GIS Based Multicriteria Approaches to Housing Site Suitability Assessment

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KEYWORDS: Housing Site Selection, Geographical information system (GIS), Multi criteria analysis (MCA), Analytical hierarchy process (AHP), Sana'a city.

ABSTRACT

Urbanization is a continuous process and it is important to identify suitable housing areas for future development. Sana'a city is already developed and the present population is exceeding the projected population. Selecting the location for housing sites is a complex process involving not only technical requirement, but also physical, economical, social, environmental and political requirements that may result in conflicting objectives. Such complexities necessitate the simultaneous use of several decision support tools such as high spatial resolution remotely sensed data, Geographical Information System (GIS) and Multi Criteria Analysis (MCA) using analytical hierarchy process (AHP). In this paper a model was developed to evaluate the possible location of building sites and to support decisions making in the location of additional housing areas in Sana'a city. This integration could benefit urban planners and decision makers. The central theme of this paper is to explain the process of developing a prototype GIS application to provide a system for supporting location decisions with respect to the implementation of urban master plans. GIS was used based on a set of criteria derived from the spatial aspects, environment, policies and national and local physical plan.

INTRODUCTION

Urbanization is now a common feature of all third world countries. Primate cities and megacities are emerging in developing countries. In Asia, Africa and Latin America, the unprecedented population growth that characterized much of the 20th century has evolved into unparalleled urban growth (Brockerhoff, 2000). The world's population continues to increase, with 96 percent of this growth in developing countries. The United Nations projects that by 2010 there will be 511 metropolises exceeding one million inhabitants and for the first time, more than 50 percent of the world's population will dwell in cities. In addition, 40 large cities will be added every five years so that by 2025 there will be 639 metropolises with more than one million residents. Seventy-six percent of these will be in developing countries. Currently, 77 percent of Latin Americans, 41 percent of Africans, and 35 percent of Asians live in urban areas (UNFPA, 1991).

In Yemen cities are growing in importance, and urban areas are expanding rapidly, primarily because the population of the nation is increasing, and proportionally more people are congregating in urban areas. The city of Sana'a, within its capacity as capital of the Yemen, has undergone tremendous urban growth in the last half century. It has the fastest-growing towns in the nation (Census, 2004). The census record show that the number of population in Sana'a city increased rapidly from 1,003,627 in 1994 to 1,747,627 in 2004 with annual growth 5.5%, which increased 2.52% more than the annual population growth for Yemen. The growth has created a higher urban land demand than previous decades, leading to significant change of landscape. The result has been a built up of pressure on environment. As urban regions grow, more land will be needed to satisfy further growth of urban population in the future (Yeh, and Li, 1998). In this context it is very important to find housing suitable areas for urban development to overcome the undesirable urban growth in Sana'a city.

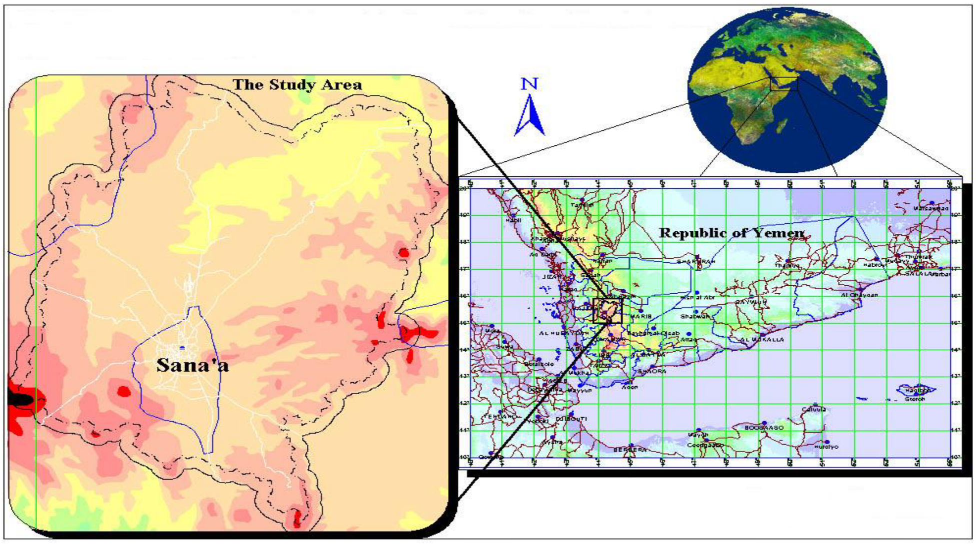
Land suitability analysis is the process of determining the fitness of a given tract of land for a defined use (Steiner, McSherry et al. 2000). In other words, it is the process to determine whether the land resource is suitable for some specific uses and to determine the suitability level. In order to determine the most desirable direction for future development, the suitability for various land uses should be carefully studied with the aim of directing growth to the most appropriate sites. Establishing appropriate suitability factors is the construction of suitability analysis. Initially, suitability analysis was developed as a method for planners to connect spatially independent factors within the environment and, consequently to provide a more unitary view of their interactions. Suitability analysis techniques integrate three factors of an area: location, development activities, and environmental processes. These techniques can make planners, landscape architects and local decision-makers analyze factors interactions in various ways. Moreover, such suitability analysis enables elected officials and land managers to make decisions and establish policies in terms of the specific landuses.

