Coupling GIS-based MCA and AHP techniques for Hospital Site Selection

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Abstract

Recently, the population of Jenin city is increasing rapidly and this amplifies the need for more infrastructural objects such as hospitals. Hospitals are considered among the most important infrastructural constructions in cites as they provide health care services. However, current hospitals and medical resources are limited and randomly allocated in Jenin city. Accordingly, in this paper we propose a suitability model that employs Geographic Information System (GIS) based Multi-Criteria Analysis (MCA) with Analytical Hierarchy Process (AHP) to identify suitable locations for building a new hospital in Jenin city. An experimental instantiation of the proposed model is instantiated and the produced results show that the majority of suitable areas are located in Northeast of Jenin. This is mainly because Northeast of Jenin is away from industrial areas and dumping sites.

Keywords: *Hospital site selection, GIS, MCA, AHP*.

I. Introduction

Recently, the number of people shifting from rural to urban areas is increasing rapidly. This rapid increase of urban population creates various social, economic and environmental changes such as unplanned sprawl, inadequate housing facilities, traffic congestion, insufficient drainage, and lack of health facilities [1]. It is very important to provide all facilities and infrastructural constructions in urbanized areas to overcome the rapid urban growth. Therefore, it becomes the government's responsibility to provide the required resources and facilities for urban areas on proper locations.

Hospitals are among the most important facilities that have a vital role in providing health care services. Identifying the best locations for new hospitals is an important issue due to the fact that selecting suitable locations will help the government to optimize the allocation of medical resources, simplify social contradictions and control the health care development in rural and urban areas. On the other hand, appropriate hospital site selection will help people reach hospitals easily, reduce the time of rescue and improve the quality of life [2].

Current hospitals in Jenin city are randomly distributed and arbitrarily allocated due to the unreasonably distribution by the government. For example, inside the city center of Jenin, hospitals are saturated. With the growth and extension of Jenin, the population increases rapidly and spreads into areas outside the city center and the contradiction between supply and demand for hospitals is becoming severe. Moreover, there is a persistent need to build quality hospitals that provide professional health care services due to the limited high quality medical buildings.

Several studies employed GIS techniques and products to address the problem of identifying the best locations for building hospitals and planning health services [3, 4]. Most of these studies take into account several parameters to allocate suitable sites for building hospitals such as existing hospitals, population, economical factors, pollution, and other laws and regulations.

In this paper, we aim to identify the most suitable areas for building a new hospital in Jenin city. In order to achieve this goal, we will exploit GIS products and methods with MCA in addition to AHP. By this, we mean that the study will take into account many factors such as existing hospitals, proximity to main roads, and distance to polluted and industrial areas. After that, we will assign them different weights (according to their importance) based on AHP.

The main contributions of our work are summarized as follows:

- Employing GIS-based MCA in order to identify the best locations for building a new hospital in Jenin city.

- Exploiting AHP to assign weights and scores for the identified criteria (i.e. factors) in order to select the best location for the new hospital.

The rest of this paper is organized as follows. Section 2 presents the related work. A general overview of the study area is presented in section 3. Section 4 presents the general architecture of the proposed model and the implementation details of the suitability model. Experimental validation and evaluation of the proposed model is presented in Section 5. In Section 6, we draw the conclusions and outline future work.

II. Related work

We will clarify our contributions in the following paragraphs by offsetting them with prior related work. Several studies have employed GIS techniques and methods in health services and for planning public health [3, 4 and 5]. For example, the authors in [6] combined GIS with Location Based Services (LBS) in order to settle the affairs of emergency medical incidents. On the other hand, other authors employed GIS techniques and methods in selecting the best site for building health care facilities. In order to build constructions that provide health care facilities, various parameters (i.e. factors) can be considered to identify the most suitable sites such as existing health care facilities, population, economic factors and pollution. These parameters can be classified, analyzed and integrated together in different methods. For example, MCA is used to identify factors that affect building new health care objects in [7]. While in [8], the researchers employed both GIS and Analytical Hierarchy Process (AHP) to determine the parameters that affect the physical accessibility of neurosurgical emergency hospitals in Sapporo city. At the same time, the authors of [9] exploited AHP to evaluate the appropriateness of the location selected for Taiwanese hospital.

Although AHP allows multi-criteria decision-making, it suffers from the fact that there are hidden assumptions like consistency. Besides, it is difficult to use when there is large number of criteria. To overcome these problems, Fuzzy Analytical Hierarchy Process (FAHP) is used later in for hospital site selection [10].

