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GIS-Enabled Multi-Criteria Assessment for Hospital Site Suitability: A Case Study of Tehran

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Abstract: In developing countries, the interaction between rapid urban expansion and population growth brings forth a host of challenges, particularly concerning essential services like healthcare. While interest in site suitability analysis for identifying optimal hospital locations to ensure equitable and secure healthcare access is on the rise, the absence of a holistic study that encompasses social and environmental aspects in the assessment of hospital site suitability is evident. The objective of this research is to introduce a hybrid methodology that combines Geographic Information Systems (GIS) with Multi-Criteria Decision-Making (MCDM) weighting methods. This methodology aims to create hospital site suitability maps for districts 21 and 22 in Tehran, taking into account socio-environmental factors. In addition to the conventional Analytical Hierarchical Process (AHP) weighting method, this study employs two relatively less-explored methods, the Best-Worst Method (BWM) and Step-wise Weight Assessment Ratio Analysis (SWARA), to enhance the analysis of hospital site suitability. In the SWARA method, there are minimal variations in weights among criteria, indicating that all socio-environmental factors (e.g., distance from existing hospitals, distance from main roads, distance from green spaces) hold significant importance in the decision-making process. Additionally, the findings indicate that the western part of the study area is the most suitable location for the construction of a new hospital. To achieve the average hospital bed availability in Tehran, an additional 2206 beds are required in the studied area, in addition to the existing facilities. Considering the ongoing urban development, population growth, and the potential for natural disasters and epidemics, it becomes essential to enhance the healthcare system by increasing the number of hospitals and available hospital beds. The sensitivity analysis showed that GIS-based SWARA-WLC was the most suitable and stable model for determining hospital site suitability in the study area. This methodology can be adapted for use in other regions and further improved by incorporating additional criteria. In conclusion, the study recommended three specific alternative sites for establishing a new hospital in the study area.

Keywords: GIS-based multi-criteria decision making; hospital site suitability; analytical hierarchy process; step-wise weight assessment ratio analysis; best-worst method

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1. Introduction

Rapid urban expansion and population growth drive the demand for essential services, particularly healthcare [1]. Access to these services significantly enhances the quality of urban living. Among these services, hospitals play a pivotal role, making the selection of their locations of paramount importance [2,3]. The unequal distribution of hospitals within cities poses a significant challenge, hindering residents' access to healthcare services [4] especially in developing nations due to urban growth, resource constraints, and construction expenses [5]. The selection of suitable healthcare locations involves the consideration of multiple, often interconnected criteria [6]. Therefore, an efficient protocol for site selection is imperative [3], relying on Multi-Criteria Decision-Making (MCDM) techniques [2,7]. MCDM is the preferred approach for addressing the complexity of hospital location requirements [8], aiding in identifying the best choice when criteria conflict [9,10].

Geographic Information Systems (GIS) play a crucial role in incorporating geographical considerations into location selection processes, thereby enhancing their effectiveness [11]. Serving as a decision support system, GIS complements the decision-making system, MCDM, collectively bolstering spatial analysis capabilities on different sources of data [11,12]. Accordingly, health-based information systems serves as a versatile analytical tool across various domains [13–17], contributing to increased precision while concurrently reducing errors, time, and costs [18–21]. In the realm of hospital location analysis, common techniques include the Analytical Hierarchy Process (AHP) and GIS-based models, often adopting hybrid approaches [22]. AHP frequently serves as the cornerstone of research in this field [7,23], often combined with GIS, Fuzzy AHP, or other strategies [24–26].

New methods and hybrid methodologies are constantly being used and implemented in other fields, and research has always been conducted on the suitability of hospital sites. New research offers new methodologies to address the shortcomings of previous studies or to introduce new topics. The present study aims to provide a comprehensive survey and comparison between conventional hospital site suitability methodologies and less studied methods. The previous methodologies mainly include three stages: providing spatial information of the criteria, criteria weighting, and combining criteria. The first stage is always done by GIS. The third stage is done by Weighted Linear Combination (WLC) in most cases. The second stage has been done by different weighting methods and has a high potential for improvement and updating. Also, the most important stage in an MCDM methodology is the weighting process. In the present study, a conventional methodology including GIS, weighting process and criteria combination is selected, and the goal is to improve this methodology by using different weighting methods. To achieve this goal, three weighting methods, including AHP, Best-Worst Method (BWM), and Stepwise Weight Assessment Ratio Analysis (SWARA) were used, and by a sensitivity analysis approach the most stable and reliable methodology was determined. In the following, the advantages and disadvantages of the weighting methods used in the present study are explained and compared.

The AHP weighting method is the most conventional and widely used weighting method in previous research in terms of hospital site suitability and other applications. This method is simple and efficient but has some shortcomings. The high number of pairwise comparisons and an inability to consider the relationships between criteria are the shortcomings of this method. The high amount of pairwise comparisons can lead to miscalculations [27]. In addition to the issues mentioned, the rank reversal problem is another shortcoming of this method [17]. Basically, to deal with these shortcomings, the Analytic Network Process (ANP) method has been introduced during development of the AHP method [28,29]. However, the design of the network structure, its implementation, and the very high pairwise comparisons of the ANP method are its shortcomings.

The new weighting method of BWM greatly reduces the number of pairwise comparisons compared to the AHP and ANP methods. The BWM method has been quickly adopted in various applications and the desirability of its performance has been determined [30,31]. This method significantly reduced pairwise comparisons and increased the ease of implementation and the consistency of the results, and consequently increased the reliability of the results [32].

Although the SWARA method was introduced before the BWM method, it has received less attention in research related to site suitability and in combination with GIS. Of course, new studies [33,34] have used this method in different applications and in combination with GIS. However, it has not been considered in hospital site suitability applications. SWARA can be successfully used instead of other MCDM and weighting methods, such as AHP and ANP [17]. The SWARA method offers distinct advantages by quantifying disparities in criteria importance and considering the perspectives of the decision-making panel [35,36]. This method greatly reduces the number of pairwise comparisons compared to other methods such as AHP, ANP, and even BWM. When the number of criteria increases, this feature is an advantage to the decision-maker. In addition to increasing the accuracy and reliability of the results, this significant reduction of pairwise comparisons also improves the ease of implementation [33,34].

The aim of this study is to determine potential hospital sites within the boundaries of the study area in Tehran, Iran, with the help of GIS-based MCDM (AHP, BWM, and SWARA). In this study, three hybrid methodologies—GIS-based AHP-WLC, GIS-based BWM-WLC, and GIS-based SWARA-WLC—were employed to assess hospital site suitability. The objectives of the study are listed as follows: (1) determination of criteria that are relevant in hospital site suitability and preparation of their spatial layers; (2) determination of criteria weights based on AHP, BWM, and SWARA methods; (3) determination of suitable areas in terms of hospital site suitability based on AHP, BWM, and SWARA methods; (4) analysis of the performance of each methodology in terms of hospital site suitability; (5) performing sensitivity analysis to survey the stability of the results obtained from different methodologies, and determination of the most stable method.

As can be seen in Section 2, most studies of hospital site suitability used AHP in their proposed methodologies. Also, some of them used BWM, but almost no research has used SWARA in its methodology. Therefore, the first contribution of the present study is the use of the SWARA method in terms of hospital site suitability. In addition, studies that compare different methods are always needed, hence, the second contribution of the present study is the surveying, evaluation and comparison of three different weighting methods in term of hospital site suitability, which has not been considered in previous research. Finally, for the third contribution, the present study has used a feasible and appropriate sensitivity analysis process in order to evaluate the stability of the results of the different methods, which has not been used in previous related works.

The rest of this paper includes the following sections. Related works are presented in the Section 2. The materials and methods used are presented in the Section 3. The experimental results are presented in the Section 4. Finally, the discussion and conclusion are presented in the Sections 5 and 6, respectively.

2. Related Works

Numerous researchers have put forth distinctive hospital site selection approaches. Hospital site suitability can be investigated as an MCDM problem [2], an optimization problem [37], and as a classification or regression problem [38,39]. In terms of hospital site suitability or hospital site selection, usually the MCDM method is used. Hybrid methods include several MCDM methods, and the combination of MCDM methods with GIS has usually been given more attention in previous research. In the following, some of the more relevant studies are presented.

Yazdi et al. [40] employed a hybrid method for ranking nine candidate sites for hospital site selection. They used BWM in combination with Pythagorean fuzzy numbers in order to determine the criteria weights, and used the Evaluation by an Area-based Method of Ranking (EAMR) for hospital candidate site ranking. Zandi et al. [4] introduced a hybrid methodology for evaluating hospital site suitability in Tehran, incorporating GIS, Criteria Importance Through Inter-criteria Correlation (CRITIC), Shannon Entropy (SE), Dempster-Shafer Theory (DST), and Order Weighting Average (OWA). At first, they selected 10 hospital candidate sites and calculated the criteria values for each site. In the next step, they calculated the criteria weights by two objective weighting methods (CRITIC and SE) without need for experts' opinions. Then, they fused the results of the two objective weighting methods by DST. Finally, they performed candidate site ranking by the OWA method, but they did not perform a sensitivity analysis on the candidate sites ranking.

