Pandemic hospital site selection: a GIS-based MCDM approach employing Pythagorean fuzzy sets

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Abstract
COVID-19 poses many challenges for hospitals around the world. Each country attempts to solve the problems in its hospitals using different methods. In Turkey, two pandemic hospitals were built in İstanbul, the most crowded province. In addition, some hospitals were designated as pandemic hospitals. This study focuses on the methods used for site selection for a pandemic hospital in Atakum, a district of Samsun City, Turkey. As a solution to the problem, initially, spatial analysis was performed using GIS to produce maps based on seven criteria obtained from the insight of an expert team. Analytic hierarchy process (AHP) augmented by interval-valued Pythagorean fuzzy numbers (PFNs) was then used to determine weights for the criteria. Distance to transportation network was the most important criterion influencing the selection process and the least significant one was the distance to fire stations. Based on the criteria weights, and five rules specified by the expert team, 13 suitable locations for a pandemic hospital were determined using GIS. The technique for order preference by similarity to ideal solution (TOPSIS) method was used to determine the final ranking of 13 alternative locations (A1–A13). A10 was identified as the most appropriate site and A11 as the least appropriate site for a pandemic hospital. Finally, sensitivity analysis was performed to investigate how changes in weight values of the criteria affect the ranking of the alternatives.

Keywords COVID-19 · Pandemic hospital · Site selection · Pythagorean fuzzy AHP · TOPSIS

Introduction

The novel coronavirus (COVID-19) has spread to many countries since its discovery at the end of 2019 in Wuhan, China, and World Health Organization (WHO) officially declared COVID-19 an unprecedented health crisis and a worldwide pandemic. The COVID-19 pandemic has changed daily lives deeply, put social life and public health under unprecedented pressure, and economies have fallen into recession (WHO 2020; Rostami-Tabar and Rendon-Sanchez 2021; Aslan et al. 2021).

The COVID-19 pandemic has caused numerous ripple effects (Ivanov and Dolgui 2021). The ripple effect (also known as risk propagation) is described as a sudden disruption at a few nodes in a supply chain network (Li and Zobel 2020; Yılmaz et al. 2021). When considered in terms of the health sector, despite the increasing demand for essential medical supplies and equipment, limited access to them reveals the whiplash effect in the supply chain. COVID-19 has also posed many challenges for hospitals around the world, including supplies, equipment, human resources, and space, in addition to putting pressure on the overall healthcare system (Yağma et al. 2020; Bragazzi et al. 2020). Each country has tried to solve the problems in its hospitals by using different methods. Countries such as China and Turkey have built emergency hospitals during the pandemic, whereas others such as Spain, the USA, Brazil, and India have turned venues such as stadiums, dormitories, and hostels into temporary pandemic hospitals (Yağma et al. 2020). Hospitals, which play a critical role in the national and local response to emergencies such as communicable disease epidemics, have revamped their procedures in order to distinguish patients with COVID-19 from non-COVID-19 (WHO 2014; Alban et al. 2020). In Turkey,
two pandemic hospitals were built in Istanbul, the most crowded province. In addition, hospitals with specialist physicians in infectious diseases and clinical microbiology, chest diseases, and internal diseases and having a tertiary level adult intensive care unit were accepted as pandemic hospitals (Yağma et al. 2020; Ministry of Health 2020).

Hospital site selection can be considered as a multi-criteria decision-making (MCDM) problem since it includes issues belonging to different fields and there are several and sometimes conflicting stakeholders to take into account (Dell’Ovo et al. 2018). This study investigates the selection of a site for a pandemic hospital to be built in Atakum, a district of Samsun with a population of 221,082 in 2020. The 5-year average annual population growth rate of Atakum district is 5.4%, which is the highest rate in Samsun Province (TSI 2020).

This paper develops an analytical tool that combines three techniques, geographic information systems (GIS), Pythagorean fuzzy analytic hierarchy process (PFAHP), and technique for order preference by similarity to ideal solution (TOPSIS) to obtain suitable sites for a pandemic hospital in Atakum. In several areas of use, GIS is an effective method of analyzing spatial data (Rızvanoğlu et al. 2020). An integrated GIS-MCDM method provides a practical approach that can manage time and costs, while reducing errors and increasing the efficiency of the decision-making process (Eghtesadifard et al. 2020). Moreover, a more accurate and systematic evaluation is ensured by integrating MCDM methods and fuzzy sets (Çalık Boyacı et al. 2021). Pythagorean fuzzy sets (PFSs) allow users to assess uncertainties in the real world more accurately and reliably, while helping to eliminate uncertainties (Ak and Gul 2019; Garg 2018). The integrated approach of combining PFSs, AHP, and TOPSIS has been effectively applied in various fields in the literature, such as risk assessment (Ak and Gul 2019; Bakioglu and Atahan 2021). ATM site selection (Yıldız et al. 2020), wind power farm location selection (Otay and Jaller 2020), hospital service quality evaluation (Yucesan and Gul 2020), green supplier selection (Çalık 2020), and transportation company selection (Sarkar and