In our proposed work, we aim to employ MCA based on GIS methods and techniques to identify the best site for building a new hospital in Jenin city. Besides, we will exploit AHP to assign weights for the factors that affect the new hospital site selection. According to the produced results, we can prove that GIS-based methods and tools play a vital role in making effective decisions in the health field.

III. Study Area

The study area is Jenin governorate. It is located in the north of West Bank as shown in Figure 1. In 2016, the city had a population of 318,958 according to the census by the Palestinian Central Bureau of Statistics [11]. It is located about 43 Kms north of Nablus, and it is about (100-250 m) above sea level. The name of Jenin was derived from Ein Ganim meaning “the spring of Ganim” and referring to the region’s plentiful spring.

Jenin is under the administration of the Palestinian Authority. Today, Jenin is built on the slopes of a hill and surrounded with different types of trees such as carob, fig, and palm trees. It is distinguished by its agriculture, producing various types of crops.

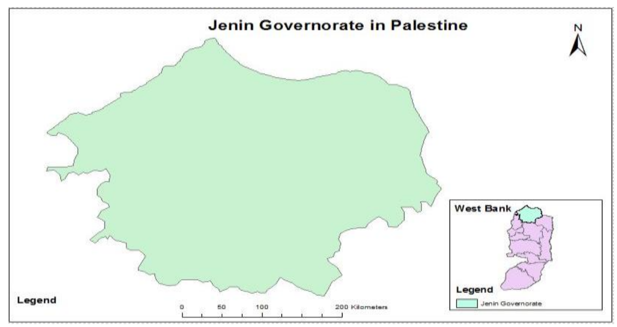

Fig.1: Jenin governorate in West Bank

Jenin governorate has 82 localities and one camp, and we divided the study area into three main regions: Jenin city, Jenin camp and villages that belong to Jenin governorate.

During our work, we focus on Jenin city that has three main hospitals. The details of these hospitals are given in Table 1, and their locations are illustrated in Figure 2.

Table 1: Existing hospitals in Jenin city.

Name	**Specialization**	**Administrated by**	**No. of beds**
Al-Razi Hospital	General	Private sector	60
Al-Amal Hospital	General	Private sector	20
Jenin Governmental Hospital	General	Government	120

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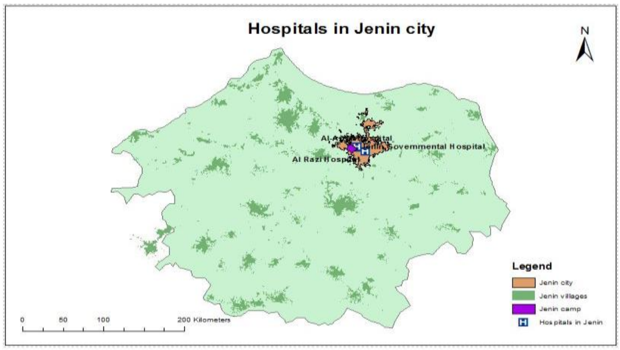

Fig.2: The main hospitals in Jenin governorate.

IV. Data and Methodology

In this section, we present the methodology used in our proposed model in order to identify the optimal site for building a new hospital in Jenin city. Figure 3 depicts the steps of our proposed model.

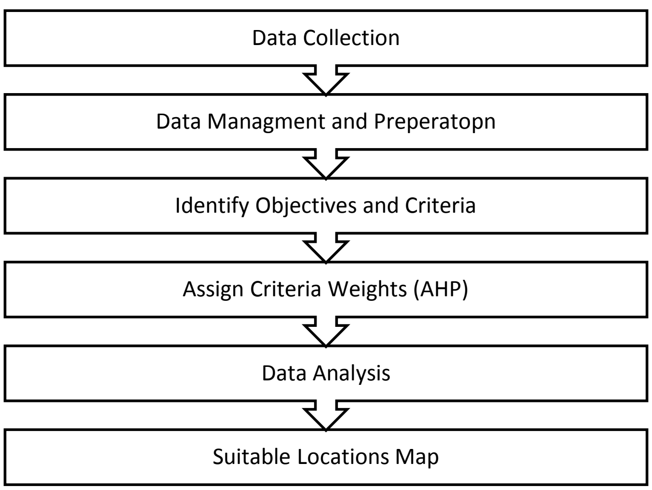

Fig.3: A flow chart depicts the methodology used in order to identify suitable locations for building a new hospital.