Study area

Sana'a city is located to the Northern-central part of Yemen. It is the political and historical capital of Yemen.. It is above sea level by 2200 meter. It is located within coordinates of latitudes 15º 10' 00" and 15º 30' 00" North and longitudes 44º 05' 00" and 44º 20' 00" East. The city is situated centrally between the other large cities like Aden, Al-Hodieda, Ibb, and Taiz. The total area is 1050 km2. The built up area is around 105 km2. The population of the city is 1,747,627 in 2004.

The urban area is extremely varied in topography relief, population density, historically, urban growth has been confined primarily to the lowlands or low slopes areas in Sana'a plateau. However, in resent year, development has spread rapidly upslope and also into small narrow valley areas, where slope stability and debris flow problem have become increasingly common. Also the uncontrolled growth occurred in the reserved land like; airport reservation land, green areas, ground water basin land, and, .., etc.

Figure (1) Location Map of Yemen indicating the Sana'a city



Site Selection Process

Site selection requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for a defined land use. The selection of housing sites involves a complex array of critical factors drawing from physical, demographical, economic, policies, and environmental disciplines. The current spatial decision making could benefit from more systematic methods for handling multi-criteria problems while considering the physical suitability conditions. Traditional decision support techniques lack the ability to simultaneously take into account these aspects.
The process of housing site selection begins with the recognition of an existing or projected need. This recognition triggers a series of actions that starts with the identification of geographic areas of interest. In the past, site selection was based almost purely on economical and technical criteria. Today, a higher degree of sophistication is expected. Selection criteria must also satisfy a number of physical, social and environmental requirements, which are enforced by legislations and government regulations (SIOR and NAIOP 1990).

Site Selection Tools

For the last three decades, geographic information systems (GIS), and Multicriteria decision-making (MCDM) techniques have been used in solving site selection problems. A brief description of the strength and weakness of each tool with regard to sitting problems is provided below

Geographic Information Systems (GIS)

Geographic information systems (GIS) have emerged as useful computer-based tools for spatial description and manipulation. Although often described as a decision support system, there have been some disputes regarding whether the GIS decision support capabilities are sufficient (Jankowski 1995). Since current GIS do not provide decision-making modules that reason a decision and are primarily based on manual techniques and human judgments for problem solving, the individual should have the decision rules in place before GIS can be utilized. Other limitations in current GIS approaches include the incapable of processing multiple criteria and conflicting objectives (Carver 1991). They are also limited in integrating geographical information with subjective values/priorities imposed by the decision maker (Malczewski 1999).

Multi criteria decision making (MCDM)

The techniques adopted in the various approaches of decision analysis are called multi criteria decision methods (MCDM). These methods incorporate explicit statements of preferences of decision-makers. Such preferences are represented by various quantities, weighting scheme, constraints, goal, utilities, and other parameters. They analyze and support decision through formal analysis of alternative options, their attribute, evaluation criteria, goals or objectives, and constraints. MCDM used to solve various site selection problems (Badri 1999, Korpela and Tuominen 1996). However, they assume homogeneity within the study area, which is unrealistic for site selection problems (Malczewski 1999).