Aydin & Seker [41] devised a hybrid approach that integrates Delphi, BWM and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). They used the Delphi method for determining the criteria and candidate site, BWM for criteria weighting, and fuzzy TOPSIS for candidate sites ranking. They also performed a sensitivity analysis on the candidate sites ranking. Based on their study, the proposed methodology was stable and results were reliable. Boyacı & Şişman [42] proposed an innovative methodology by integrating fuzzy AHP, GIS, and TOPSIS in their approach. They used GIS for preparing criteria layers, fuzzy AHP for criteria weighting, and TOPSIS for candidate sites ranking. Halder et al. [24], in order to assess hospital site suitability in India, proposed a hybrid approach including GIS for preparing criteria layers, AHP for criteria weighting, and WLC for criteria layer integration. They also suggested four suitable sites for building a new hospital. Tripathi et al. [3] performed a comparison of GIS-based AHP and fuzzy AHP in order to assess hospital site suitability in India. Based on their study, fuzzy AHP may be more suitable for hospital site suitability. Other research, such as that of Şahin et al. [23] and Vahidnia et al. [43] used AHP, while Lin & Tsai [44] used ANP and TOPSIS, and Kumar et al. [45] used fuzzy extended elimination and choice expressing reality (ELECTRE) in order to assess hospital site suitability. Table 1 shows a summary of the previous research. In previous methodologies, GIS was primarily used for preparing criteria information, and the AHP method was used to weigh the criteria. The BWM Weighting method has been relatively underutilized in research, and the SWARA method was not employed in the reviewed studies.

Table 1. Summary of previous research.

Reference	Year	Location	Applied Methods
[40]	2023	Chile	Delphi, BWM, and EAMR
[46]	2022	Iran	GIS, Fuzzy Logic, and AHP
[26]	2022	Egypt	GIS and AHP
[4]	2022	Iran	GIS, CRITIC, SE, SDT, and OWA
[24]	2022	India	GIS and AHP
[42]	2021	Turkey	GIS, fuzzy AHP, and TOPSIS
[41]	2021	Turkey	Delphi, BWM, and fuzzy TOPSIS
[23]	2019	Turkey	AHP
[45]	2016	India	fuzzy ELECTRE
[44]	2010	China	ANP and TOPSIS
[43]	2009	Iran	GIS and fuzzy AHP

3. Materials and Methods

3.1. Study Area

Tehran, the capital of Iran, encompasses an expansive area exceeding 615 square kilometers and is home to over 9.430 million people, residing in approximately 3.253 million households [47]. Geographically, it is situated between 51°17′ to 51°33′ east longitudes and 35°36′ to 35°44′ north latitudes (Figure 1). Tehran is geographically defined by the imposing Alborz mountains to the north, Lavasanat to the east, Varamin to the south, and Karaj city to the west [47].

The 21st and 22nd Districts, home to 940,000 residents, have access to only three hospitals providing 428 hospital beds [48]. With urban expansion plans on the horizon for the 21st and 22nd Districts, and the evident shortage of healthcare facilities in these areas, there is an urgent need to establish new hospitals. A fundamental initial step in this endeavor is identifying the most suitable locations for these new healthcare facilities. Therefore, this research is focused on the 21st and 22nd Districts of Tehran as the primary study area for this purpose.

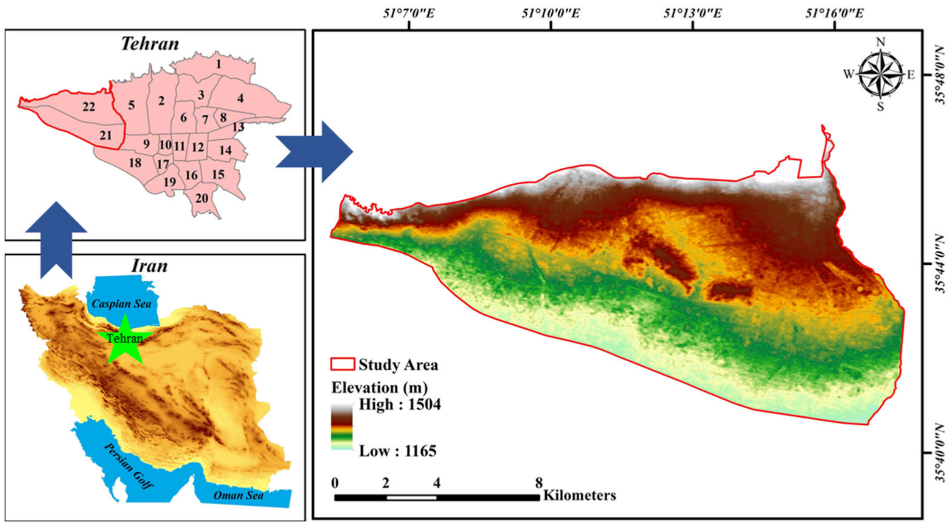

Figure 1. Study area.

3.2. Methodology

This study endeavors to create a site suitability map for potential hospital construction within the sprawling urban landscape of Tehran. The research assesses the efficacy of integrating three distinct MCDM weighting methods with GIS. The research methodology, illustrated in Figure 2, is encapsulated in the subsequent steps: First, determining the appropriate criteria for preparing the hospital site suitability map based on the literature review and data availability. Second, collecting relevant spatial information and preparing the spatial layer of each criterion using spatial analysis. Third, analyzing the opinions and pairwise comparisons of experts and calculating the criteria weights by MCDM weighting methods including AHP, BWM, and SWARA. Fourth, normalizing the criteria layers prepared in step 2, preparing the hospital site suitability map by integrating the normalized criteria layers based on the weights calculated in step 3, evaluating and comparing the suitability maps, performing sensitivity analysis by the OAT method, and finally, suggesting potential sites in suitable areas of the study area for building a new hospital.

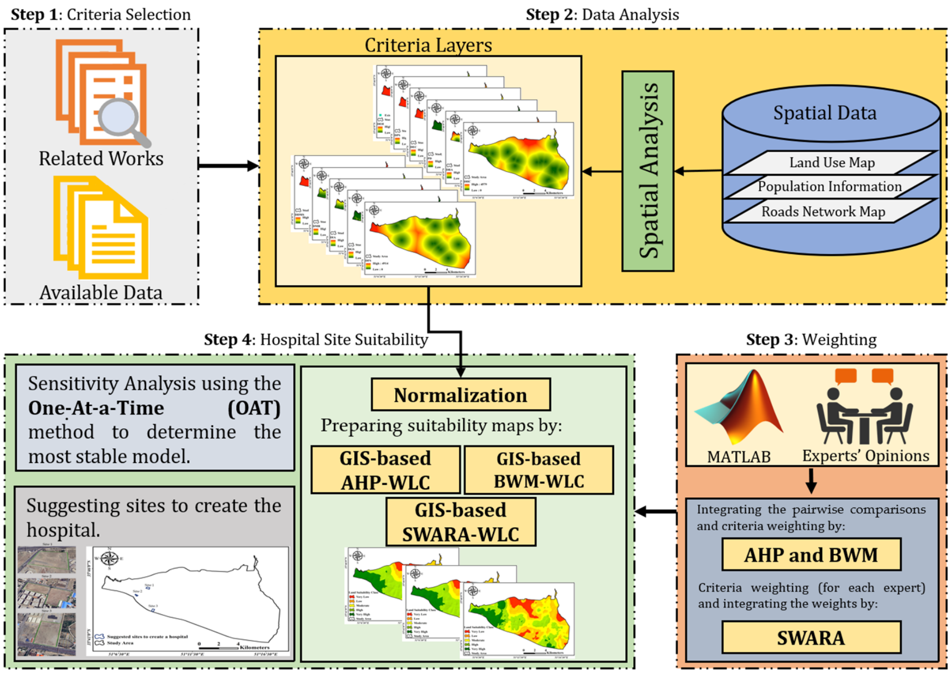

Figure 2. Research methodology.

3.3. Criteria Selection and Layers Preparation

Previous studies have employed diverse criteria to pinpoint ideal hospital locations, with a fundamental principle being the need for compatibility with neighboring land uses. Ensuring compatibility minimizes any potential negative impact on the efficiency and performance of adjacent land uses. Hospital locations are ideally compatible with green spaces, roads, healthcare centers, and fire stations, but are less compatible with educational centers (schools and elementary schools) and industrial areas [49].

