.

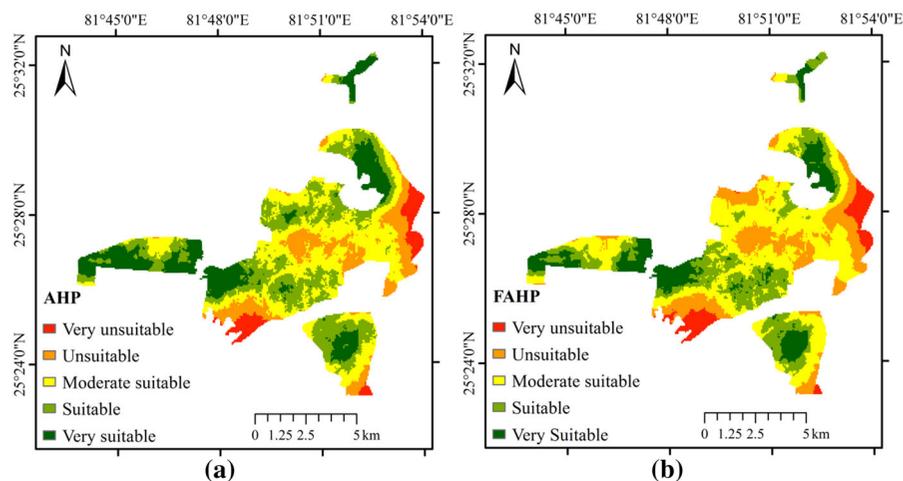$$A_j = \sum X_i * W_i, with \sum W_i = 1 \qquad (12)$$

Fig. 8 Classified suitability map of hospital site selection for the Prayagraj city **a** classified suitability map of AHP **b** classified suitability map of FAHP

Table 6 Comparison of suitability area calculated by AHP and FAHP

Suitability category for opening new hospital	Area by AHP (in km^2)	Area by FAHP (in km^2)
Very suitable	13.83	10.55
Suitable	21.10	16.83
Moderate suitable	24.37	28.04
Unsuitable	10.50	13.90
Very unsuitable	3.81	4.22

where A_j represents the alternatives score of jth pixel in the final suitability map, X_i represents the standardized score of ith criterion, and W_i represents the normalized weight of ith criterion.

The resulting hospital site suitability maps generated via WLC method are shown in Fig. 7. Here, each criterion GIS layer is multiplied by AHP and FAHP weight separately to generate the corresponding hospital site suitability maps. Raster calculator is used to generate the final hospital site suitability maps for the study area. Figure 7a and b shows the normalized suitability map generated from AHP and FAHP, respectively.

To analyze the spatial pattern and distribution of the most appropriate location for the hospital, the normalized maps are classified into five suitability classes: very suitable, suitable, moderately suitable, unsuitable and very unsuitable. This is achieved by applying the natural break (Jenks) classification method to the normalized suitability map. The classified suitability map for AHP and FAHP is shown in Fig. 8a and b, respectively.

Hospital suitability maps generated from AHP and FAHP show some differences in results. It can be seen from Fig. 8a and b that there is a significant difference in a very suitable class. This is due to ranking and weight differences in AHP and FAHP. A quantitative comparison of the differences in the suitability area is also performed, which is summarized in Table 6. This is done by converting all five suitability classes into polygon layers. The results show that 18.78% of the area in AHP and 14.33% of area in FAHP are identified as suitable locations for setting up the new hospitals. Higher suitability values are envisioned primarily in an area that is far from the city center as most existing hospitals are located in this area. The total unsuitable and very unsuitable area is about

19.44% and 24.62% of the total area in AHP and FAHP respectively.

Comparative analysis

A comparison between AHP and FHAP results is made in this section on the basis of three parameters, which are (1) divergence in criteria ranking (2) extent and location of hospital sites and (3) weight change influence on sites ranking in different scenario based on sensitivity analysis.

Criteria ranking

The one of the critical input in GIS-based MCDA analysis is the ranking of criteria based on the relative importance of each criterion. Here from Table 5, it can be seen that the criteria ranking and weighting results derived by AHP and FAHP are quite different. By criterion weighting, it appears that the relative local weights of each criterion and sub-criterion are the same in AHP and FAHP. However, the global weight ranking differs in both methods. For example, in AHP, population density (C11) is ranked as the most important criterion, whereas in FAHP, distance to other hospital (C22) is assigned as the most important criterion. The Possibility of extension (C24) and slope (C25) are given the lowest priority for both AHP and FAHP.