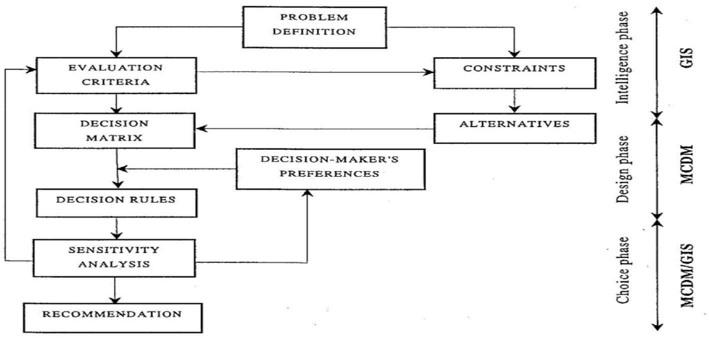
The choice of the MCDA method is very important since it has a significant effect on the final outcome. MCDA characteristics and properties should be compatible with the specific nature of the decision problem (Laaribi et al. 1996, Salminen et al. 1998). For example, some MCDA techniques efficiently handle a continuous set of alternatives and criteria belonging to the same domain (e.g. economic). Other MCDA methods can only consider a small set of discrete alternatives but are more efficient to handle heterogeneous criteria (Florent et al. 2001).

If there is a conflict between the various actors, they can negotiate the subjective parameters, like the weights associated with each criterion before adopting a common set of values. It is also possible to repeat the MCDA process and thus select, for each different group of stakeholders, a solution that is adapted to its specific needs. MCDA results can be mapped in order to display the spatial extent of the best areas or index of land suitability. The negotiating parties can then discuss and compare the results by overlaying these maps, which are in fact geographical representations of their own set of preferences.

Spatial multi criteria decision making (MCDM)

Spatial multi criteria decision problems typically involve a set of geographically-defined alternatives (events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria [Jankowski, 1995; Malczewski, 1996]. Spatial multicriteria analysis is vastly different from conventional MCDM techniques due to inclusion of an explicit geographic component. In contrast to conventional MCDM analysis, spatial multicriteria analysis requires information on criterion values and the geographical locations of alternatives in addition to the decision makers' preferences with respect to a set of evaluation criteria. This means analysis results depend not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Therefore, two considerations are of paramount importance for spatial multicriteria decision analysis: (1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives) [Carver, 1991; Jankowski, 1995]. The major elements involved in spatial multicriteria analysis are shown in Figure 1 [Malczewski, 1999].

Figure (2) Decision flowchart for spatial multicriteria analysis [Malczewski, 1999].



The Analytical Hierarchy Process

The most frequently raised problem in MCDM is how to establish weights for a set of activities according to importance. Location decisions such as the ranking of alternative communities are representative multi-criteria decisions that require prioritizing multiple criteria. Saaty (1980) has shown that this weighting of activities in MCDM can be dealt with using a theory of measurement in a hierarchical structure. The analytic hierarchy process (AHP) is a comprehensive, logical and structural framework, which allows to improve the understanding of complex decisions by decomposing the problem in a hierarchical structure. The incorporation of all relevant decision criteria, and their pairwise comparison allows the decision maker to determine the trade-offs among objectives. Such multicriteria decision problems are typical for housing sites selection. The AHP allows decision-makers to model a complex problem in a hierarchical structure showing the relationship of the goal, objectives (criteria), sub-objectives, and alternatives. Uncertainties and other influencing factors can also be included. It is not only supports decision makers by enabling them to structure complexity and exercise judgement, but also allows them to incorporate both objective and subjective considerations in the decision process (Saaty, 1980).

Pairwise comparisons method

The Pairwise comparisons method was developed by Saaty (1980) in the context of the Analytical Hierarchy Process (AHP). This method involves pairwise comparisons to create a ratio matrix. As input, it takes the pairwise comparisons of the parameters and produces their relative weights as output.

Table 1: Pairwise Comparison Matrix

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

Source: Satty (1980**)**

Multi criteria analysis and GIS for land-use suitability assessment

Progress in computing sciences, including Geographical Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA) can help planners handle this complexity. The recent literature is replete with proposals combining GIS and MCDA which meet the above mentioned objectives either partially or entirely.