As shown in figure 3, the proposed model starts with collecting data from various resources to represent the aspects of the study area. Some of those data are collected from online resources such as GeoMOLG [12] and others are manually digitized with a suitable scale. After that, the collected data are managed and prepared for use. By this, we mean that the data are organized and stored efficiently for further analysis. Then, analysis objectives and criteria are identified to use them in further steps. Once analysis criteria are identified, they are assigned weights based on AHP. Those weights are used to indicate the importance of each criterion. After that, during the data analysis step, various GIS tools and methods are employed in order to produce the set of suitable locations for building a new hospital.

A. *Data Collection*

In order to find the best location for building a new hospital, we need to collect data in the format of vector shape files. These shapefiles are collected from GeoMOLG [12] and some of them created by digitizing maps obtained from Jenin municipality. Once the vector data are collected, they are converted later during the analysis step into raster format.

B. *Data Managment and Preperation*

During this step, the collected data are prepared to be used in the analysis process. Data are often collected with missing values and errors, so we need to correct these errors and organize the data in datasets and geodatabases. The process of correcting the data and integrating them into feature data sets constitute a vital role in this step.

Additionally, it is important in this step to answer some questions about the collected data such as:

- What is the data format?
- At what scale it was collected?
- Are the data projected?
- Does the data have all the needed attributes?
- Does the data have constraints and the features geometry support the analysis process?

C. *Identify Objectives and Criteria*

In our proposed model, we aim to select the optimal site for building a new hospital. Various factors have been involved in the selection process including the following:

1) *Land use.*
2) *Distance to existing hospitals.*
3) *Intersection with main roads.*
4) *Distance to dumping sites.*
5) *Distance industrial areas.*
6) *Elevation.*

These factors are divided into three main types:

1- Technical factors: these factors have a clear impact on the construction process and they include the elevation, the slope, distance to existing hospitals and

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the land use of the proposed site. The land use refers to how the land being used by human. While the distance to existing hospitals is how fare the new hospital from other hospitals in the same city.

2- Environmental factors: there is a strong relationship between human and the environment. The main environmental concerns that may affect hospital site selection are noise and pollution. And thus, the new hospital should be away from noisy and polluted areas such as industrial areas and dumping sites.

3- Socio-economic factors: these factors mainly includes proximity to transportation and main roads.

D. *Assign Criteria Weights (AHP)*

In this step, we assign weights and scores for the identified factors in the previous step based on AHP. AHP has been widely exploited in health-care and medical related problems. The following steps are used to assign weights for all identified factor based on AHP:

1- Layout and expose the overall factors.

2- All factors can be compared using pair wise comparisons in order to generate weights for factors through distributing questionnaires on experts. In pair wise comparisons, we decide which factor is more and how much important than another using 1-5 scale as shown in Table 2 [13]. The produced wrights quantify the importance of factors in the analysis and decision making process.

3- Check the consistency ratios of all pair-wise comparisons.

In this step, we use the Consistency Index (CI) and Consistency Ratio (CR) formulas to check the consistency as follows:

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

Where:

n: the number of 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.

4- The relative scores are aggregated using geometric mean method.

Table 2: Pair wise comparison scale

Verbal judgment	Explanation	Number
Extremely Un-Important	A criterion is strongly inferior to another	1/5
Moderately Un-Important	A criterion is slightly inferior to another	1/3
Equally Important	Two factor contribute equally	1
Moderately Important	Judgment slightly favor one criterion over another	3
Extremely Important	Judgment strongly favor one criterion over another	5

E. *Data Analysis*

In this step, a model is developed in order to identify the optimal location for building a new hospital. In this model, the raw data should have the same spatial reference and they are converted into a raster with the same cell size, making them easier reclassified in Analysis steps.

The data anlysis steps and tools are detailed as follows.

- Distance to existing hospitals based on network analysis: as detailed earlier, there are six factors taken into account for building our model. In this step, we derive a series of polygons (service areas) that represent the distance that is required to reach each hospital. As a prerequisite to finding the service areas, we need to construct a network dataset. The results of applying this step are depicted in Figures 4 and 5.