| Author(s)      | Year | Method(s) used          | Application region | Criteria                                                                 |
|----------------|------|-------------------------|--------------------|---------------------------------------------------------------------------|
| Vahidnia et al.| 2009 | GIS, FAHP               | Iran               | (1) Distance from arterial routes, (2) travel time, (3) contamination, (4) land cost, (5) population density |
| Soltani and Marandi | 2011 | GIS, FAHP, FANP        | Iran               | (1) Cost of land, (2) distance to existing hospitals, (3) parcel area, (4) population density |
| Chatterjee and Mukherjee | 2013 | AHP                     | India              | (1) Cost of land, (2) land topography, (3) land ownership, (4) running/maintenance cost, (5) population density, (6) education, (7) economic condition, (8) proximity to public transport, (9) space for future construction, (10) availability of existing infrastructure, (11) proximity to market |
| Rahimi et al.  | 2017 | GIS, AHP                | Iran               | (1) Population density, (2) fair distribution of hospitals all over the city, (3) fast and easy accessibility, (4) proximity to the main roads, (5) being far from airport, (6) not being located on the river path, (7) being far from industrial centers, (8) proximity to fire stations, (9) land area |
| Dell’Ovo et al.| 2018 | GIS, AHP                | Italy              | (1) Center of Urban redevelopment, (2) flexibility, (3) building density, (4) accessibility, (5) services, (6) green area, (7) network infrastructures, (8) noise pollution, (9) air pollution, (10) unhealthy industries, (11) value of the area, (12) land ownership, (13) land suitability |
| Soltani et al. | 2019 | GIS, AHP                | Iran               | (1) Transportation network, (2) existing healthcare centers, (3) land use, (4) population density, (5) distance from industrial centers, (6) distance from existing fire stations, (7) distance from urban green spaces |
| Sahin et al.   | 2019 | AHP                     | Turkey             | (1) Medical technology, (2) number of total beds, (3) units, (4) total hospitals, (5) population, (6) possibility of population change, (7) population age structure, (8) income, (9) air pollution, (10) access to water resources, (11) inner-city, (12) upstate, (13) medical industry, (14) medicine industry, (15) labor market, (16) incentive, (17) legislation, (18) policies, (19) tax |
| Nsaif et al.   | 2020 | GIS, MCA                | Iraq               | (1) Existing hospitals and medical centers, (2) distance to roads, (3) river, (4) slope, (5) population |
| Kahev et al.   | 2020 | GIS, AHP, Improved Genetic Algorithm | Iran | (1) Distance from existing hospitals, (2) distance from population centers, (3) distance from fire stations, (4) distance from strong power lines, (5) distance from road network, (6) distance from fault, (7) distance from parks |
| Rezayee        | 2020 | GIS, MCA                | Malaysia           | (1) Existing hospital, (2) residential area, (3) main road, (4) river, (5) ferry route, (6) ferry terminal |
Methodology

A methodology that combines three techniques, GIS, PFAHP, and TOPSIS, for a pandemic hospital site selection is proposed in this study. This section explains these methods.

Geographic information systems (GIS)

GIS is a computer-based tool that is used in many areas, such as land management, emergency management, environmental sciences, and public health. The ability to ask complex questions about the environment, analyze features together, and then show multiple aspects of the results on a map makes GIS a powerful tool. GIS allows the investigation of many factors based on spatial data, including monitoring, evaluation of risk factors, development of control strategies, and the management of the process (Sisman 2013). The spatial and non-spatial data are combined in separate layers and can be queried and analyzed together in GIS (see Fig. 1).