In this research, based on the review of previous research, 11 criteria have been selected to be used for the hospital location selection. The selected criteria include the following: distance from existing hospitals (DEH), distance from main roads (DMR), distance from green spaces (DGS), distance from industrial areas (DIA), distance from healthcare centers (DHC), distance from educational centers (DEC), distance from fire stations (DFS), distance from disaster management stations (DDMS), distance from petrol stations (DPS), population density (PD), and distance from residential areas (DRA). Descriptions of the hospital site suitability criteria are presented in Table 2. The selected criteria have been chosen due to their use in previous research and the availability of spatial data. Some criteria, such as land cost and spatial distribution of patients and diseases, have not been used despite their use in previous research, due to the authors' lack of access to these data. The data sources for all criteria were the land use map and road network map of Tehran city, and statistical information on population blocks of Tehran. All criteria layers were prepared and extracted using ArcGIS version 10.8. Figure 3 shows the spatial layers of the decision-making criteria prepared for use in the site suitability process.

Table 2. Description of the hospital site suitability criteria.

Criterion	Description	Previously Used in Research
DEH	Hospital site should be far from existing hospitals. The site's suitability increases as the DEH increases.	[4,24,26,41–43,45,46]
DMR	Hospital site should be near to main roads. The site's suitability increases as the DMR decreases.	[4,24,26,39,42–44,46]
DGS	Hospital site should be near to dense vegetation. The site's suitability increases as the DGS decreases.	[4,24,46]
DIA	Hospital site should be far from industrial areas. The site's suitability increases as the DIA increases.	[4,26,42,46]
DHC	Hospital site should be near to healthcare centers. The site's suitability increases as the DHC decreases.	[4,45]
DEC	Hospital site should be far from educational centers (preschool and primary schools). The site's suitability increases as the DEC increases.	[24,45,46]
DFS	Hospital site should be near to fire stations. The site's suitability increases as the DFS decreases.	[42]
DDMS	Hospital site should be near to disaster management stations. The site's suitability increases as the DDMS decreases.	Not used
DPS	Hospital site should be far from petrol stations. The site's suitability increases as the DPS increases.	Not used
PD	Hospital site should be near to popuated zones. The site's suitability increases as the PD increases.	[4,26,39,41,42,45]
DRA	Hospital site should be near to residential areas. The site's suitability increases as the DRA decreases.	[4,24,39,46]

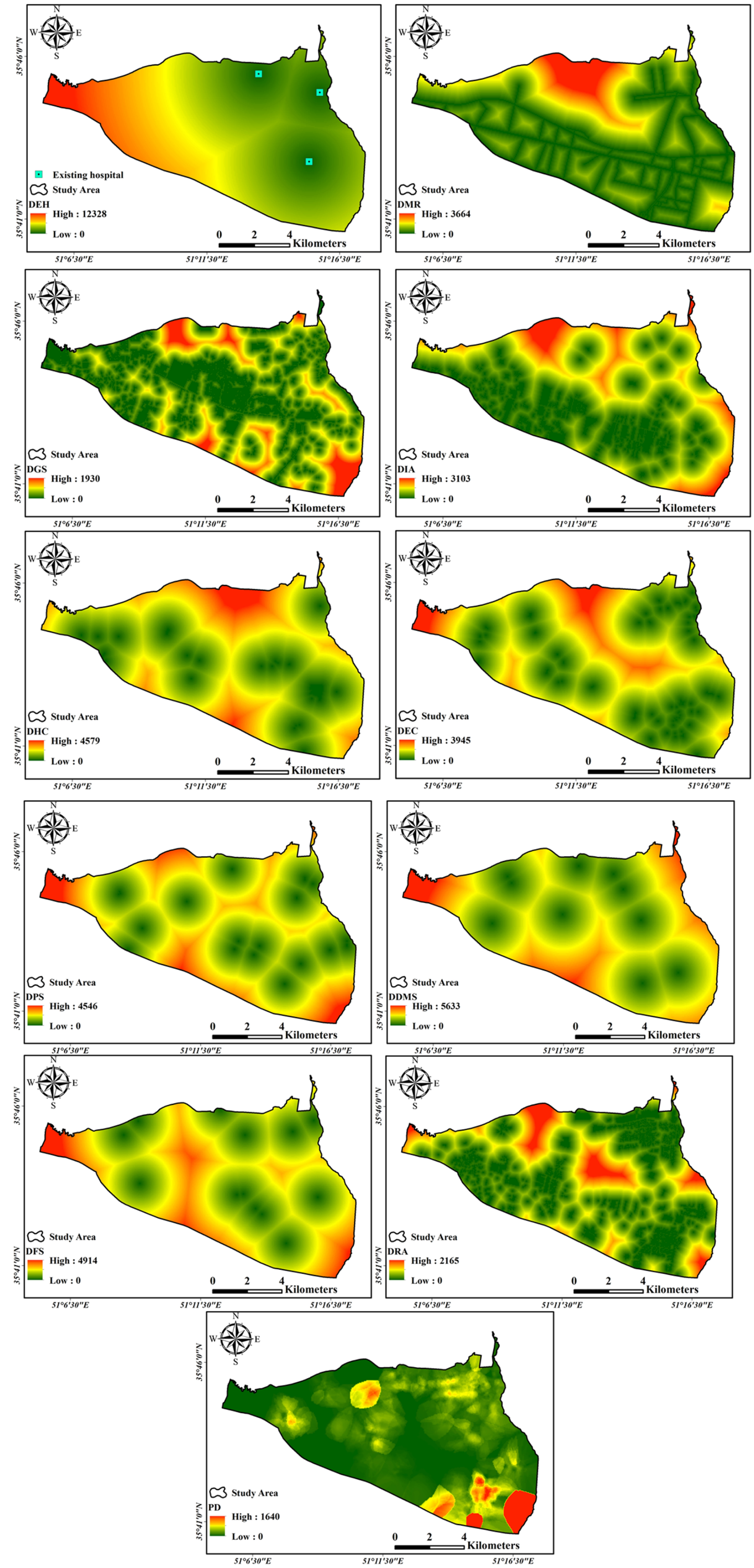

Figure 3. Decision-making criteria maps.

3.4. AHP

AHP was introduced by Saaty [50] in order to help the decision-maker when faced with multiple conflicting and subjective criteria [51]. In this method, criteria are compared based on scales 1 to 9 [52,53]. They can be equally important (scaled 1), moderately important (scaled 3), strongly important (scaled 5), very strongly important (scaled 7), extremely important (scaled 9), or take intermediate values (scaled 2, 4, 6, 8). After calculating the pairwise comparisons matrix, the weights of the criteria are calculated using the Saaty method [50]. Then, in order to check the logical inconsistency value between the decision-makers' opinions, the consistency rate (CR) is calculated by Equation (1) [24]. In Equation (1), CI is the consistency index and RI is the random index. In order to calculate the CI, Equation (2) is used. In Equation (2), n is the number of criteria (the dimension of the decision matrix) and λ_{max} is the highest eigenvector and degree of the matrix [54]. If the discrepancy rate is greater than the threshold, the comparison matrix should be revised [54]. The CI is used to calculate the overall inconsistency of the pairwise comparison matrix, and its value should be less than the threshold of 0.1 [50,54]. CI is calculated from Equation (2) and RI from information addressed in Supplementary Table S1 [50].

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

3.5. BWM

BWM [32] is a novel MCDM method. It primarily serves to compute criteria weights through a two-vector system of pairwise comparisons. In this method, the best criterion (most desirable) and the worst criterion (least desirable) are initially determined. Subsequently, the preference of the best criterion over all criteria, and the preference of all criteria over the worst criterion, are determined by a number in the range 1–9 (as in the AHP method). This process consequently transforms the task of determining weights into a non-linear programming problem. Noteworthy merits of this model include a reduction in pairwise comparisons relative to other methods like AHP and ANP, as well as enhanced consistency in pairwise comparisons [32,55].

This model's ability to trim down pairwise comparisons, while simultaneously enhancing accuracy, accelerates the pace of decision making. In the ensuing section, a concise elucidation of the implementation steps of this method is presented based on [32].

Step 1. The best and worst criteria in the decision-making process are determined.

Step 2. Using Equation (3), the preference vector of the best criterion over all of the criteria (A_B) is formed based on a 1–9 number as in the AHP method.

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bm}) \tag{3}$$

In Equation (3), a_{Bj} represents the preference (importance) of the best criterion to the j^{th} criterion. Then, the preference of the best criterion to itself (a_{BB}) is equal to 1.

Step 3. Using Equation (4), the preference vector of all the criteria over the worst criterion (A_w) is formed based on a 1–9 number.

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{mW})^T \tag{4}$$

In Equation (4), a_{jW} represents the preference of the jth criterion to the worst criterion. Then, the preference of the worst criterion to itself (a_{WW}) is equal to 1.

