Hospital Site Selection in Jeddah City using AHP and Mathematical Variations Analysis

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Abstract
Saudi Arabia's Vision 2030 focus on the quality of health care in recent years has led to the development of policies and strategies to improve healthcare and medical services through the establishment of new hospitals., the hospital's location is considered a crucial factor to potential patients for hospitals to be competitive. Many methods are used in site suitability selection. GIS-based Analytic Hierarchy Process (AHP) models gained high popularity in hospital site suitability selection as the most contributing approaches to the solutions, in the execution of the models based on these methods and techniques, little attention has been paid to the evaluation of the final to the priority of weights. In Multi-criteria Analysis GIS-based analytic hierarchy process was used to produce a hospital site suitability map considering resident population, exciting hospitals, polluted areas, and main roads. The weight of each criterion was calculated based on a pairwise comparison matrix. Mathematical variations analysis and sensitivity analysis are used to examine the priority of weight. This method measures and displays spatial change dynamics and the stability of results with respect to the variation of different parameter weights. The suitability map will be useful for the health care organizations by choosing the best site for their facilities to reduce the pressures in the hospitals.
Keywords:
Hospital, Weight, Suitability, AHP, Sensitivity Analysis, Variation of Function

1. Introduction

Saudi Arabia's Vision 2030 focus on the quality of health care in recent years has led to the development of policies and strategies to improve healthcare and medical services. Meanwhile, Jeddah city has seen a significant increase in the total number of hospital reviewers especially during pandemic covid19 [1].

The closest location will help to reduce rescue time for the patients and improve health-related accessibility [2]. Therefore, healthcare organizations need effective tools to aid them in selecting proper locations among alternatives. GIS and multi-criteria analysis are powerful tools in site suitability problems [3]. Some methods place more emphasis upon the possible limiting factors imposed by environmental conditions value [4], while others value the degree of suitability of resource properties [5]. Qualitative criteria are used in some methods while others are more quantitative.

A systematic literature review was conducted of the hospital location selection problem considering the application areas and applied methods. GIS-based Analytic Hierarchy Process (AHP) models gained high popularity in hospital site selection as the most contributing approaches to the solutions. Site selection criteria are mostly population, environment, government, distance to some important places, demand, and cost [6, 7, 8, 9, 10]. It integrates a large amount of heterogeneous data and the ease in assigning the weights of enormous criteria [11, 12, 13, 14, 15, 16]. In the AHP method, every criterion under consideration was ranked in the order of the decision maker's preference. Meanwhile, the individual judgment, which never agreed perfectly with the degree of consistency achieved in the ratings, was measured by using the Consistency Ratio (CR), indicating the probability that the matrix ratings were randomly generated. This mathematical foundation provides several advantages to the AHP method to be used successfully in both subjective and objective evaluations [7].

2. Material and Methods

2.1 Study Area

Jeddah City is located on the Red Sea, the principal gateway to Mecca This location of the city contributed to economic development and increases the number of visitors The city has a population that represents 14% of the total population in Saudi Arabia—estimated at 25.37 million [17]. Its health facilities are divided into public and private health facilities. The study will be restricted to public hospitals that have services including an ED (East Jeddah General Hospital, King Abdullah Medical Complex, King Abdulaziz Hospital, Ophthalmology Hospital, Al Thaghr Hospital, Al Azizyah Children Hospital, Mental Health Hospital, King Abdulaziz University Hospital and King Fahed General Hospital (Fig. 1). The main factor considered in selecting these hospitals is the availability to all people, especially low-income individuals.

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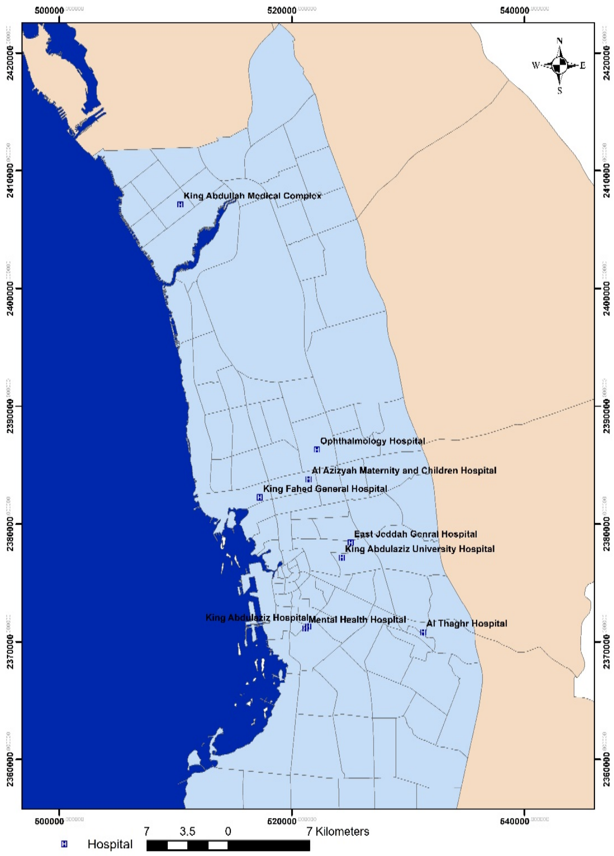