PFAHP

Preliminaries of PFSs

PFSs, which are an extension of intuitionistic fuzzy sets, were first proposed by Yager (2014) and have been applied to a variety of problems respecting uncertainty such as interval type-2 fuzzy sets, hesitant fuzzy sets, and intuitionistic fuzzy sets (Ak and Gul 2019). PFSs are more efficient and flexible to solve problems that include uncertainty (Ilbahar et al. 2018; Ak and Gul 2019; Gul 2020). In PFSs, unlike intuitionistic fuzzy sets, the sum of membership and non-membership degrees can exceed 1, but their sum of squares cannot (Zhang and Xu 2014; Zeng et al. 2016; Ilbahar et al. 2018; Ak and Gul 2019; Gul 2020). This is expressed in Eqs. (1) and (2).

**Definition 1** Let a set \( X \) be a universe of discourse. A PFS \( P \) is an object having the form (Zhang and Xu 2014; Zeng et al. 2016; Ilbahar et al. 2018; Ak and Gul 2019; Gul 2020):

\[
P = \{ x, P(\mu_P(x), v_P(x)) > |x \in X \}
\]

where the function \( \mu_P : X \to [0, 1] \) defines the degree of membership and \( v_P : X \to [0, 1] \) defines the degree of non-membership of the element \( x \in X \) to \( P \), respectively, and for every \( x \in X \), it holds:

\[
(\mu_P(x))^2 + (v_P(x))^2 \leq 1
\]

For any PFS \( P \) and \( x \in X \), \( \pi_P(x) = \sqrt{1 - \mu_P^2(x) - v_P^2(x)} \) is called the degree of indeterminacy of \( x \) to \( P \).

**Definition 2** Let \( \beta = P(\mu, v) = P(\mu_{\beta_1}, v_{\beta_1}) \) and \( \beta_2 = P(\mu_{\beta_2}, v_{\beta_2}) \) be three Pythagorean fuzzy numbers (PFNs), and \( \lambda > 0 \), then the operations on these three PFNs are defined as Eqs. (3) to (6) (Zhang and Xu 2014; Zeng et al. 2016):

\[
\beta_1 \ominus \beta_2 = P\left(\sqrt{\mu_{\beta_1}^2 + \mu_{\beta_2}^2 - 2\mu_{\beta_1} \mu_{\beta_2}}, v_{\beta_1} v_{\beta_2}\right)
\]

\[
\beta_1 \ominus \beta_2 = P\left(\mu_{\beta_1} \mu_{\beta_2}, \sqrt{v_{\beta_1}^2 + v_{\beta_2}^2 - 2v_{\beta_1} v_{\beta_2}}\right)
\]

\[
\lambda \beta = P\left(\sqrt{1 - \left(1 - \mu_{\beta}^2\right)^2}, (v_{\beta})^2\right), \lambda > 0
\]

\[
\beta_1 \ominus \beta_2 = P\left(\mu_{\beta}^2, \sqrt{1 - (1 - v_{\beta}^2)^2}\right), \lambda > 0
\]
To compare the PFSs, a score function is proposed (Zhang and Xu 2014). For a PFN $\beta = P(\mu, v)$, the score function of $\beta$ can be defined as Eq. (7) (Zhang and Xu 2014; Zeng et al. 2016): 

$$\beta_1 \geq \beta_2 \text{ if and only if } \mu_{\beta_1} \geq \mu_{\beta_2} \text{ and } v_{\beta_1} \leq v_{\beta_2}. $$

Fig. 2. The flow chart of the proposed method.
On the basis of score function of PFNs, the following laws are defined to compare two PFNs (Zhang and Xu 2014).

\[
s(\beta) = (\mu_{\beta_j})^2 - (v_{\beta_j})^2
\]

(7)

Definition 4 Let \(\beta_j = P\left(\mu_{\beta_j}, v_{\beta_j}\right)\) \((j = 1, 2)\) be two PFNs, \(s(\beta_1)\) and \(s(\beta_2)\) be the scores of \(\beta_1\) and \(\beta_2\), then

- If \(s(\beta_1) < s(\beta_2)\), then \(\beta_1 < \beta_2\)
- If \(s(\beta_1) > s(\beta_2)\), then \(\beta_1 > \beta_2\)
- If \(s(\beta_1) = s(\beta_2)\), then \(\beta_1 \sim \beta_2\)

Steps of the PFAHP

The steps of interval-valued PFAHP are as follows (Ilbahar et al. 2018):

Step 1. Construct the compromised pairwise comparison matrix \(R = (r_{ik})_{m \times m}\) based on linguistic evaluations of experts using the scale proposed by Ilbahar et al. (Ilbahar et al. 2018).