The biggest differences in global weight can be seen for proximity to railway (C23) and unhealthy industry (C33), as they have almost the same impact in AHP while in FAHP method proximity to the railway (C23) has a greater impact than unhealthy industry (C33). This happens because in the AHP method, an exact numerical number is given as a weight by the

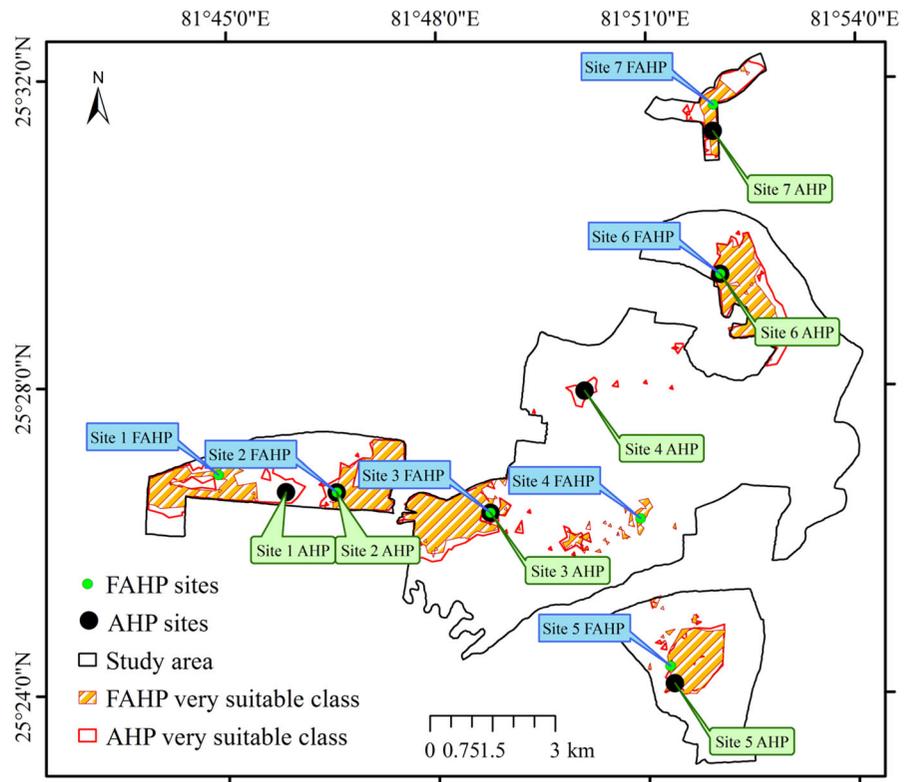**Fig. 9** Alternative hospital sites in the AHP and FAHP

Table 7 Ranking of sites using AHP

	C11	C12	C13	C21	C22	C23	C24	C25	C31	C32	C33	Weight	Rank
Site 1 AHP	0.082	0.167	0.120	0.187	0.076	0.106	0.235	0.198	0.186	0.132	0.256	0.145	2
Site 2 AHP	0.144	0.167	0.064	0.187	0.080	0.071	0.043	0.070	0.186	0.240	0.167	0.142	5
Site 3 AHP	0.250	0.167	0.120	0.098	0.134	0.071	0.069	0.286	0.065	0.048	0.051	0.127	6
Site 4 AHP	0.250	0.167	0.051	0.187	0.080	0.066	0.157	0.070	0.305	0.240	0.082	0.172	1
Site 5 AHP	0.082	0.083	0.215	0.058	0.276	0.226	0.346	0.060	0.043	0.076	0.075	0.127	7
Site 6 AHP	0.144	0.167	0.215	0.098	0.134	0.297	0.043	0.198	0.108	0.132	0.114	0.143	4
Site 7 AHP	0.050	0.083	0.215	0.187	0.221	0.163	0.108	0.118	0.108	0.132	0.256	0.143	3

experts. While at FAHP, experts' decisions are driven by the consideration of triangular fuzzy numbers, which can have a large impact on the final weight of the criteria.

Although this comparison shows differences in AHP and FAHP weights and rankings, it does not recognize the true impact of this difference on the final result. Therefore, the next section is done to see the difference between the outcomes of both methods.