Fig. 1 Public hospital in Jeddah

2.2 Data collection

. The sets of data were collected:

a) Locations of public hospital

data is entered into the GIS as a point shapefile and each feature has got a unique ID number with hospital name and capacity.

b) Main road

Main roads are an essential factor to evaluate Hospital accessibility. The layer was extracted from ArcGIS online street map as a line shapefil e.

c) Jeddah neighborhoods boundaries

Jeddah Municipality neighbourhoods were Entered as polygon shapefile the attribute data for area and population were entered. The populat ion density was calculated for each polygon.

d) Gas and petroleum stations are collected and enter ed as a point shapefile.

2.3 Site Selection

GIS-based multi-criteria methods were used to produce hospital site suitability maps considering resident population, exciting hospitals, polluted areas and main roads. The selection of criteria was restricted by the available data. The ranking method was used, where every criterion under consideration was ranked in the order decision maker's preference. The Euclidian distance was used to identify suitability for each criterion. The nearer away from the residential population area and the main roads are evaluated with the higher rank value, while the further away from exciting hospitals, gas and petroleum station are better (Table 1). The inverse ranking was applied to these factors. Class 1 is the least important, while class 5 is the most important. The data were converted to a raster format, then the linear weightage combination using the map calculator and the final weights were used to provide the results. Figure 2 illustrates the flow chart of site selection methodology.

Table 1. Ranking and classification for each criterion.

Code	Criteria	Setting	Classes	Rank
A	Residential area	The nearer away from the residential population area, the better	Population Density < 3000 3000 to < 7000 7000 to < 15000 15000 to 25000 > 25000	 1 2 3 4 5
B	Exciting hospitals	The further away from the existing hospital, the better	Distance (km) from ED < 1.5 1.5 to < 5 5 to < 10 10 to 16 >16	 1 2 3 4 5
C	Main roads	The nearer away from the road, the better	Distance (km) from main roads < 0.5 0.5 to < 1.5 1.5 to < 5 5 to 10 >10	 5 4 3 2 1
D	Gas- Petroleum Stations	The further away from the polluted area, the better	Distance (km) from gas-Petroleum stations < 0.5 0.5 to < 1 1 to < 3 3 to 10 >10	 1 2 3 4 5