Step 4. The optimal weights of the decision-making criteria are obtained when relations of $\frac{W_B}{W_j} = a_{Bj}$ and $\frac{W_j}{W_w} = a_{jw}$ are established for each pair $\frac{W_B}{W_j}$ and $\frac{W_j}{W_w}$. In order to establish the specified conditions for all $j$ths, maximum absolute differences $\left|\frac{W_j}{W_w} - a_{jw}\right|$ and $\left|\frac{W_B}{W_j} - a_{Bj}\right|$ (Equation (5)) should be minimized in the process of solving the problem.

$$\begin{aligned} &\min_j \max \left\{ \left|\frac{W_j}{W_w} - a_{jw}\right|, \left|\frac{W_B}{W_j} - a_{Bj}\right| \right\} \\ &\text{s.t.} \\ &\sum_{j=1}^{m} w_j = 1 \\ &\text{and} \\ &w_j \geq 0,\ for\ all\ j \end{aligned} \tag{5}$$

In order to program this problem, the relations mentioned are considered as Equations (6)–(10).

$$\min \xi \tag{6}$$

$$\left|\frac{W_B}{W_j} - a_{Bj}\right| \leq \xi,\ for\ all\ j \tag{7}$$

$$\left|\frac{W_j}{W_w} - a_{jw}\right| \leq \xi,\ for\ all\ j \tag{8}$$

$$\sum_{j=1}^{m} w_j = 1 \tag{9}$$

$$w_j \geq 0,\ for\ all\ j \tag{10}$$

By solving the above problem, the optimal weights of criteria $\left(W_1^*, W_2^*, \ldots, W_m^*\right)$ and ξ^* are calculated during successive iterations. The parameter ξ^* is used to calculate the CR using Equation (11). If the CR is less than 0.1, the pairwise comparisons are compatible; otherwise, the process of pairwise comparisons should be reviewed. The consistency index is determined based on the preference of the best criterion to the worst criterion, as in Supplementary Table S2 [56].

$$Consistancy\ Ratio = \frac{\xi^*}{Consistancy\ Index} \tag{11}$$

3.6. SWARA

The SWARA weighting method is a subjective weighting method presented in [57]. The main feature of this method is the possibility of estimating experts' opinions about the importance of criteria in the weighting process. In other words, in this method, the opinions of experts are highly preferred [58]. Establishing coordination among experts' opinions is one of the advantages of this method [59]. In other words, the main capability of SWARA is the estimation of the decision-making criteria significance ratio in the weighting process based on experts' opinions [57]. In this method, first, the experts determine the decision-making criteria significance based on their opinion, then the criteria weights are calculated as follows.

Step 1. Decision criteria are ranked by an expert based on her experience.

Step 2. The relative importance (S) of each criterion to the previous criterion is determined by an expert for all criteria. S measure is not determined for the first criterion.

Step 3. Coefficient k is calculated for all criteria using Equation (12). The k for the criterion with the first rank is considered equal to 1, and for other criteria, it is the sum of the value 1 and the S measure of that criterion.

$$k_j = 1 + s_j,\ j \neq 1 \tag{12}$$

Step 4. The recovered importance (q) of the first criterion is equal to 1, and for other criteria, as Equation (13), it is equal to the result of dividing q of the previous criterion by k of that criterion.

$$q_j = \frac{q_{j-1}}{k_j},\ j \neq 1. \tag{13}$$

Step 5. The weight of criteria is calculated based on Equation (14) by dividing q of each criterion by the total q of all criteria.

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_j} \tag{14}$$

3.7. WLC

WLC is the most used decision rule in GIS-based MCDM [60,61]. This method is the simplest MCDM method, and in many applications was used to integrate spatial layers and prepare the suitability map. The WLC is composed of two components including the criterion weight and value [60]. The WLC method is as shown in Equation (15). Where S_k is suitability of the kth spatial unit (pixel or site), n is the number of criteria, W_i is the ith criterion weight, and C_i is the ith criterion value of kth spatial unit.

$$S_k = \sum_{i=1}^{n} W_i C_{ik} \tag{15}$$

Before using Equation (15), the criteria must be normalized using Equation (16) for the benefit criteria and Equation (17) for the cost criteria. A criterion is considered benefit when the increase of the criterion value leads to increasing the suitability of the alternative for the decision-making objective. A criterion is considered cost when the increase of the criterion value leads to reduction in the suitability of the alternative for the decision-making objective.

$$x^*{}_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \tag{16}$$

$$x^*{}_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \tag{17}$$

3.8. Sensitivity Analysis

Sensitivity analysis shows how inputs affect the model's output. In other words, sensitivity analysis shows the behavior of the model based on the rate of change in the output caused by the change in the inputs [13]. This sensitivity analysis explains how the inputs affect the output, and determines the strengths of the inputs based on the change in the output [62]. One popular method for conducting sensitivity analysis on input changes is the One-At-a-Time (OAT) method [63]. In this method, at a certain time, all input variables of the model are kept fixed and only one variable (the selected variable) changes. Therefore, any change in the model's output will be a result of a change in the selected variable. Additionally, this issue allows for easy comparison of results and simple implementation with straightforward calculations [64].

In this study, the sensitivity analysis of criteria weights was performed using the OAT method. After calculating the weights using weighting methods, the next step involves conducting sensitivity analysis. In each stage of the sensitivity analysis, the weight of one criterion is set equal to 0, and the other weights are updated using Equation (18), where $w^*{}_i$ is the ith criterion weight that must be changed at the present time, and $w^*{}_j$ is the jth criterion weight that must be fixed at the present time.

$$\begin{gathered} w^*{}_i = 0 \\ w^*{}_j = w_j + \frac{w_j}{\sum_{k \neq i} w_k} \times w_i \end{gathered} \tag{18}$$

Finally, after preparing the suitability map, the changes in the suitability index of spatial units are investigated and the most important changes and their factors are identified.

4. Experimental Results

4.1. Calculating the Weights of the Criteria Using the AHP Method

Given that the AHP method is well-suited for decision-making scenarios characterized by low inter-criteria correlation, the essential step involved computing the correlation among the spatial layers of the criteria, depicted in Supplementary Figure S1. The correlations all fall below the threshold of 0.5, indicating the viability of employing this method. In the AHP method, the essential step involves constructing the decision process hierarchy. In this study, the hierarchy is established with three levels, comprising the goal, criteria, and alternatives, as illustrated in Figure 4. After applying the AHP method to weight the criteria, the WLC method is used to combine the criteria and evaluate the alternatives.

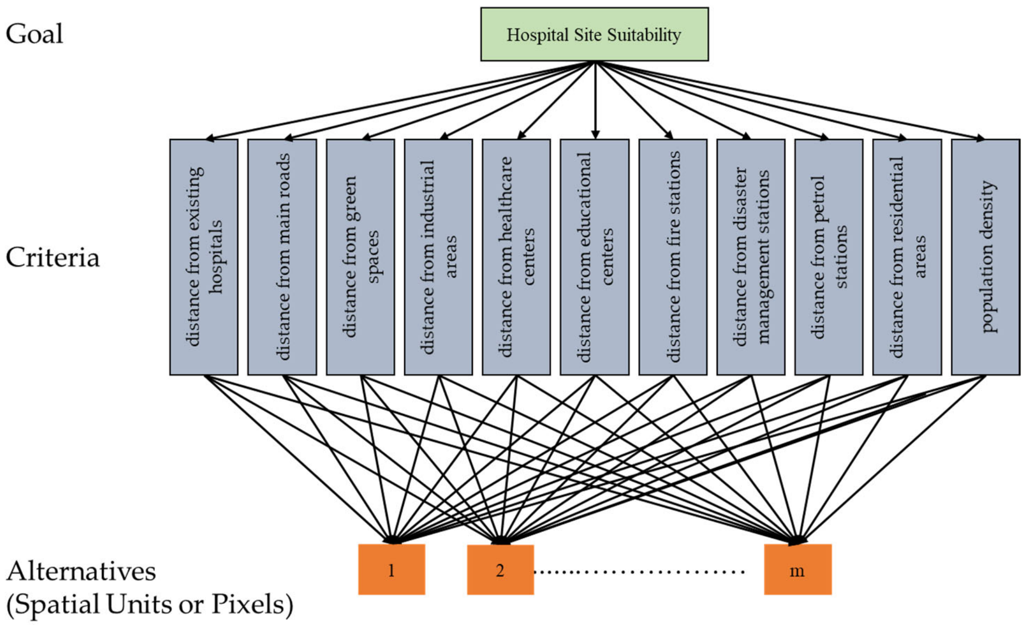

Figure 4. The hierarchy used in the AHP method.