Extent and location of hospital sites

This comparison is done on the basis of alternative sites identified by APH and FAHP method where new hospitals are to be established. Here, the area that falls under the very suitable class is considered for further selection. Along with this, another consideration has also been taken that new hospital sites should be in only those wards which do not have any hospital. The location for the new hospital is identified based on the

Table 8 Ranking of sites using FAHP

	C11	C12	C13	C21	C22	C23	C24	C25	C31	C32	C33	Weight	Rank
Site 1 FAHP	0.227	0.231	0.170	0.166	0.150	0.107	0.134	0.171	0.052	0.262	0.002	0.158	3
Site 2 FAHP	0.003	0.202	0.074	0.257	0.209	0.192	0.011	0.259	0.119	0.057	0.144	0.132	6
Site 3 FAHP	0.234	0.030	0.170	0.307	0.106	0.107	0.229	0.066	0.176	0.120	0.069	0.136	5
Site 4 FAHP	0.003	0.202	0.074	0.004	0.243	0.192	0.286	0.265	0.176	0.196	0.283	0.182	1
Site 5 FAHP	0.249	0.029	0.170	0.257	0.001	0.192	0.010	0.002	0.053	0.048	0.002	0.095	7
Site 6 FAHP	0.101	0.278	0.170	0.005	0.243	0.019	0.318	0.066	0.176	0.120	0.283	0.139	4
Site 7 FAHP	0.182	0.029	0.170	0.005	0.048	0.192	0.011	0.171	0.248	0.196	0.216	0.159	2

Table 9 Sensitivity analysis result of AHP weights

	C11	C12	C13	C21	C22	C23	C24	C25	C31	C32	C33
50%	0.136	0.088	0.033	0.151	0.274	0.086	0.004	0.007	0.118	0.076	0.027
40%	0.140	0.090	0.034	0.155	0.255	0.088	0.004	0.007	0.121	0.078	0.028
30%	0.143	0.092	0.035	0.159	0.237	0.090	0.004	0.008	0.124	0.080	0.028
20%	0.147	0.095	0.035	0.162	0.219	0.092	0.004	0.008	0.127	0.082	0.029
10%	0.150	0.097	0.036	0.166	0.201	0.094	0.004	0.008	0.130	0.084	0.030
0%	0.153	0.099	0.037	0.170	0.182	0.097	0.004	0.008	0.133	0.086	0.030
− 10%	0.157	0.101	0.038	0.174	0.164	0.099	0.004	0.008	0.136	0.088	0.031
− 20%	0.160	0.103	0.039	0.178	0.146	0.101	0.004	0.008	0.139	0.090	0.032
− 30%	0.164	0.106	0.040	0.181	0.128	0.103	0.004	0.009	0.142	0.092	0.032
− 40%	0.167	0.108	0.040	0.185	0.109	0.105	0.004	0.009	0.145	0.094	0.033
− 50%	0.170	0.110	0.041	0.189	0.091	0.107	0.004	0.009	0.148	0.095	0.034