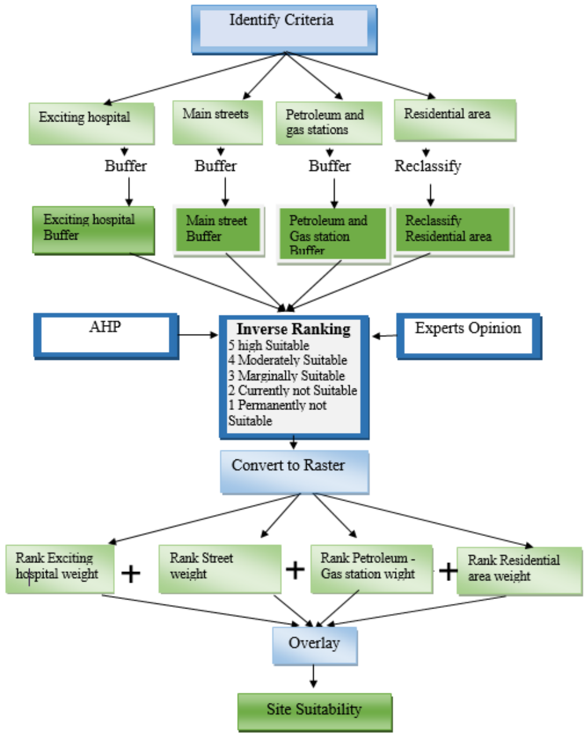

Fig. 2 The methodology flow chart of site suitability

The AHP has been employed in the GIS-based hospital site suitability procedures [18]. The GIS-based AHP gained high popularity because of the ease in obtaining the weights of enormous alternatives (criteria) and its capacity to integrate a large amount of heterogeneous data, therefore, it is applied in a variety of decision-making problems. In the AHP method, to generate the criterion values for each evaluation unit, each factor was weighted according to the estimated significance based on experts' opinions. The square pairwise comparison matrix is listed in Table 2. The normalized matrix is presented in Table 3. The degree of consistency achieved in the ratings was measured by using the Consistency Ratio (CR). The Random Indices for four criteria are 0.9.

The rule of thumb is that a CR over 0.1 indicates that the matrix should be revised, while less or equal to 0.1 indicates an acceptable reciprocal matrix. CR and consistency index (CI) and are depicted as Equation (1) and Equation (2) below

$$CI = (\lambda_{max} - n) / (n - 1) \qquad (1)$$

Where n = the number of the criterion

λ_{max} = the biggest eigenvalue of the comparison matrix.

$$CR = CI/RI \qquad (2)$$

Where RI = a constant corresponding to the mean random consistency index value based on n.

Table 2. Normalize Matrix

Table 3. Pairwise Comparison Matrix for ER site Suitability

	A	**B**	**C**	**D**	**Priority Vector**
A	1	2	2	3	
B	0.5	1	2	2	
C	0.5	0.5	1	2	
D	0.3	0.5	0.5	1	
	2.3	**4**	**5.5**	**8**	

2.4 Mathematical Variations Analysis based Sensitivity Analysis

	A	**B**	**C**	**D**	**Priority Vector**
A	0.43	0.5	0.36	0.375	0.41625
B	0.22	0.25	0.36	0.25	0.27
C	**0.**22	**0.**125	0.18	0.25	0.19375
D	0.13	**0.**125.	**0.**1	0.125	0.12
	1	1	1	1	1

Variations of functions with sensitivity analyses are used to determine the levels of importance of each criterion. The method further includes applying a plurality of weighting schemes for suitability criteria; visualizing a spatial pattern for each scenario; and testing the stability of results using variations of functions; this will determine the levels of importance of each criterion, such as the main roads, residential area, exciting of hospitals and gas and petroleum stations. This is useful in situations such as where uncertainties exist in the definition of the importance of different criteria. This method determines the level of importance of each criterion and therefore attempts to reduce the subjectivity of weights.

If R^4 is the four-dimensional spaces, function *S*, the suitability site classification for hospital, is defined on R^4, i.e. it is a function of four variables:

$S = S\ (eh; ra; gp; mr);$

where *eh* is exciting of hospitals, *ra* is residential area, *gp* is gas and petroleum stations and, *mr* is main roads. The arguments of this function satisfy the condition:

$R^4 = W_{eh} + W_{ra} + W_{gp} + W_{mr} = S\ (S1, S2, S3, S4, S5)$

$W_1+W_2+W_3+\ldots+W_n= 1$

Where: *W*: is the level of importance (i.e. the influence of the criteria in the dimensional education space).

n: is number of criteria

The function S takes values from 0 till 100.

S1: Highly Suitable

S2: Moderately Suitable

S3: Marginally Suitable

S4: Marginally Not Suitable

S5: Permanently Not Suitable

Different scenarios will be applied of each criterion. The aim of each scenario is to identify criteria that are especially sensitive to weight changes and visualize the spatial change dynamics, hence the level of importance

for each criterion can be determined. To achieve this purpose, different weighting schemes were applied for the suitability criteria. If the first scenario was to test the sensitivity *eh* weights on the output W_1 would refer to weight of is exciting hospitals, then

$W_2=W_3=W_n= (100-W_1)/\ n-1$

In the basic computation, an equal weight of 10% was given to the four criteria. Twelve weighting schemes were constructed and run using the model's implementation in ArcGIS. The weighting schemes were applied for hospital site suitability, see Table 4.