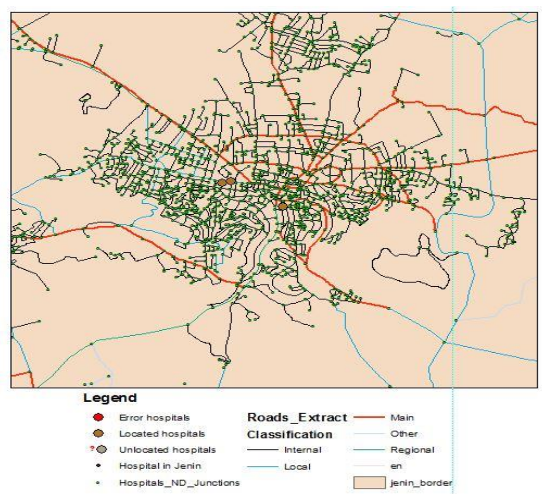

Fig.4: The result of creating a Network Dataset for Jenin roads and facilities.

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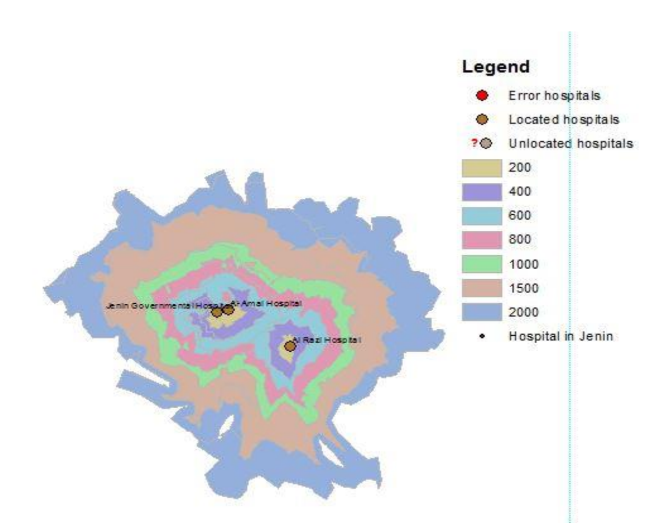

Fig.5: Distance to hospitals based on Service Area polygons.

- Euclidean distance: In this step, we derive the Euclidian distance from facilities (dumping sites and industrial areas) to each pixel in the generated output raster. The formula for finding the Euclidian distance is depicted below:

$$d(q,p) = \sqrt{\sum_{i=1}^{n}(qi - pi)^2} \quad (3)$$

Where:

p = (p1, p2,..., pn) and q = (q1, q2,..., qn) are two points in Euclidean n-space.

d: Distance from p to q

The results of applying this step are depicted in Figures 6 and 7.

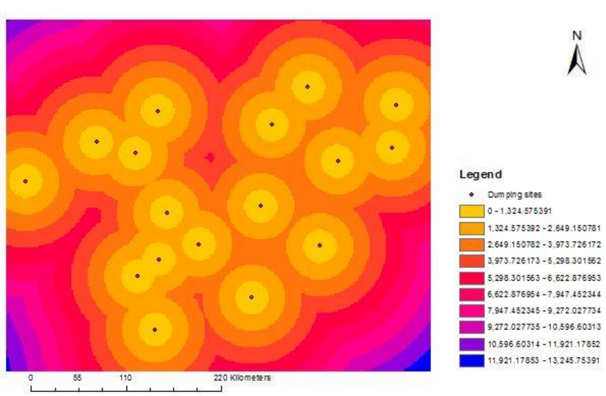

Fig.6: Euclidean distance to dumping sites

- Feature to raster: During this step, we convert the land use feature class (vector data) to a raster that has the same cell size as the derived raster layers from the previous step. Accordingly, we can use all of them for further processing.

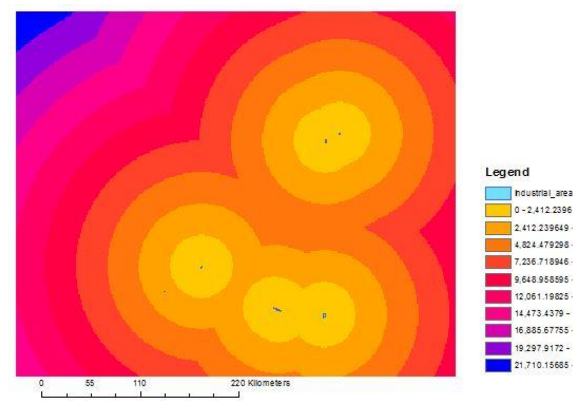

Fig.7: Euclidean distance to industrial areas

- Slope: In order to build a hospital, the land should be relatively flat. Therefore, we consider the slope of the land in our model by deriving the slope of the elevation dataset as shown in Figure 8. By this, we mean that the rate of maximum change in elevations is calculated.