Step 2. Calculate the differences matrix \(D = (d_{ik})_{m \times m}\) between the lower and upper values of the membership and non-membership functions using Eqs. (8) and (9):

\[
d_{ikl} = \mu_{\beta_k}^2 - v_{\beta_k}^2
\]

(8)

\[
d_{iku} = \mu_{\beta_k}^2 - v_{\beta_k}^2
\]

(9)

Step 3. Compute the interval multiplicative matrix \(S = (s_{ik})_{m \times m}\) using Eqs. (10) and (11):

\[
s_{ikl} = \sqrt{1000d_{ikl}^2}
\]

(10)

Step 4. Calculate the determinacy value \(\tau = (\tau_{ik})_{m \times m}\) using Eq. (12):

\[
\tau_{ik} = 1 - \left(\mu_{\beta_k}^2 - \mu_{\beta_k}^2\right) - \left(v_{\beta_k}^2 - v_{\beta_k}^2\right)
\]

(12)

Step 5. Multiply the determinacy degrees with \(S = (s_{ik})_{m \times m}\) matrix to obtain the matrix of weights \(T = (t_{ik})_{m \times m}\) before normalization using Eq. (13):

\[
t_{ik} = \frac{(s_{ikl} + s_{iku})}{2} \tau_{ik}
\]

(13)

Step 6. Compute each normalized priority weight \(w_i\) using Eq. (14):

\[
w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m} \sum_{k=1}^{m} t_{ik}}
\]

(14)

TOPSIS

The TOPSIS method was presented by Hwang and Yoon (1981). The basic principle of the TOPSIS method is that the chosen alternative has the shortest distance to the ideal solution and the furthest distance to the negative ideal solution. The stages to be followed in the TOPSIS method can be summarized as follows:

Step 1. Calculate the normalized decision matrix.
Step 2. Form the weighted normalized decision matrix.
Step 3. Determine the ideal and negative-ideal solutions.
Step 4. Calculate the separation of each alternative from the ideal solution and the separation from the negative-ideal solution.
Step 5. Calculate the relative closeness to the perfect solution.
Step 6. Rank the preference order.
(a) Population density (C1)

(b) Distance to transportation network (C2)

(c) Distance to existing hospitals (C3)

(d) Distance to fire stations (C4)

(e) Land value (C5)

(f) Slope (C6)

(g) Distance to industrial areas (C7)
Details of the TOPSIS method are found in numerous papers (Hwang and Yoon 1981; Opricovic and Tzeng 2004; Mousavi-Nasab and Sotoudeh-Anvari 2017; Ramya and Devadas 2019; Adalı and Tuş 2021).

Implementation of the proposed methodology

The implementation of the proposed methodology is described in this section. The flow chart of the proposed method adopted for a pandemic hospital site selection problem is given in Fig. 2. There are two phases for the proposed method: problem definition and data collection and the GIS-based PFAHP and TOPSIS model (Fig. 2).

Problem definition and data collection

This study focuses on the selection of the site for a pandemic hospital in Atakum district using GIS-based PFAHP and TOPSIS methods. Atakum has a total area of 355 km² but with varying population density. The eastern coastal part is the most densely populated region of the district. The study area is shown in Fig. 3.

In this study, criteria influencing the site selection process were determined by eliciting opinion from an expert team of five members and by considering previous studies given in Table 1, as follows. The criteria are represented by $C_j$, where $C_1$, $C_3$, and $C_7$ are to be maximized and $C_2$, $C_4$, $C_5$, and $C_6$ are to be minimized. The detailed information about the expert team is listed in Table 2.

- $C_1$: Population density
- $C_2$: Distance to transportation network
- $C_3$: Distance to existing hospitals
- $C_4$: Distance to fire stations
- $C_5$: Land value
- $C_6$: Slope
- $C_7$: Distance to industrial areas

Production of maps

In this study, seven criteria were used to determine the most suitable alternative locations for a pandemic hospital. Data used in the study were obtained from several sources. Population density maps for 2020 of the 57 neighborhoods in Atakum District (TSI 2020) were obtained. The industrial area map was based on the Atakum zoning plan. The location of existing hospitals, fire stations, and transport network including main roads and the tramway system was obtained using a handheld receiver and satellite images. Land value data was based on sale prices present on web pages; 93 sales data were used to produce a value map of the study area. The topographic gradient map was produced based on the Shuttle Radar Topography Mission (SRTM) digital elevation model (USGS 2021).