Table 4. The weighting schemes applied for suitability

Scenario	*Model Run*	*exciting hospitals %*	*residential area %*	*main roads %*	*Gas-petroleum stations %*	*Sum %*
Exciting hospitals	1	10	30	30	30	100
1	2	40	20	20	20	100
	3	70	10	10	10	100
residential area	4	30	10	30	30	100
2	5	20	40	20	20	100
	6	10	70	10	10	100
main roads	7	30	30	10	30	100
2	8	20	20	40	20	100
	9	10	10	70	10	100
Gas-petroleum stations	10	30	30	30	10	100
3	11	20	20	20	40	100
	12	10	10	10	70	100

2.4.1 Variations of Function

The influence of each criterion can be visualized in the spatial pattern for each scenario and the variations of function were used to test the stability of the result. The study aims to give a clear indicator for the best suitable area for hospital location, therefore the consideration will be given to the high suitable are (S1 class). The equation below was used to calculate the variations in function for *S1*

$$V_j = \sum \left| f(x_{i+1}) - f(x_i) \right| \qquad (3)$$

Where *V*= Variation of function, *j*= Number of scenario

3. Results and Discussion

This paper applied GIS-based multi-criteria analysis to produce site suitability for a new hospital location. Healthcare providers can consider this map as an essential step in future planning to ensure receiving care in a timely fashion. Four layers (hospitals, main road, residential areas and petroleum-gas stations) were overlaid and ranked based on the criteria of hospital site selection suitability (Fig. 4. 3, 5 and 6). Score 1 is the least important area and graduating to score 5 is the most important areas factor. Each factor was weighted according to the estimated significance for site suitability. The individual judgment was used to determine the importance level of each criterion in the pairwise comparison method. Meanwhile, this judgment, which never agreed perfectly, was measured by using Consistency Ratio (CR), indicating the probability that the matrix ratings were randomly generated.