- Reclassification: Each cell in the study area now has a value for the following factors (existing hospitals, dumping sites, industrial areas, land use and elevation). We should combine the derived datasets in order to identify the potential location for building a new hospital in the next step (Weighted overlay). However, we cannot combine them in their current form. For example, there is no meaning to combine cell values that have 15 degrees slope with cell values that have agriculture land use that equals (6). Accordingly, to combine datasets, we need to derive a common measurement scale such as from 1 to 10. This scale identifies how suitable a specific location for building a new hospital. Lower values indicates

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locations that are more suitable. The reclassification process is depicted in Figure 9.

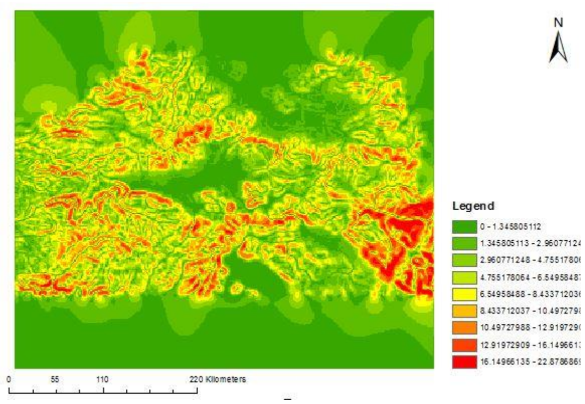

Fig.8: Slope of Jenin governorate

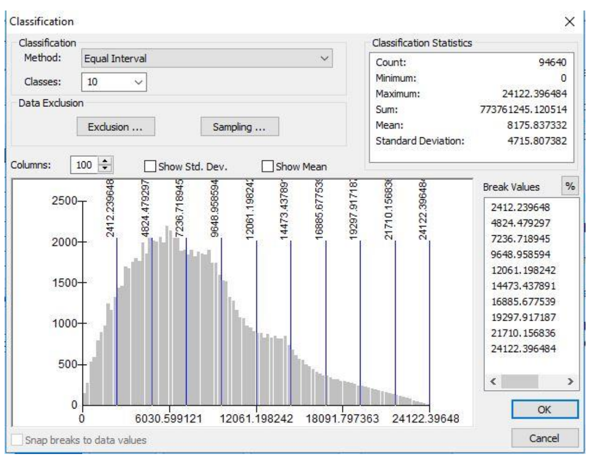

Fig.9: Classification of Euclidean distance values to classes from 1 to 10

As shown in figure 9, we classify the produced distance values from the Euclidean distance process into 10 classes by dividing the produced ranges into equal intervals.

- Weighted overlay: Using this technique, we weight the values of each dataset by assigning each a percentage of influence. The higher the percentage, the more influence an input has in the suitability model. Some input values will be restricted. For example, areas that belong to “C” administrative division in West Bank are restricted as shown in Figure 10. The result of this step indicates how suitable each location for building a new hospital.

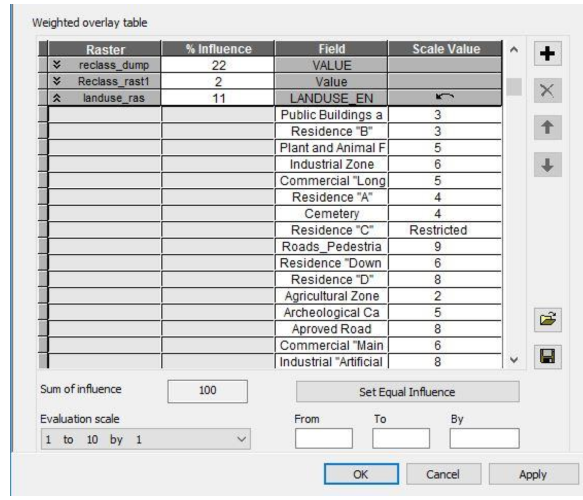

Fig.10: Weighted overlay

- Majority filter: The size of the suitable area is an important criterion in identifying the optimal site for building a new hospital. Thus, we use this tool to ensure that the number of neighboring cells of a similar value must be large enough to build a new hospital.

- Condition: Pixels with values less than 3 indicates suitable locations. Thus, the condition tool used to identify those locations.

V. Experimental Results and Discussion

This section describes the experiments carried out to evaluate our proposed suitability model. A prototype of the proposed model is implemented and experiments are conducted using a PC with dual-core CPU (2.1GHz) and (8 GB) RAM. The used operating system is Windows 10.