Choosing an appropriate location for an activity or a facility is obviously related to decision support and MCDA. The problem can be generalized as a question of what must be done and where it should be realized. The purpose of planning (what) can involve a hospital (Malczewski and Ogryczak 1990, Malczewski 1991), a solid waste transfer station (Gil and Kellerman 1993), or more generally, any type of public facility (Yeh and Hong 1996). In a series of two articles, Malczewski and Ogryczak (1995, 1996) clearly define the multiple criteria location problem. They also compare the advantages and the disadvantages of different MCDA methods. Localization problems have also been treated with a more intensive use of GIS. Carver (1991) uses GIS to evaluate various alternatives for nuclear waste sites. Then, he evaluates the effectiveness of three MCDA techniques used to compare scenarios in order to select the best one.

Land suitability assessment is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area. Senes and Toccolini (1998) combine UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Hall et al. (1992) and Wang (1994) also use map overlays to define homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone. These classification techniques can be based on Boolean and fuzzy theory (Hall et al. 1992) or artificial neural networks (Wang 1994). Combining GIS and MCDA is also a powerful approach to land suitability assessments. GIS enable computation of the criteria while a MCDA can be used to group them into a suitability index. Following a similar approach, Eastman et al. (1993) produced a land suitability map for an industry near Kathmandu using IDRISI (a raster GIS) and AHP (Analytical Hierarchy Process) (Saaty 1990). Pereira and Duckstein (1993) have used MCDA and raster GIS to evaluate a habitat for endangered species. Finally, some other papers have focused on the technical aspects of combining GIS and MCDA (Jankowski 1995).

Identifying Criteria

The development of urban residential land use is influenced by numerous factors. These include physical, socio-economic and environmental quality and amenities. (Chapin and Kaiser 1978). The first step that was taken in this analysis was to collect all of the data that would be needed to meet all of the criteria. Criteria were selected to evaluate potential housing sites and to support decisions concerning the location of additional housing areas. The criteria must be identified and include factors and constraints. The criteria were selected on the light of literature and planning guidelines (master plan) in Sana'a city and in the other countries like Malaysia. These factors include:

Topographical aspect

Topography factors affect the land use planning and the important factors associated with topography include aspect, elevation and steep slopes. From the master plan policies, considered that the sites on or near cliffs is not suitable for housing development also we have to a void the high elevation area because the planning in these areas costs a lot to the government, particularly supplying the mountains area by facilities like roads, water supply, electricity, and so on, are much more costly in comparisons with the flat areas.

Among the physical factors that are commonly studied in residential site selection. Areas with exceeding 10 % are usually not suitable for residential development (Chapin and Kaiser 1978). The idlest areas for housing residential use are areas with 2-6 % slopes. However, in master plan in Sana'a city the slopes exceeding 20% is not suitable for residential development.

The Aspect is the direction the slope faces Eastern, western and southern exposures were identified to be more suitable sites, the south is moderate suitable, they are generally drier and are exposed to sunlight for a longer period.

From the goal of safety

The presence physical hazard reduces the suitability of a site. For Selecting safe housing sites and a void the risks deriving from water. The risks here can arise from flooding in the rainwater season whether from wadi Sailah canalization, the other canals, or low-lying land subject. Each of them would be buffered according to the severity of the hazard. In addition the location must be far at least 1 km far from the military camps.

From the goal of minimization of the cost of urban development reducing mobility

Road accessibility is one of the important parameters for urban development as it provides linkage between the settlements The distance to existing urban areas is important because the significantly impact moving costs, so the roads are an important factor in housing development because their presence indicates human activity. The locations must be adjacent to built up areas (existing neighborhood), in the low-density population areas, within 1-5 km from the main and secondary roads. (A G-o Yeh, 1999).

From the goal of safeguarding nature areas

- To safeguarding nature areas: No building sites are allowed within the ground water basin.
- The locations must be far at least 3 km from the airport. The exclusion zones may be based on noise from airport operation, areas affected by aircraft landing pattern, and areas that would interfere with airport radar. (Jeffery stars, et al, 1990)

The environment aspect

- Housing areas should be located at least 200 meters away from industry areas. (Seberang Perai Municipal Council, Malaysia, 1989).
- The location must be far at least 5 km from the waste water treatment station.