In this study, several types of spatial analysis were used, and the maps of the seven criteria given in Fig. 4a to g were produced using ArcGIS software. Euclidean distance analysis was used to produce the distance maps of the transport network, existing hospitals, fire stations, and industrial areas. The population density map was produced using kernel density analysis based on the population of neighborhoods, and the value map was produced based on the location of real estate for sale, using inverse distance weighted (IDW) analysis, which is an interpolation method.
Table 5  Pairwise comparison of the criteria obtained by using PFNs

|    | C1   | C2   | C3   | C4   | C5   | C6   | C7   |
|----|------|------|------|------|------|------|------|
| C1 | [(0.1965, 0.1965], | (0.35, 0.45], | (0.55, 0.65], | (0.80, 0.90], | (0.35, 0.45], | (0.65, 0.80], | (0.35, 0.45], |
|    | [0.1965, 0.1965)] | [0.55, 0.65)] | [0.35, 0.45)] | [0.10, 0.20)] | [0.35, 0.45)] | [0.20, 0.35)] | [0.35, 0.45)] |
| C2 | (0.55, 0.65], | (0.1965, 0.1965], | (0.55, 0.65], | (0.80, 0.90], | (0.65, 0.80], | (0.80, 0.90], | (0.65, 0.80], |
|    | [0.35, 0.45)] | [0.1965, 0.1965)] | [0.35, 0.45)] | [0.10, 0.20)] | [0.20, 0.35)] | [0.20, 0.20)] | [0.20, 0.35)] |
| C3 | (0.35, 0.45], | (0.1965, 0.1965], | (0.1965, 0.1965], | (0.65, 0.80], | (0.55, 0.65], | (0.55, 0.65], | (0.45, 0.55], |
|    | [0.55, 0.65)] | [0.1965, 0.1965)] | [0.1965, 0.1965)] | [0.20, 0.35)] | [0.35, 0.45)] | [0.35, 0.45)] | [0.45, 0.55)] |
| C4 | (0.10, 0.20], | (0.10, 0.20], | (0.10, 0.20], | (0.1965, 0.1965], | (0.35, 0.45], | (0.45, 0.55], | (0.35, 0.45], |
|    | [0.08, 0.90)] | [0.08, 0.90)] | [0.08, 0.90)] | [0.1965, 0.1965)] | [0.35, 0.45)] | [0.45, 0.55)] | [0.35, 0.45)] |
| C5 | (0.35, 0.45], | (0.20, 0.35], | (0.55, 0.65], | (0.35, 0.45], | (0.55, 0.65], | (0.35, 0.45], | (0.35, 0.45], |
|    | [0.55, 0.65)] | [0.65, 0.80)] | [0.55, 0.65)] | [0.35, 0.45)] | [0.55, 0.65)] | [0.35, 0.45)] | [0.35, 0.45)] |
| C6 | (0.20, 0.35], | (0.20, 0.20], | (0.45, 0.55], | (0.35, 0.45], | (0.35, 0.45], | (0.1965, 0.1965], | (0.35, 0.45], |
|    | [0.65, 0.80)] | [0.80, 0.90)] | [0.45, 0.55)] | [0.35, 0.45)] | [0.35, 0.45)] | [0.1965, 0.1965)] | [0.35, 0.45)] |
| C7 | (0.35, 0.45], | (0.20, 0.35], | (0.45, 0.55], | (0.55, 0.65], | (0.55, 0.65], | (0.1965, 0.1965], | (0.1965, 0.1965], |
|    | [0.55, 0.65)] | [0.65, 0.80)] | [0.45, 0.55)] | [0.35, 0.45)] | [0.35, 0.45)] | [0.1965, 0.1965)] | [0.1965, 0.1965)] |

Results and discussion

PFAHP method for determining the criteria weights

The weights for the criteria were obtained using interval-valued PFAHP. The weighting scale of interval-valued PFAHP is given in Table 3. The linguistic terms presented in Table 3 are used by the expert team to evaluate the relative importance of the seven criteria (Table 4). Table 5 is obtained using lower and upper values of membership degree ($\mu_L$, $\mu_U$) and lower and upper values of non-membership degree ($\nu_L$, $\nu_U$). The difference matrix ($D$) and interval multiplicative matrix ($S$) are given in Tables 6 and 7, respectively. The determinacy value matrix ($T$) and weights before normalization ($L$) are given in Tables 8 and 9, respectively. Finally, weights of the criteria determined by using PFAHP method are given in Fig. 5. As shown in Fig. 5, C2 “distance to transportation network” is the most important criterion influencing the selection process, with a weight of 0.385; and the least significant one is the C4 “distance to fire stations” with a weight of 0.038. Distance to transportation network is a critical criterion for the selection of a hospital site. Studies by Dell’Ovo et al. (2018) and Rahimi et al. (2017) determined a similar finding. The results further indicate that C1 “population density” is the second most important criterion.