- Comparing the Produced Results When Changing the Weights Assigned for all Input Data Sets

In this section, we compare between the produced results by the proposed model when we change the weights assigned for the input data sets according to the following table.

Table 3: The weights assigned for input datasets in different experiments.

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Input data set	Random weights in EXP.1	Random weights in EXP.2	AHP weights in EXP.3
Land use.	0.09	0.10	0.22
Distance to existing hospitals	0.04	0.20	0.13
Near main roads	0.24	0.04	0.30
Distance to dumping sites	0.13	0.06	0.22
Distance industrial areas	0.30	0.30	0.02
Elevation	0.20	0.30	0.11

As shown in table 3, we assigned different weights for each input data set in different experiments. After running the proposed model with weights from the first experiment (EXP.1) and the second experiment (EXP.2), we get the results shown in Figure 12.

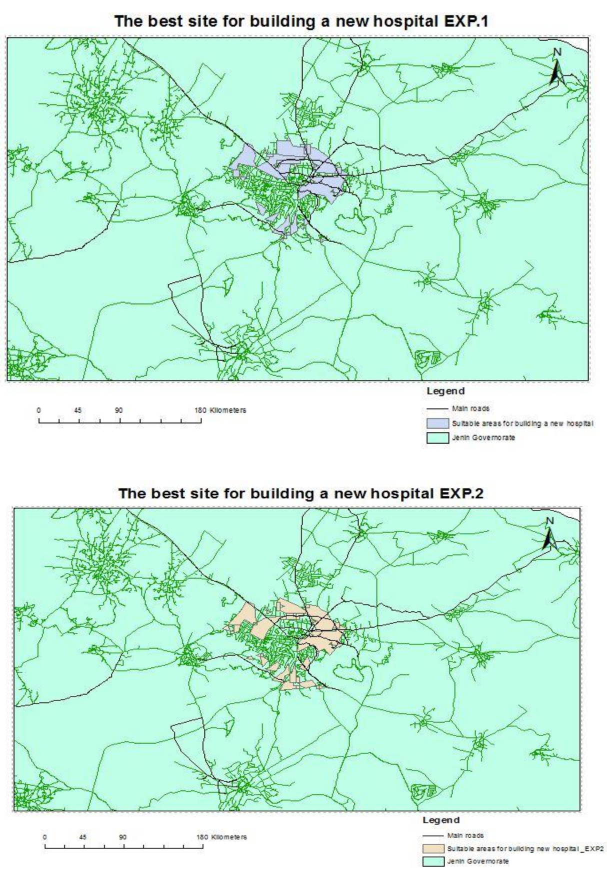

Fig.12: The optimal sites for building a new hospital with weights from EXP.1 and EXP.2 respectively.

As we can see in Figure 12, the produced results have various contiguous alternatives, which may be confusing for the decision maker. This is because the weights are randomly assigned for the input datasets without extensive care or research.

However, we were able to achieve promising results for decision makers when using the weights produced from applying AHP as shown in Figure 13.

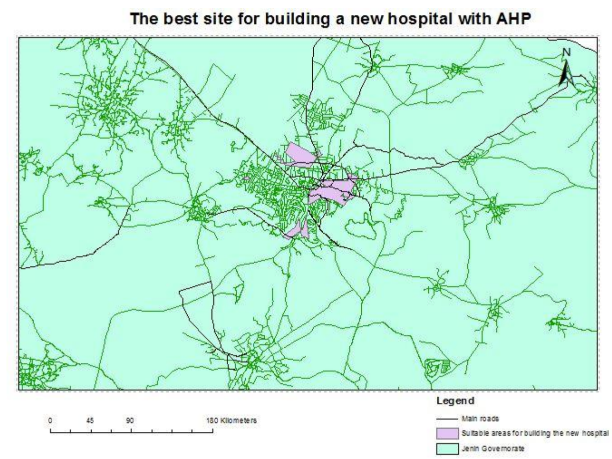

Fig.13: The optimal sites for building a new hospital with AHP weights.

VI. Conclusion and future work

In this paper, we built a suitability model for selecting the optimal site for building a new hospital based on coupling GIS-based MCA and AHP. GIS tool and techniques are employed to analyze the list of identified criteria in hospital site selection. The analysis process incorporates assigning weights for the identified criteria based on AHP. And at the end of the analysis process, the optimal site for building a new hospital is identified. The results showed that assigning weights based on AHP is better than assigning weights randomly for the set of identified criteria.

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