ANALYSIS AND RESULTS

A mosaic of six scenes high resolution images (Quickbird satellite images 0.60 m) was used for land use classification and Spatial database of various thematic maps of the study area is created by digitization, vectorization methodology using GIS software (Arcview GIS 3.2). The features were derived from the images like road networks, built up area, industries land, and agricultural land. 3D analysis was used to obtain the TIN model from digital topographic map (10 m contour interval) to generated and obtain elevation, slope and aspect maps.

In the case study, the formation of main criterion factors and sub-criterion factors uses the Saaty's normal AHP technique. The assumption is that the weightings derived from hierarchical comparison in normal AHP would be influenced by the preferences given to a particular criterion factor. Therefore a sensitivity test was carry out on the criterion preferences. It was evaluated based on five preference factors thought to influence weightings. The factors considered were preferences given to: 1) elevation factor; 2) slope factor; 3) aspect factor; 4) transportation factor; and 5) landuse factor.

Five separate hierarchical pairwise comparisons of main criterion factors were made for each preference to analyze the sensitivity of the weights obtained. The pairwise comparisons of criteria and sub-criterion factors were carried out independently and given same judgements for all the preferences. To reflect the preferences towards a certain factor, a definite to very strong preferences was given to that factor in their pairwise comparison. Table (2).
The next stage in the analysis, the consistency must be checked to verify the reliability of the judgment of the decision maker. In this study the CR=0.05, and depend on Satty if CR $\leq$ 0.10 the ratio indicators a reasonable level of consistency in the pairwise comparisons. (Malczewski, 1999).

In this study perform a GIS Spatial analysis and 3D analysis using ArcView Model Builder Figures (3). In model builder process the convert these themes to grid themes using the Vector Conversion Process. Models are represented as sets of spatial processes, such as buffer, classification, and reclassification and overlay techniques. Each of the input themes is assigned a weight influence based on its importance, then the result successively multiplying the results by each of the constraints. This process is often used in site suitability studies where several factors affect the suitability of a site. (Esri, 2000). Then the GIS overlay process can be used to combine the factors and constraints in the form of a Weighting Overlay process. The result is then summed up producing a suitability map as shown by the formula;

$$\text{Suitability Map} = \Sigma \left[\text{factor map } (c_n) * \text{weight}(w_n) * \text{constraint}(b_{0/1}) \right]$$

Where,

c_n = standardised raster cell,

w_n = weight derived from AHP pairwise, comparison, and

$b_{0/1}$ = Boolean map with values 0 or 1

Figure (3) The potential land suitability for housing Modelbuilder process

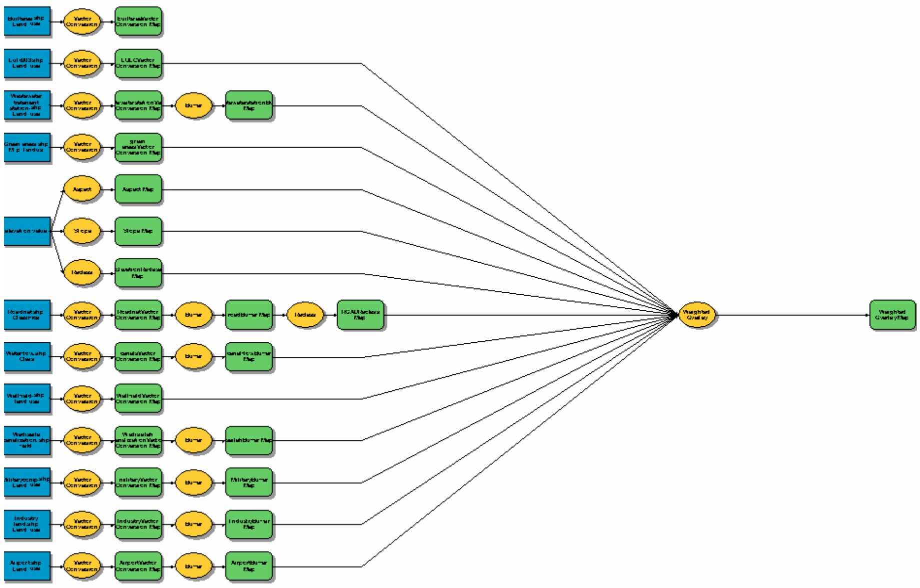


Table (2) Pairwise comparison matrix and weights of importance for the evaluation criteria[1]

	slope	elevation	Road proximity	aspect	landuse	weight	Lemda(λ)
slope	1	3	5	7	9	0.50	5.455432