Table 10 Sensitivity analysis result of FAHP weights

|	C11	C12	C13	C21	C22	C23	C24	C25	C31	C32	C33
50%	0.241	0.078	0.048	0.118	0.127	0.059	0.038	0.037	0.111	0.089	0.054
40%	0.225	0.080	0.049	0.120	0.130	0.060	0.039	0.038	0.114	0.091	0.055
30%	0.209	0.081	0.050	0.123	0.132	0.061	0.040	0.039	0.116	0.093	0.056
20%	0.193	0.083	0.051	0.125	0.135	0.062	0.041	0.040	0.118	0.094	0.058
10%	0.177	0.085	0.052	0.128	0.138	0.063	0.042	0.041	0.121	0.096	0.059
0%	0.161	0.086	0.053	0.130	0.140	0.065	0.042	0.041	0.123	0.098	0.060
− 10%	0.144	0.088	0.054	0.133	0.143	0.066	0.043	0.042	0.125	0.100	0.061
− 20%	0.128	0.090	0.055	0.135	0.146	0.067	0.044	0.043	0.128	0.102	0.062
− 30%	0.112	0.091	0.056	0.138	0.148	0.068	0.045	0.044	0.130	0.104	0.063
− 40%	0.096	0.093	0.057	0.140	0.151	0.070	0.046	0.044	0.133	0.106	0.065
− 50%	0.080	0.095	0.058	0.143	0.154	0.071	0.046	0.045	0.135	0.108	0.066
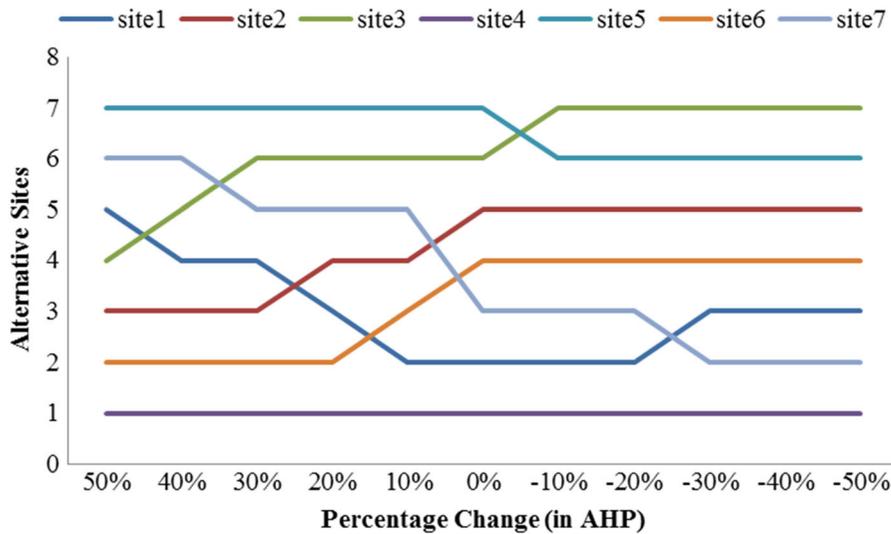
Fig. 10 Impact of sensitivity analysis in the sites determined in AHP sites

Fig. 11 Impact of sensitivity analysis in the sites determined in FAHP sites
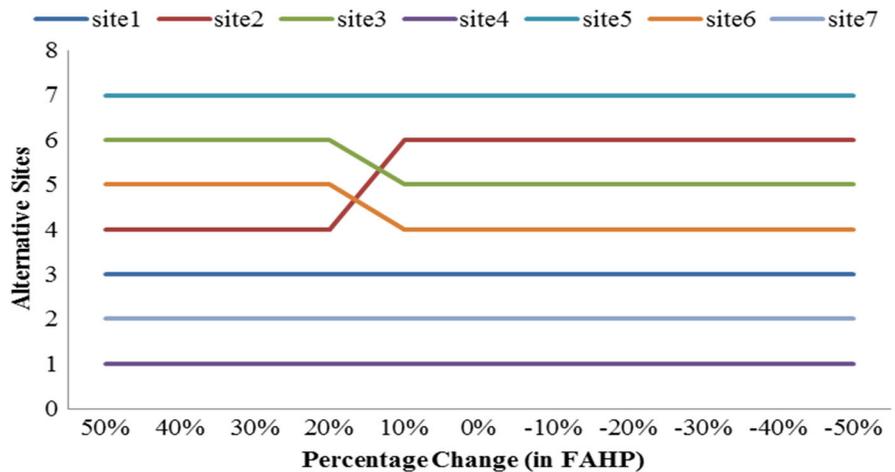
pixel values. A higher pixel value indicates greater adherence to the criterion, thus it is more appropriate than a lower pixel value. Based on the above conditions, seven alternative locations for hospital sites are identified by both methods from a very suitable class. Very suitable class area with the alternative sites by AHP and FAHP is shown in Fig. 9. Here, it can be seen that three of those sites are identified at the same location by both methods.

Next, the spatial distribution and ranking order of these identified alternative sites is calculated and then compared in both methods. For this purpose, weight order of each site with respect to each criterion is calculated by AHP and FAHP methods. Here, criteria weights and PCM of each alternative site in regard to each criterion are taken part to calculate the final weight and ranking of each site. The overall weight and ranking of each criterion by both methods are shown in Tables 7 and 8, respectively. This analysis shows that the ranking order of sites differed slightly in both methods. For example, Site 1, Site 2, Site 3 and Site 7 are located in the same ward, but the ranking order differs in both methods. However, Site 5 and Site 6 are not only located in one place, but they ranked in the same order by both methods. Although Site 4 option from the AHP and FAHP is located in separate

wards, this analysis ranked it as the most appropriate location for the hospital site.