Identification of suitable locations using GIS

This subsection presents maps for the seven criteria (Fig. 4), which were normalized and combined according to their weight to form a single weighted map (Fig. 5a) and classified weighted map (Fig. 5b).

The classified weighted map (Fig. 5b) identifies the regions most suitable for the location of a pandemic hospital. To

Table 6  The difference matrix

|    | C1   | C2   | C3   | C4   | C5   | C6   | C7   |
|----|------|------|------|------|------|------|------|
| C1 | (0.00, 0.00] | (-0.30, -0.10) | (0.10, 0.30] | (0.60, 0.80] | (0.10, 0.30] | (0.30, 0.60] | (0.10, 0.30] |
| C2 | (0.10, 0.30] | (0.00, 0.00] | (0.10, 0.30] | (0.60, 0.80] | (0.30, 0.60] | (0.60, 0.80] | (0.30, 0.60] |
| C3 | (-0.30, -0.10) | (-0.30, -0.10) | (0.00, 0.00] | (0.30, 0.60] | (0.10, 0.30] | (0.10, 0.30] | (-0.10, 0.10] |
| C4 | (-0.80, -0.60) | (-0.80, -0.60) | (-0.60, -0.30) | (0.00, 0.00] | (-0.30, -0.10] | (-0.10, 0.10] | (-0.30, -0.10] |
| C5 | (-0.30, -0.10) | (-0.60, -0.30) | (-0.30, -0.10) | (0.10, 0.30] | (0.00, 0.00] | (0.10, 0.30] | (-0.30, -0.10] |
| C6 | (-0.60, -0.30) | (-0.80, -0.60) | (-0.30, -0.10) | (-0.10, 0.10] | (0.00, 0.00] | (-0.30, -0.10] | (-0.30, -0.10] |
| C7 | (-0.30, -0.10) | (-0.60, -0.30) | (-0.10, 0.10] | (0.10, 0.30] | (0.10, 0.30] | (0.00, 0.00] | (-0.30, -0.10] |
determine the most suitable locations, further conditions must be considered:

- Nsaif et al. (2020) used a topographic gradient of less than 10% for the immediate vicinity in their hospital site selection study. The area of the current study is relatively flat, and so the gradient has been set as less than 5%.
- Some studies specify that an ambulance should reach the hospital within 8 min (Pell et al. 2001; Pons and Markovchick 2002; Zègre-Hemsey et al. 2011; Terzi et al. 2013). The current study has applied an 8-min time limit and 50 km/h average speed (Terzi et al. 2013). This sets an 8.3-km radius from the point of densest population within which the location of the pandemic hospital must lie.
- The Regulation of Spatial Plans Production in Turkey and the Regulation of Investment Principles of Ministry of Health Hospitals specify 25 hospital beds per 10K population with an area of 130 m² per bed. Given a population of 221K, a hospital in Atakum would require an area at least 50.000 m² for a suitable location (Regulation of Spatial Planning 2014; Regulation of Investment Principles of Ministry of Health Hospitals 2003).
- Any suitable location must be at least 100 m from existing buildings.
- Every selected location must be at least 500 m from all other selected locations.

According to the reclassified map (Fig. 7a), redrawn to include the supplementary conditions, 13 suitable locations were identified for a pandemic hospital (Fig. 7b).

**Ranking the alternatives using TOPSIS method**

The TOPSIS method was used to rank the locations (A1 –A13). In Table 10, the normalized values obtained from the ArcGIS software are used to construct the decision matrix, and then TOPSIS was applied to obtain the ranking of the locations. According to Table 10, A10 is identified as the most appropriate site and A11 as the least appropriate site for a pandemic hospital in Atakum.

In terms of mathematical simplicity and flexibility, the TOPSIS approach has advantages. It is also excellent at solving large, complicated decision-making problems (Adali and Tuş 2021). TOPSIS is implemented effectively for site selection problems (Yal and Akgün 2014; Çetinkaya et al. 2016; Jozaghi et al. 2018; Luo et al. 2020; Adali and Tuş 2021).  