For the purpose of criteria weights calculation via the AHP method, a pairwise comparison matrix was determined by five GIS experts. The conclusive pairwise comparison matrix, integral to the AHP method, was generated through the geometric mean of the pairwise comparison matrices contributed by the experts, as outlined in Table 1.

To facilitate AHP calculations, the procedural steps were implemented using the MATLAB 8.3 programming environment. The resultant weights from the AHP method are presented in the final column of Table 3. As demonstrated in Table 3, the criteria DEH and DMR carry the most significant weight, whereas DGS and DIA exhibit comparatively lower weights.

After calculating the criteria weights, in order to calculate the CI, the value of λ_{max} was calculated to be equal to 11.023, and using Equation (2), the CI value of 0.0023 was obtained. The value of the RI was considered equal to 1.52 according to Supplementary Table S3. Then using Equation (1), the CR value of 0.0016 was obtained, which is far less than the threshold limit of 0.1, and therefore the obtained weights are reliable for decision-making criteria.

Table 3. The final inputs and results of the AHP method.

Criterion	DEH	DMR	DGS	DIA	DHC	DEC	DFS	DDMS	DPS	PD	DRA	Weight
DEH	1.00	1.60	9.00	5.20	2.40	3.60	5.40	4.60	4.80	3.40	4.40	0.266
DMR	0.63	1.00	5.60	3.20	1.40	2.20	3.40	2.80	3.00	2.20	2.80	0.165
DGS	0.11	0.18	1.00	0.60	0.20	0.40	0.60	0.60	0.60	0.40	0.60	0.031
DIA	0.19	0.31	1.67	1.00	0.40	0.80	1.00	0.80	1.00	0.60	0.80	0.050
DHC	0.42	0.71	5.00	2.50	1.00	1.60	2.40	2.00	2.00	1.40	1.80	0.118
DEC	0.28	0.45	2.50	1.25	0.63	1.00	1.40	1.20	1.40	1.00	1.20	0.072
DFS	0.19	0.29	1.67	1.00	0.42	0.71	1.00	0.80	0.80	0.60	0.80	0.048
DDMS	0.22	0.36	1.67	1.25	0.50	0.83	1.25	1.00	1.00	0.80	1.00	0.059
DPS	0.21	0.33	1.67	1.00	0.50	0.71	1.25	1.00	1.00	0.80	1.00	0.056
PD	0.29	0.45	2.50	1.67	0.71	1.00	1.67	1.25	1.25	1.00	1.20	0.076
DRA	0.23	0.36	1.67	1.25	0.56	0.83	1.25	1.00	1.00	0.83	1.00	0.060

4.2. Calculating the Weights of the Criteria Using the BWM Method

In order to determine the criteria weights using the BWM method, first, the best and worst criteria were selected based on the opinion of five experts. By summarizing the opinions of the experts, DEH was chosen as the best criterion and DGS as the worst criterion in decision making. In the following, pairwise comparisons between the best criterion to other criteria and other criteria to the worst criterion were conducted by experts in the form of two separate questionnaires. Then, the geometric mean of the questionnaires was considered as final BWM input data (Table 4).

Table 4. The final inputs and results of the BWM method.

	DEH	DMR	DGS	DIA	DHC	DEC	DFS	DDMS	DPS	PD	DRA
Best to Others	1.0	1.6	9.0	5.2	2.4	3.6	5.4	4.6	4.8	3.4	4.4
Others to Worst	9.0	5.6	1.0	1.8	3.8	2.4	1.6	2.0	1.8	2.6	2.0
Weight	0.266	0.165	0.030	0.052	0.113	0.073	0.049	0.058	0.055	0.078	0.061

In the next step, the BWM steps were programmed in the Lingo 11 software environment. The weights of the criteria obtained from the BWM are presented in the last row of Table 4. As can be seen in Table 4**,** the DEH and DMR have the highest weight, and the DGS and DFS have the least weight, respectively. In this study, the parameter ξ^* was equal to 0.0554 and, according to Supplementary Table S4, the *CI* value of 5.23 was obtained. Using Equation (11), the *CR* value of 0.0106 was obtained. Considering that the *CR* is less than 0.1, it is acceptable and the comparisons are consistent and the obtained weights are reliable.

4.3. Calculating the Weights of the Criteria Using the SWARA Method

To determine the criteria weights through the SWARA method, experts were initially requested to rank the criteria based on their perceived importance and to establish the relative importance of successive criteria in relation to each other. Each expert then delineated the order and importance of criteria based on their insights and expertise, resulting in distinct criterion weights. Using the insights provided by each expert, the SWARA method was employed to compute the criteria weights, with its procedural steps implemented through the MATLAB 2014 programming environment (Table 5).

The final criterion weight was computed by calculating the geometric mean of the weights derived from the perspectives of all five experts, as presented in the final column of Table 5. Observing Table 5, it is apparent that DEH and DMR are endowed with the highest weights, while DGS and DFS exhibit comparatively lower weights.

Table 5. The inputs and results of the SWARA method.

Criterion	Expert 1	Rank	Expert 2	Rank	Expert 3	Rank	Expert 4	Rank	Expert 5	Rank	Final Weight
DEH	0.125	1	0.122	1	0.119	1	0.129	1	0.120	1	0.123
DMR	0.104	2	0.104	3	0.105	2	0.105	2	0.105	2	0.105
DGS	0.065	11	0.072	11	0.068	11	0.073	9	0.065	11	0.068
DIA	0.074	9	0.073	10	0.075	10	0.071	10	0.089	8	0.076
DHC	0.097	4	0.101	4	0.099	4	0.096	5	0.090	6	0.096
DEC	0.094	5	0.079	8	0.082	8	0.082	8	0.090	7	0.085
DFS	0.071	10	0.076	9	0.075	9	0.071	11	0.078	10	0.074
DDMS	0.088	7	0.089	6	0.090	6	0.086	6	0.086	9	0.088
DPS	0.094	6	0.087	7	0.090	7	0.086	7	0.091	4	0.090
PD	0.103	3	0.106	2	0.100	3	0.102	3	0.095	3	0.101
DRA	0.086	8	0.091	5	0.096	5	0.099	4	0.090	5	0.092

4.4. Preparing the Hospital Site Suitability Maps

To generate a site suitability map, it is imperative to first normalize the spatial layer of criteria based on their impact, either as a cost or a benefit, on the decision-making process. In this study, criteria like DEH, DIA, DEC, DPS, and PD are deemed beneficial, while others are treated as costs. Benefit criteria were normalized using Equation (16), whereas cost criteria were normalized by Equation (17).

Once the criteria weights (derived from AHP, BWM, and SWARA) were obtained, the GIS environment was employed to assess the suitability of each spatial pixel for establishing a new hospital. Utilizing the WLC method, the decision criteria layers were integrated through the Raster Calculator tool within the ArcGIS 10.8 environment. By evaluating the suitability across all spatial pixels within the study area, definitive hospital site suitability maps were generated. These maps were subsequently categorized into five classes—very low, low, moderate, high, and very high suitability—using the Reclassify tool within the ArcGIS 10.8 environment. The site suitability maps, depicted in Figure 5, vividly illustrate the outcome. Notably, the western portion of the study area appears consistently suitable for a new hospital in all maps. The suitability maps obtained from AHP and BWM are very similar. The great similarity of these two suitability maps is due to the high similarity of the weights obtained from the two methods. The suitability map obtained from SWARA is significantly different from the previous two maps. The difference between this suitability map and the previous two suitability maps is due to the weights calculated by SWARA, which were very different from the weights of the previous two methods.

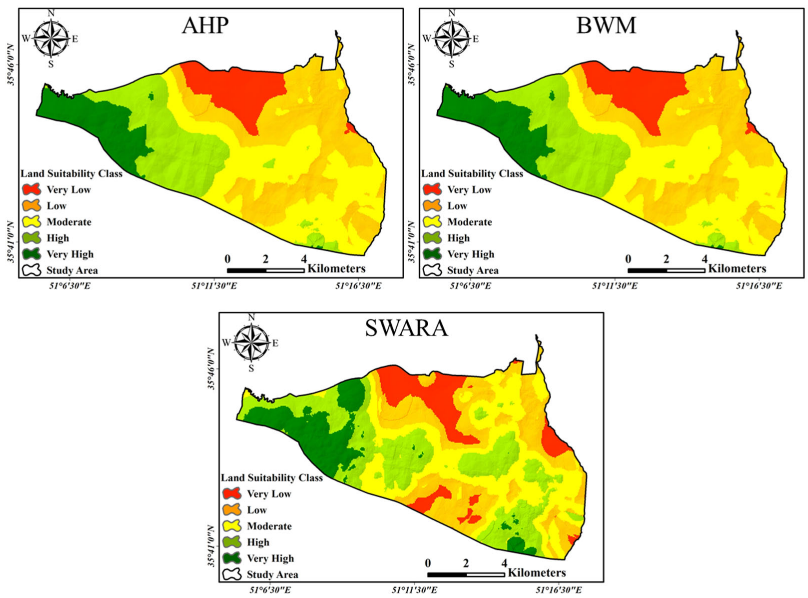

Figure 5. Site suitability maps by AHP, BWM, and SWARA.