λmax = 4.063

CI = 0.021

CR= CI/RI = 0.02

CR less than or equal to 0.1 indicates an acceptable reciprocal matrix

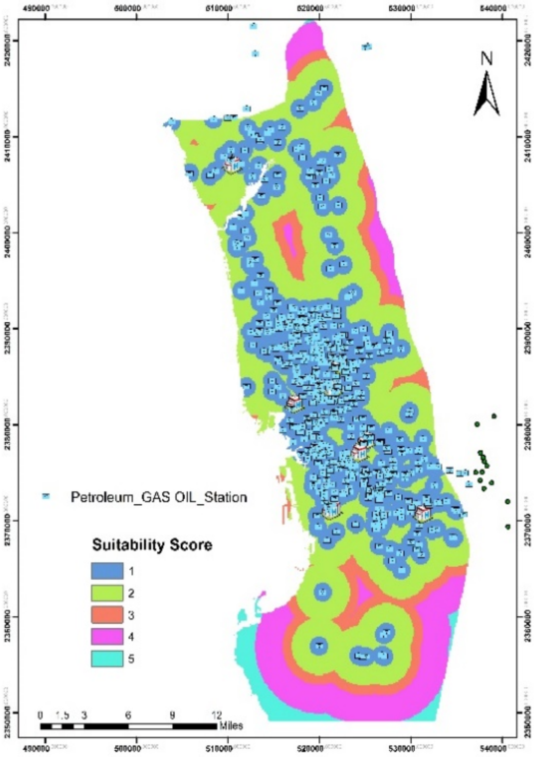

Fig. 3. Rank based Petroleum and gas

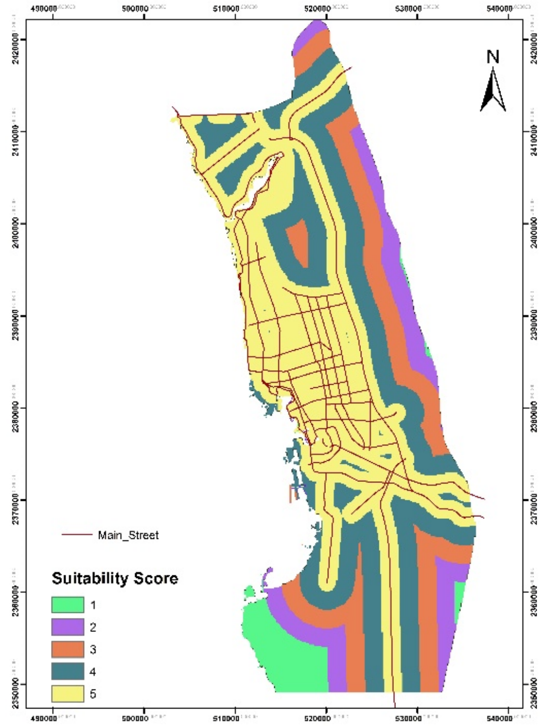

Fig. 4. Rank based on main streets

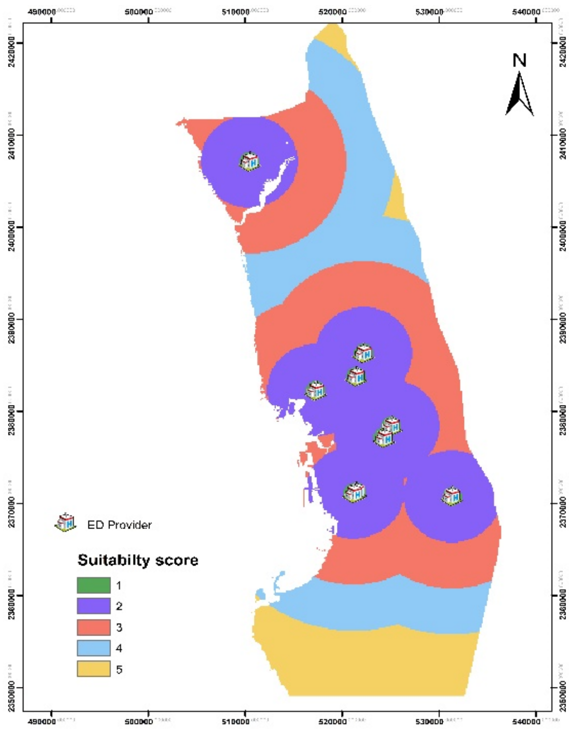

Fig. 5. Rank based exciting hospital

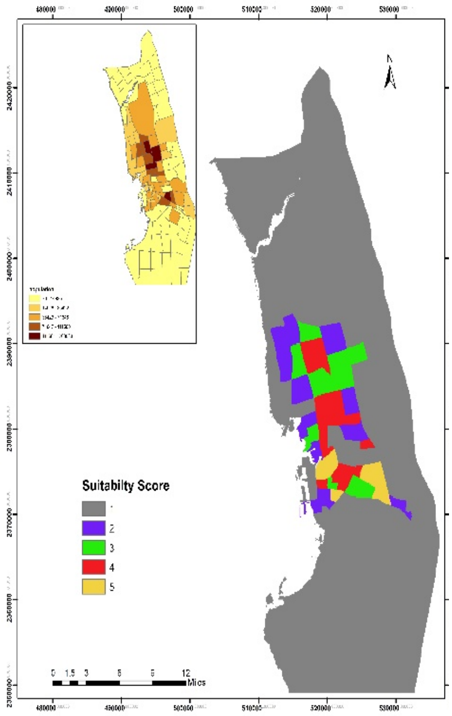

Fig. 6. Rank based on Residential area

Table 5. The result of weighting schemes for erosion scenario

Model Run	**S1% eh**	**S1% ra**	**S1% *gp;***	**S1% mr**
1	9			
2	22			
3	10			
4		5		
5		14		
6		62		
7			15	
8			17	
9			12	
10				27
11				19
12				13

$V_{eh} = |(22-9)| + |(10-22)| = 35$

$V_{ra} = |(14-5)| + |(62-14)| = 57$

$V_{gp} = |(15-17)| + |(12-17)| = 7$

$V_{mr} = |(19-27)| + |(13-19)| = 14$

Table 5, highlights The result of weighting schemes for the suitability scenario. Variation for each parameter was calculated. From the results of variations of function, it can be noted that the outputs of sensitivity analysis for hospital site suitability indicated how the suitability patterns have changed with the variations of the weighting schemes. For the exciting of hospital and residential area criteria, there were significant changes in the highly suitable class when their weighting of them changed. For gas and petroleum stations, the result indicated that there were minor changes in the highly suitable class, but lesser than the changes in the main roads criteria. The sensitivity analysis and variation function revealed that the residential area and hospital exciting are the most important factor, while gas-petroleum stations and main roads were the least important factors. The result of sensitivity analysis and variation of functions supported the result of the AHP method but without asking for experts' opinions, so it reduces the subjectivity

4. Conclusions

The suitability map will be useful for health care planners by choosing the best site for their facilities to reduce the pressures in the public hospitals. Moreover, the value of weights can be delivered from AHP method, but more attention should be provided to the priority of weights. Mathematical variations analysis and sensitivity analysis measures the stability of results against variations of different parameter weights and display spatial change dynamics. It supplies more immediate feedback to evaluators. and improves the reliability of MCE, reducing the subjectivity of weights by providing a mechanism for non-experts to provide weights of criteria by learning how changes in criteria weights may affect the evaluation outcomes spatially.

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