**Sensitivity analysis**

Sensitivity analysis was performed to investigate how changes in weight values of the criteria affect the ranking of the alternatives. For this reason, the weight values of the criteria are adjusted for two separate situations.

### Table 7: The interval multiplicative matrix

|    | C1         | C2         | C3         | C4         | C5         | C6         | C7         |
|----|------------|------------|------------|------------|------------|------------|------------|
| C1 | ([1.000, 1.000]) | ([0.355, 0.708]) | ([1.413, 2.818]) | ([7.943, 15.849]) | ([1.413, 2.818]) | ([2.818, 7.943]) | ([1.413, 2.818]) |
| C2 | ([1.413, 2.818]) | ([1.000, 1.000]) | ([1.413, 2.818]) | ([7.943, 15.849]) | ([2.818, 7.943]) | ([1.413, 2.818]) | ([1.413, 2.818]) |
| C3 | ([0.355, 0.708]) | ([0.355, 0.708]) | ([1.000, 1.000]) | ([2.818, 7.943]) | ([1.413, 2.818]) | ([1.413, 2.818]) | ([0.708, 1.413]) |
| C4 | ([0.063, 0.126]) | ([0.063, 0.126]) | ([0.126, 0.355]) | ([1.000, 1.000]) | ([0.355, 0.708]) | ([0.708, 1.413]) | ([0.355, 0.708]) |
| C5 | ([0.355, 0.708]) | ([0.126, 0.355]) | ([0.355, 0.708]) | ([1.413, 2.818]) | ([1.000, 1.000]) | ([1.413, 2.818]) | ([0.355, 0.708]) |
| C6 | ([0.126, 0.355]) | ([0.063, 0.126]) | ([0.355, 0.708]) | ([0.708, 1.413]) | ([0.355, 0.708]) | ([1.000, 1.000]) | ([0.355, 0.708]) |
| C7 | ([0.355, 0.708]) | ([0.126, 0.355]) | ([0.708, 1.413]) | ([1.413, 2.818]) | ([1.413, 2.818]) | ([1.413, 2.818]) | ([1.000, 1.000]) |

### Table 8: The determinacy values

|    | C1         | C2         | C3         | C4         | C5         | C6         | C7         |
|----|------------|------------|------------|------------|------------|------------|------------|
| C1 | 1.00       | 0.80       | 0.80       | 0.80       | 0.70       | 0.80       | 0.80       |
| C2 | 0.80       | 1.00       | 0.80       | 0.80       | 0.70       | 0.80       | 0.70       |
| C3 | 0.80       | 0.80       | 1.00       | 0.70       | 0.80       | 0.80       | 0.80       |
| C4 | 0.80       | 0.80       | 0.70       | 1.00       | 0.80       | 0.80       | 0.80       |
| C5 | 0.80       | 0.70       | 0.80       | 0.80       | 1.00       | 0.80       | 0.80       |
| C6 | 0.70       | 0.80       | 0.80       | 0.80       | 0.80       | 1.00       | 0.80       |
| C7 | 0.80       | 0.70       | 0.80       | 0.80       | 0.80       | 0.80       | 1.00       |

### Table 9: Weights before normalization

|    | C1         | C2         | C3         | C4         | C5         | C6         | C7         |
|----|------------|------------|------------|------------|------------|------------|------------|
| C1 | 1.000      | 0.425      | 1.692      | 9.517      | 1.692      | 3.767      | 1.692      |
| C2 | 1.692      | 1.000      | 1.692      | 9.517      | 3.767      | 9.517      | 3.767      |
| C3 | 0.425      | 0.425      | 1.000      | 3.767      | 1.692      | 1.692      | 0.848      |
| C4 | 0.076      | 0.076      | 0.168      | 1.000      | 0.425      | 0.848      | 0.425      |
| C5 | 0.425      | 0.168      | 0.425      | 1.692      | 1.000      | 1.692      | 0.425      |
| C6 | 0.168      | 0.076      | 0.425      | 0.848      | 0.425      | 1.000      | 0.425      |
| C7 | 0.425      | 0.168      | 0.848      | 1.692      | 1.692      | 1.692      | 1.000      |
and the alternative locations are re-evaluated. Table 11 shows the results of the proposed model, Scenario 1 (S1), in which all criteria were given equal weight, and Scenario 2 (S2), in which the weight value of the most important criterion (C2) and the weight value of the least important criterion (C4) were swapped. It can be seen from Table 11 that A10 is the first alternative according to the proposed model and S1; A6 is the first alternative according to S2. In addition, it is possible to say that the rankings of A8 and A10 have not changed significantly. The sensitivity analysis results show that the criteria weights are very important in the pandemic hospital site selection.