Figure 6 shows the percentage of site suitability classes for hospital construction. In AHP and BWM, the largest part of the studied area is in the class with low suitability (32%). Meanwhile, the areas with very high and high suitability constitute 10% and 20% of the studied area, respectively. In SWARA, the largest part of the studied area is in the class with high suitability (26%) and the areas with very high suitability constitute 12% of it.

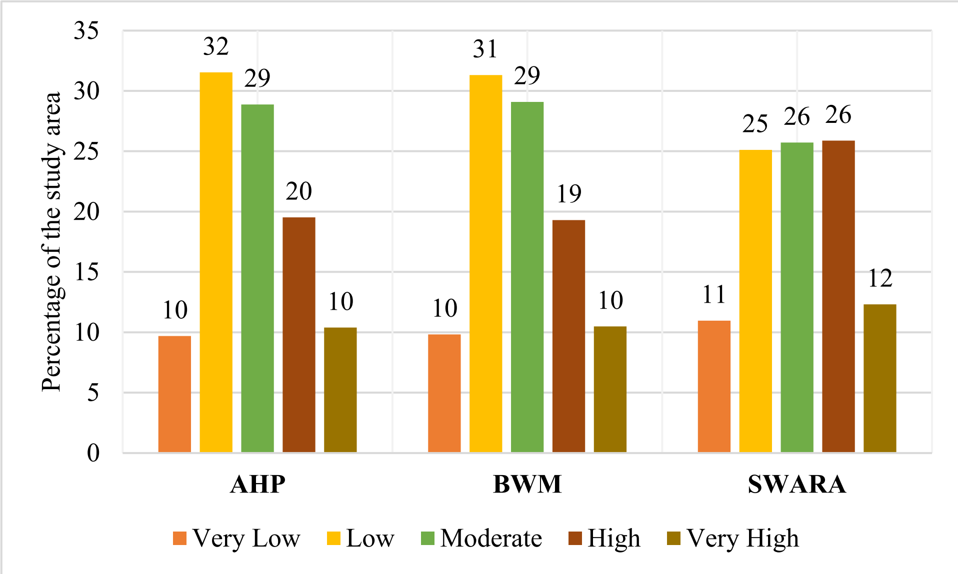

Figure 6. The percentage of site suitability classes.

4.5. Comparing the Results of the Weighting Methods

As depicted in Table 6 and Figure 7, the criteria weights obtained through the AHP and BWM methods exhibit remarkable similarity. In both methods, DEH, DMR, and DHC emerge as the criteria with the highest weights, while DIA, DGS, and DFS consistently hold the lowest weights in the AHP method, and DGS, DFS, and DIA exhibit the lowest weights in the BWM method. Notably, the three criteria with the lowest weights are identical in both AHP and BWM, and the criteria weights in AHP and BWM are nearly identical.

Table 6. Criteria weights using AHP, BWM, and SWARA.

No.	Criterion	AHP	Rank	BWM	Rank	SWARA	Rank
1	DEH	0.266	1	0.266	1	0.123	1
2	DMR	0.165	2	0.165	2	0.105	2
3	DGS	0.031	10	0.03	11	0.068	11
4	DIA	0.050	11	0.052	9	0.076	9
5	DHC	0.118	3	0.113	3	0.096	4
6	DEC	0.072	5	0.073	5	0.085	8
7	DFS	0.048	9	0.049	10	0.074	10
8	DDMS	0.059	7	0.058	7	0.088	7
9	DPS	0.056	8	0.055	8	0.090	6
10	PD	0.076	4	0.078	4	0.101	3
11	DRA	0.060	6	0.610	6	0.092	5

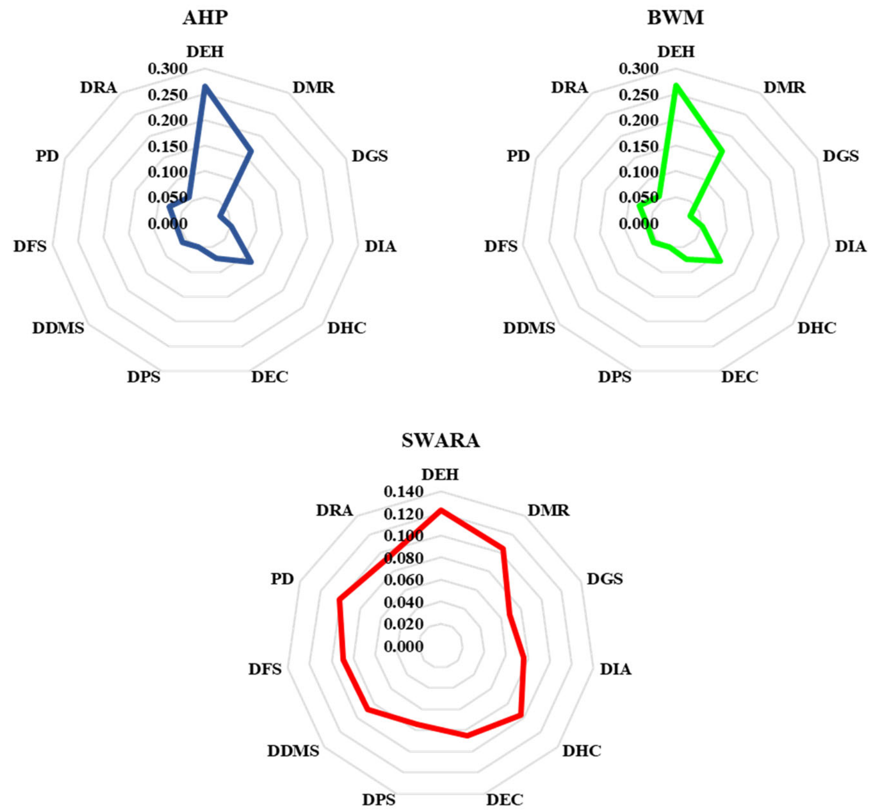

Figure 7. Criteria weights using AHP, BWM, and SWARA.

On the other hand, when employing the SWARA method, DEH, DMR, and PD emerge as the criteria with the highest weights, while DGS, DFS, and DIA consistently hold the lowest weights.

In the following, the correlation of the weights and maps obtained from all three methods together is calculated as shown in Table 7. As is shown in Table 7, the correlation of the weights of the three methods is very high, but the correlation of AHP and BWM is higher than their correlation with SWARA. As is shown in Table 7, the correlation of three suitability maps is very high, but the correlation of suitability maps of AHP and BWM is higher than their correlation with SWARA. In other words, the suitability maps of AHP and BWM are almost equal.

Table 7. Correlation of the calculated weights and suitability maps.

	Weights			Suitability Maps		
Method	**AHP**	**BWM**	**SWARA**	**AHP**	**BWM**	**SWARA**
AHP	1.0000	0.9996	0.8868	1.0000	0.9999	0.8846
BWM	0.9996	1.0000	0.8876	0.9999	1.0000	0.8820
SWARA	0.8868	0.8876	1.0000	0.8846	0.8820	1.0000

4.6. Sensitivity Analysis

In this section, an OAT sensitivity analysis was conducted to assess the stability of the models used against changes in the weights of the criteria. To conduct OAT sensitivity analysis, the weight of a criterion is set to 0 in each model (GIS-based AHP-WLC, GIS-based BWM-WLC, and GIS-based SWARA-WLC), while other weights remain constant after updating with Equation (18). This process is repeated in 11 steps to prepare a site suitability map and determine changes in different suitability classes (compared to the original site suitability map). The weights for the criteria in each step for the three models used are shown in Supplementary Tables S3–S5. As can be seen in Supplementary Tables S3–S5, during the

OAT sensitivity analysis approach, the weights of the criteria changed in different steps. This change in the weights of the criteria in the AHP and BWM methods reach values of 0.05, while in the SWARA method this change is at most 0.01. In other words, the SWARA method was more stable when changing the weights of the criteria.

Tables 7–10 show the changes in suitability classes during the OAT sensitivity analysis approach of different models. They specify the total number of pixels whose suitability class changed during the sensitivity analysis process, and the change of each class relative to the neighboring class/classes and other classes. Tables 8–10 and Figure 8 show the percentage of pixel class change in the study area during the sensitivity analysis process. As can be seen, the percentage of pixel class change in the GIS-based SWARA-WLC model is significantly lower than in the other two models. This case demonstrates the stability of the proposed GIS-based SWARA-WLC model compared to the other two models when the inputs (criteria weights) are changed. Given that, aside from the weighting method, all parts of the three models are the same, it can be inferred that the increased stability in the GIS-based SWARA-WLC model is attributed to the use of the SWARA weighting method. Therefore, the utilization of the GIS-based SWARA-WLC model yields more dependable outcomes than those of the other models and enhances the decision-making quality. Also, the GIS-based BWM-WLC model is more stable than the GIS-based AHP-WLC model.