Sensitivity analysis

Sensitivity analysis is used to test the reliability and robustness of alternative sites in various models. In other words, it identifies the sensitivity of alternatives to the criteria weight changes. To examine this analysis, the weight of one criterion is changed while keeping the others to the same. In this way different combinations of weights are prepared. Experiments are then conducted to evaluate the impact of the weight variation on the output. High degree of change shows high sensitivity in output.

To perform the sensitivity analysis, weight (w_i) of each criterion is altered at a certain percentage change (PC). Weight is calculated by the following equations:

$$w_i = w_{i0} \pm w_{i0} \times \text{PC} \tag{13}$$

$$w_j = (1 - w_i) \times \frac{w_{j0}}{(1 - w_{i0})} \tag{14}$$

where w_{i0} is the weight of the main affecting criterion. w_i and w_j is the new weight value assigned to the ith and jth criterion. w_{i0} and w_{j0} are the weights of criterion i and j, which are used as an input at base run.

To apply criteria weight change analysis, weight deviation range from +50 to −50% with the percent change of 10% is applied in this study. To do the fair comparison between AHP and FAHP results, the sensitivity analysis is done separately for both methods. Due to having highest weight among other criteria, population density and distance to other hospital criterion is selected as the main affecting criterion for AHP and FAHP, respectively. Criteria weight change according to AHP and FAHP is shown in Tables 9 and 10, respectively.

After generating the criteria weight changes, their impact in the overall ranking is analyzed. For this, overall weight of sites with respect to each criteria weight change is calculated using the weighted operation. The results of ranking order of sites in AHP and FAHP are shown in Figs. 10 and 11, respectively. The AHP result shows a continuous variation in the order of site ranking in respect to criteria weight change. In FAHP, the order of site ranking varies only between +10 and +20% criterion weight while other weight deviations have no effect on

site ranking. From the results, it can be seen that Site 4 is identified as the most suitable location for hospital siting both ways. Thus the impact of criteria weight change in the FAHP sites is nearly negligible. The sensitivity analysis results suggest that the FAHP site ranking is more tolerant for the criteria weight change than the AHP ranking.

Conclusions

The site selection like problems that have multiple conflicting criteria requires MCDA based decision making. AHP can be used for this purpose as it can handle both qualitative and quantitative parameters. It integrates expert opinion, specialist experience and public feedback to assign the weights to these criteria. Sometimes, FAHP is used instead of AHP to incorporate the vagueness of human thinking. FAHP use the fuzzy number instead of the crisp number in the weight assignment. In this research work, a four-step methodology is proposed for hospital site selection along with the comparative analysis of AHP and FAHP. In the first step, the parameters are picked under three broad categories, viz, socio-economic criteria, geographical criteria and environmental criteria. Eleven sub-criteria are subsequently identified under them: population density, proximity to slum, land cost, proximity to road, distance to other hospitals, proximity to railway, possibility of extension, slope, air pollution, green area and unhealthy industry. After the screening and selecting of criteria and sub-criteria, thematic layers are generated and weight is assigned to them on a nine-point scale. In FAHP, the extend analysis method is used to calculate the crisp weights. Finally, suitability maps are generated using both methods. Total of nine sites are identified in each of the methods where hospitals can be established.

The AHP and FAHP are compared based on the criterion ranking, location of sites and sensitivity analysis. It shows that these methods' difference in the criterion weight assignment is ultimately reflected in the respective criterion ranking. The criterion weight change has an impact on the final suitability map which varies between these two methods. For example, in AHP, the population density criterion greatly impacts the final suitability map, whereas in FAHP, it is the distance to other hospitals. The results of both methods on final suitability indicate high variance in

the ranking of their respective alternative locations. The result of sensitivity analysis shows high differences in the outcomes of both methods. This difference is not only due to distinct sets of alternative sites from AHP and FAHP but also due to the spatial extent of site location. The sensitivity analysis results show that the FAHP site ranking is more tolerant of the criteria weight change than the AHP ranking.

This study has shown the use of AHP and FAHP in the complex decision making of hospital site selection. It could help the local administrators in the handling of the emerging health threats in a more efficient manner. The solution can reduce the widening gap between the patients and the availability of health infrastructure in present COVID-19 like situations. In the future, this study can be further enhanced by including more demographic parameters of that location like age, medical insurance, education and employment.

Declarations

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