**Conclusion**

Hospitals play a critical role in the national and local response to emergencies such as pandemics. This paper describes a scientific framework that combines GIS, PFAHP, and TOPSIS that is used to determine the optimum location for a pandemic hospital in Atakum. As the first step, spatial analysis is performed using GIS to produce maps for the criteria elicited from the insight of the expert team. AHP strengthened by interval-valued PFNs was then used to obtain the criteria weights. Distance to transportation network was the most important criterion, and the least significant one was the distance to fire...
stations. Based on the criteria weights, and the five rules determined from the expert team, 13 suitable locations for a pandemic hospital were identified using GIS. The TOPSIS method was then used to determine the ranking of the 13 alternative locations (A1−A13). Finally, a sensitivity analysis was performed to show the robustness of the framework.

The proposed method has the advantage of encouraging decision-makers to address complex decision-making problems with a highly methodological basis for decision support. Use of linguistic term sets is another functional benefit of the proposed approach since decision-makers often prefer linguistic evaluations to construct the decision matrix. In addition, use of PFSs manages the uncertainty and vagueness of the perceptions of the expert team during the subjective judgment process.

This study may be expanded to other crowded cities in Turkey for future work. Criteria and the number may be amended based on the characteristics of the study area. Furthermore, other fuzzy MCDM methods can be compared to the proposed method.

| Table 10  | Ranking of the alternative locations |
|-----------|-------------------------------------|
| Site      | Normalized value | TOPSIS rank |
| C1        | C2        | C3        | C4        | C5        | C6        | C7        |
| A1        | 0.120     | 0.004     | 0.082     | 0.255     | 0.194     | 0.000     | 0.037     | 2         |
| A2        | 0.244     | 0.018     | 0.067     | 0.225     | 0.182     | 0.035     | 0.041     | 4         |
| A3        | 0.153     | 0.031     | 0.084     | 0.198     | 0.142     | 0.027     | 0.018     | 11        |
| A4        | 0.125     | 0.005     | 0.076     | 0.180     | 0.121     | 0.040     | 0.027     | 3         |
| A5        | 0.037     | 0.005     | 0.105     | 0.197     | 0.075     | 0.017     | 0.029     | 5         |
| A6        | 0.274     | 0.030     | 0.068     | 0.101     | 0.192     | 0.031     | 0.122     | 6         |
| A7        | 0.071     | 0.028     | 0.084     | 0.133     | 0.172     | 0.035     | 0.107     | 12        |
| A8        | 0.040     | 0.022     | 0.122     | 0.153     | 0.110     | 0.017     | 0.124     | 9         |
| A9        | 0.006     | 0.019     | 0.164     | 0.193     | 0.023     | 0.016     | 0.134     | 8         |
| A10       | 0.177     | 0.003     | 0.068     | 0.102     | 0.141     | 0.035     | 0.203     | 1         |
| A11       | 0.033     | 0.044     | 0.078     | 0.128     | 0.122     | 0.025     | 0.312     | 13        |
| A12       | 0.022     | 0.014     | 0.109     | 0.158     | 0.083     | 0.012     | 0.337     | 7         |
| A13       | 0.038     | 0.024     | 0.118     | 0.170     | 0.051     | 0.038     | 0.320     | 10        |

| Table 11  | Sensitivity analysis results |
|-----------|-----------------------------|
| Site      | Rank | Prop model | S1 | S2 |
| A1        | 2    | 5          | 11 |
| A2        | 4    | 8          | 3  |
| A3        | 11   | 12         | 4  |
| A4        | 3    | 9          | 5  |
| A5        | 5    | 7          | 13 |
| A6        | 6    | 4          | 1  |
| A7        | 12   | 13         | 6  |
| A8        | 9    | 10         | 10 |
| A9        | 8    | 6          | 12 |
| A10       | 1    | 1          | 2  |
| A11       | 13   | 11         | 7  |
| A12       | 7    | 2          | 8  |
| A13       | 10   | 3          | 9  |
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Aziz Şişman: software, methodology, formal analysis, data curation, writing (original draft), writing (review and editing), and visualization

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