In general, the GIS-based SWARA-WLC model has shown the most instability due to changes in the weights of criteria DEH and DMR. However, the GIS-based AHP-WLC model exhibits very high instability when the weights of criteria DEH, DMR, DGS, and DEC are altered. Additionally, the model does not maintain good stability when the weights of other criteria are changed. As for the GIS-based BWM-WLC model, the greatest instability arises from changes in the weight of criteria PD, DEH, and DMR, while in other instances, the instability is much lower compared to the GIS-based AHP-WLC model.

After creating the hospital site suitability map and performing the sensitivity analysis, specific alternative sites for the new hospital need to be proposed. Following a field visit and analysis of satellite images, three potential sites with high and very high suitability for a new hospital in the western part of the study area have been identified (Figure 9). These sites were chosen based on criteria including access to main roads, land availability, and an area of over 4000 square meters. The three sites suggested are highly suitable for new hospital construction, and this study recommends to health decision makers that they build a hospital at one of these locations.

Table 8. Changes in suitability classes during the OAT sensitivity analysis method of GIS-based AHP-WLC. NCP: total number of pixel class changes, PCP: percentage of pixel class changes, VL: very low suitability, L: low suitability, M: moderate suitability, H: high suitability, VH: very high suitability, N: the other classes except for the neighboring classes.

Step	NCP	PCP	VL → L	VL → N	L → VL	L → M	L → N	M → L	M → H	M → N	H → M	H → VH	H → N	VH → H	VH → N
$w_{DEH} = 0$	39,631	0.79	2453	1773	0	4780	10,819	0	5953	7196	359	3239	174	2546	339
$w_{DMR} = 0$	41,046	0.81	669	143	13,326	0	292	8043	0	6145	6773	0	1939	3498	218
$w_{DGS} = 0$	38,277	0.76	84	186	9266	158	284	10,413	0	885	10,692	0	1212	4848	249
$w_{DIA} = 0$	28,613	0.57	2012	192	353	6620	513	307	8313	302	57	9698	158	12	76
$w_{DHC} = 0$	23,527	0.47	1117	202	2937	1338	285	6154	324	283	7385	532	409	2481	80
$w_{DEC} = 0$	32,594	0.65	1765	384	416	6513	2069	63	8734	2406	251	9526	188	203	76
$w_{DFS} = 0$	21,712	0.43	1504	186	545	5619	295	517	6168	148	530	5555	201	347	97
$w_{DDMS} = 0$	22,552	0.45	469	186	5347	337	284	6324	426	336	5617	790	368	1992	76
$w_{DPS} = 0$	21,272	0.42	244	186	5356	701	284	5864	698	372	4301	1060	283	1847	76
$w_{PD} = 0$	27,229	0.54	2076	151	0	10,505	276	121	7339	118	0	6316	163	31	133
$w_{DRA} = 0$	14,651	0.29	186	151	2912	218	276	6490	11	118	2509	3	163	1481	133

Table 9. Changes in suitability classes during the OAT sensitivity analysis method of GIS-based BWM-WLC.

Step	NCP	PCP	VL → L	VL → N	L → VL	L → M	L → N	M → L	M → H	M → N	H → M	H → VH	H → N	VH → H	VH → N
$w_{DEH} = 0$	38,909	0.77	2336	1583	0	5249	10,118	0	6838	5948	729	2032	166	3483	427
$w_{DMR} = 0$	40,118	0.80	873	305	9285	325	316	8402	0	3542	8495	0	3357	4442	776
$w_{DGS} = 0$	11,191	0.22	0	143	2056	23	292	5487	0	112	1578	0	166	1206	128
$w_{DIA} = 0$	9553	0.19	345	151	213	3410	276	410	2317	118	74	1941	163	2	133
$w_{DHC} = 0$	19,403	0.38	461	151	4023	563	276	8349	20	128	3646	379	163	1111	133
$w_{DEC} = 0$	17,519	0.35	523	151	257	7380	276	42	4258	118	8	4158	163	52	133
$w_{DFS} = 0$	6728	0.13	46	151	261	1954	276	677	1398	118	134	1380	163	37	133
$w_{DDMS} = 0$	9619	0.19	0	151	1736	176	276	4716	42	118	1212	80	163	816	133
$w_{DPS} = 0$	18,109	0.36	0	143	4806	0	292	8227	0	112	2611	8	166	1616	128
$w_{PD} = 0$	42,744	0.85	2180	2861	160	3912	8201	73	3426	8958	15	12,724	158	0	76
$w_{DRA} = 0$	27,899	0.55	903	188	6566	978	290	7877	523	350	6764	181	203	3000	76

Table 10. Changes in suitability classes during the OAT sensitivity analysis method of GIS-based SWARA-WLC.

Step	NCP	PCP	VL → L	VL → N	L → VL	L → M	L → N	M → L	M → H	M → N	H → M	H → VH	H → N	VH → H	VH → N
$w_{DEH} = 0$	38,409	0.76	3341	1256	8	5629	5567	91	5526	5720	797	8188	311	1766	209
$w_{DMR} = 0$	39,983	0.79	764	151	12,967	0	276	8269	0	5905	6772	0	1389	3335	155
$w_{DGS} = 0$	7003	0.14	14	151	1258	68	276	3289	10	118	869	1	163	653	133
$w_{DIA} = 0$	7402	0.15	225	143	279	2296	292	667	1432	112	126	1529	166	7	128
$w_{DHC} = 0$	18,406	0.37	567	143	3227	645	292	7934	7	114	3702	525	166	956	128
$w_{DEC} = 0$	12,361	0.25	236	143	443	4882	292	173	3110	112	65	2533	166	78	128
$w_{DFS} = 0$	5262	0.10	8	143	436	981	292	1007	731	112	268	925	166	65	128
$w_{DDMS} = 0$	8675	0.17	1	143	1589	218	292	4191	48	112	1034	90	166	663	128
$w_{DPS} = 0$	14,391	0.29	0	151	3788	16	276	6719	8	118	1631	3	163	1385	133
$w_{PD} = 0$	22,197	0.44	1531	143	0	8786	292	190	5756	112	15	5052	166	26	128
$w_{DRA} = 0$	13,165	0.26	149	143	2615	192	292	6077	18	112	1991	8	166	1274	128

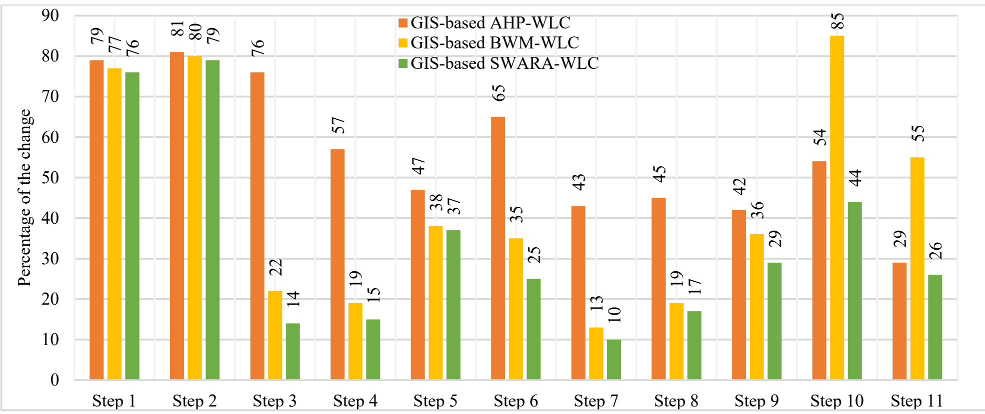

Figure 8. The percentage change in pixel classes.

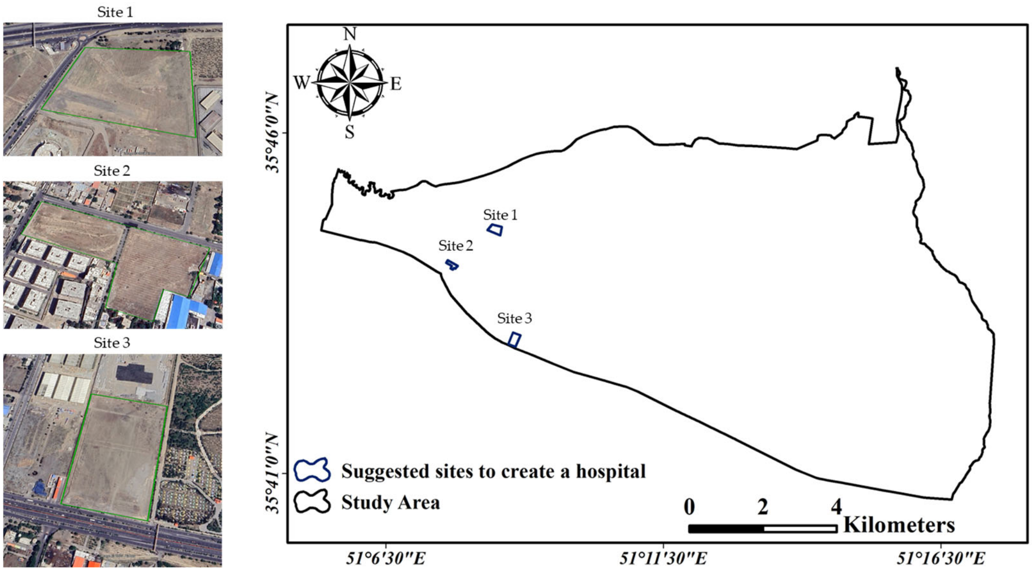

Figure 9. The suggested sites for building a hospital and their locations on the satellite image.

5. Discussion

Based on the suitability maps generated using the AHP, BWM, and SWARA weighting methods, the study designates areas within the study region as 'very low suitability', 'low suitability', 'moderate suitability', 'high suitability', and 'very high suitability' for the construction of new hospitals, with varying percentages ranging from 10–11% to 26–29%.

Our research findings reveal significant similarities in the calculated criteria weights between the AHP and BWM methods, with the weights nearly equal. In contrast, studies conducted by Ajrina et al. [65], Sahraei et al. [66], and Tan et al. [67], did not observe such pronounced similarities. Both methods consistently assign notably higher weights to the first three criteria (distance from existing hospitals, distance from main roads, distance from green spaces) and considerably lower weights to the last three criteria (distance from petrol stations, distance from residential areas, and population density). This similarity may be attributed to the use of the same preference scales in both methods. Notably, the congruence in results across the two methods aligns logically, given that the same experts were involved in the assessment.

A comparative analysis between the BWM and AHP methods indicates that the BWM method outperforms AHP, primarily due to the significantly reduced number of pairwise comparisons. Specifically, the BWM method necessitated only 19 pairwise comparisons, while the AHP method required 55 pairwise comparisons. This preference for BWM aligns with previous research, which has also favored BWM over AHP [68].

The calculated criteria weights derived from the AHP and BWM methods significantly differ from those obtained through the SWARA method. However, the ranking of criteria weights in SWARA closely aligns with that of AHP and BWM. In the SWARA method, weight differences among criteria are minimal, suggesting that all criteria carry significant importance in the decision-making process. In contrast, both AHP and BWM methods assign considerably higher weight to some criteria while diminishing the importance of others. Sharma et al. [68] found that the fuzzy SWARA method outperforms AHP and BWM methods, which is consistent with our findings in the present study. Our results, based on the hospital suitability map created using the SWARA weighting method, reinforce the superior performance of SWARA over AHP and BWM, primarily due to the simpler calculations required by SWARA (only $n-1$, or 10, pairwise comparisons).

It is noteworthy that SWARA demands fewer input data (expert opinions and pairwise comparisons) compared to AHP and BWM, resulting in significantly reduced complexity in its calculations. The implementation of SWARA is notably more straightforward than the other two methods, leading to a lower probability of calculation errors and more reliable results.

Furthermore, the high correlation observed among the weights and site suitability maps derived from all three methods underscores the suitability of SWARA as a viable alternative to AHP and BWM. Across all three weighting methods, distance from existing hospitals consistently emerges with the highest weight, aligning with previous studies by Tripathi et al. [3] and Dutta et al. [69]. It is worth noting that this contrasts with findings in studies like Halder et al. [24] and Zandi et al. [4], where distance from existing hospitals was assigned a notably lower weight. Other studies, such as Boyacı & Şişman [42], Halder et al. [24], Zandi et al. [4], Zolfani et al. [70], and Beshr et al. [26], have identified different criteria, such as distance to main roads, distance to residential areas, distance from green spaces, distance to industrial areas, and population density, as the most influential factors in hospital site suitability. In our study, distance from main roads, consistent with Halder et al. [24] and Zandi et al. [4], emerges as an important criterion in hospital site suitability. Interestingly, in our study, distance from green spaces and distance from industrial areas are assigned the lowest weights among criteria, contrary to Zandi et al. [4], which assigns a very high weight to distance from green spaces.

In the present study, a sensitivity analysis process based on the OAT approach was performed. The OAT results showed that GIS-based SWARA-WLC is the most stable model for hospital site suitability when compared with GIS-based AHP-WLC and GIS-based BWM-WLC. The amount of change in suitability class of pixels in the study area in GIS-based SWARA-WLC was much lower than in the other two methods. However, the change in the suitability class of pixels due to the change in the weights of the distance from existing hospitals and distance from main roads criteria in GIS-based SWARA-WLC was also high, and almost equivalent to the other two methods. In general, the stability of GIS-based SWARA-WLC was the highest, followed by GIS-based BWM-WLC. GIS-based AHP-WLC was unstable when changing the weights of all criteria.

Hospitals serve as crucial pillars in delivering healthcare services to communities. The World Health Organization recommends having 3.5 hospital beds per 1000 people, but developing countries typically fall short of this standard [45]. Tehran exhibits an improved situation with 2.8 hospital beds per 1000 people in 2020 [71]. Nevertheless, the distribution of hospitals and hospital beds within the city remains suboptimal. The studied area, encompassing Districts 21 and 22 of Tehran, houses just three hospitals, resulting in approximately 0.45 hospital beds per 1000 people. Given the trajectory of urban development, population growth, and the potential for natural disasters and epidemics, it becomes imperative to enhance the existing healthcare system and augment the number of hospitals and hospital beds.

Limitations

This study exhibits a few notable limitations. Firstly, the omission of key criteria, such as land cost and vulnerability to natural disasters, both crucial in hospital location decisions [3,4,43], was due to the unavailability of their respective spatial data layers. Additionally, the spatial distribution of patients and diseases, a highly influential criterion, was not included in this research due to data unavailability. Future research endeavors should consider incorporating these essential criteria to enhance the comprehensiveness of the assessment.

In recent years, data-driven weighting methods, which do not rely on pairwise comparisons and expert opinions, have gained traction in various applications, including hospital site suitability [2,4]. While addressing intricate issues like hospital site suitability typically involves the input of experts, it is advisable for future research to explore a comparative analysis between knowledge-driven methods, like those utilized in this study, and data-driven methods such as CRITIC [72], Robustness, Correlation, and Standard Deviation (ROCOSD) [73], and Method based on the Removal Effects of Criteria (MEREC) [74].

6. Conclusions

This study introduces a robust scientific framework that leverages GIS in conjunction with various MCDM weighting methods to create a hospital suitability map for Tehran. In our analysis, we employed three distinct MCDM weighting methods: AHP, BWM, and SWARA, for the development of site suitability maps. Notably, these methods have been relatively underutilized in the context of hospital site suitability assessments. Additionally, our study utilized WLC as the decision rule to integrate the spatial layers of criteria. Based on the sensitivity analysis, GIS-based SWARA-WLC was the most suitable and stable model for hospital site suitability in the study area. Moreover, the proposed method addresses hospital site suitability by considering criteria selected from previous research. Accordingly, it can be applied to other regions and enhanced with additional criteria. Thus, researchers can incorporate new criteria into this methodology based on the requirements of their study area, ultimately enhancing the quality of decision making.

To achieve the average hospital bed availability in Tehran, the studied area requires an additional 2206 beds alongside the existing facilities. Establishing a hospital with 200 beds would provide a marginal improvement, resulting in approximately 0.67 hospital beds per 1000 people. However, this falls short of the ideal distribution of hospital resources.

Future research could benefit from exploring alternative MCDM decision rules to potentially enhance the accuracy of the hospital site suitability map. The proposed methodology presented here holds promise for expansion to other cities in Iran in future research endeavors, facilitating a broader understanding of hospital location suitability across the country. Future studies should consider data related to hospitals and the economic status of people living nearby in order to better understand the suitability of the proposed methodology for hospital site suitability in addressing the needs of the community.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16052079/s1, Figure S1: The criteria correlation; Table S1: The random inconsistency index (RI) values [42]; Table S2. Consistency Index [48]; Table S3. The OAT sensitivity analysis in the AHP method; Table S4. The OAT sensitivity analysis in the BWM method; Table S5. The OAT sensitivity analysis in the SWARA method.

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