[1] The importance of the criteria and sub-criteria was determined by the expert people in the Ministry of Housing and urban planning and from the objective of master plan in Sana'a city, Yemen.

elevation	1/3	1	3	5	7	0.26	5.43179
Road proximity	1/5	1/3	1	3	5	0.13	5.20352
aspect	1/7	1/5	1/3	1	3	0.07	5.029699
landuse	1/9	1/7	1/5	1/3	1	0.03	5.092594
sum						1.00	5.24

Table (2 -1) Pairwise comparison of sub-criterion to elevation factor

Category	range	score	class
1	2170-2300	5	Extremely suitable
2	2300-2350	4	High suitable
3	2350-2400	3	suitable
4	2450-2500	2	Moderate suitable
5	2500-2600	1	Less suitable
6	2600-3200	restricted	unsuitable

Table (2 -2) Pairwise comparison of sub-criterion to slopes factor

Category	range	score	class
1	0-5	5	Extremely suitable
2	5-10	4	High suitable
3	10-15	3	suitable
4	15-20	2	Moderate suitable
5	20-25	1	Less suitable
6	25 +	restricted	unsuitable

Table (2 -3) Pairwise comparison of sub-criterion to aspect factor

Category	range	score	class
1	North	1	Less suitable
2	East	5	High suitable
3	south	3	Moderate suitable
4	west	5	High suitable
6	flat	restricted	unsuitable

Table (2-4) Pairwise comparison of sub-criterion to road networks factor

Category	range	score	class
1	1000-2000	5	Extremely suitable

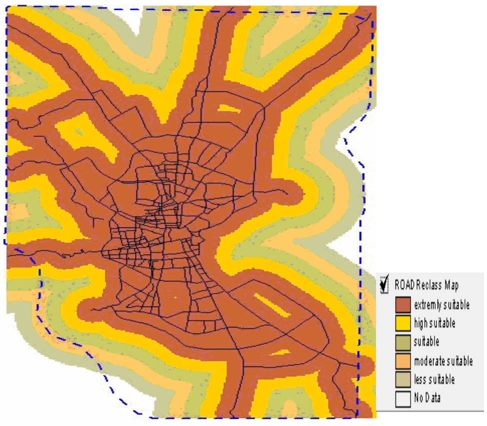
2	2000-3000	4	High suitable
3	3000-4000	3	suitable
4	4000-5000	2	Moderate suitable

Table (2 -5) Pairwise comparison of sub-criterion to land use factor

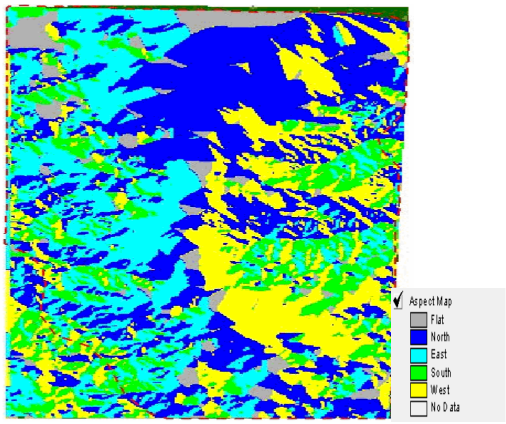
Category	**landuse**	**score**
1	Agricultural land	5
2	Built up area	restricted
3	Industry land	restricted
4	Military comp	restricted
5	Green area	restricted
6	Mountain	3
7	park	restricted
8	stadium	restricted
9	Wastewater treatment station	restricted

Figure (4) Criteria Layer Maps

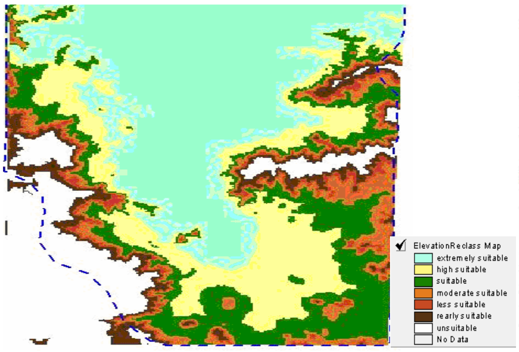
Criterion Map for Road Network suitability



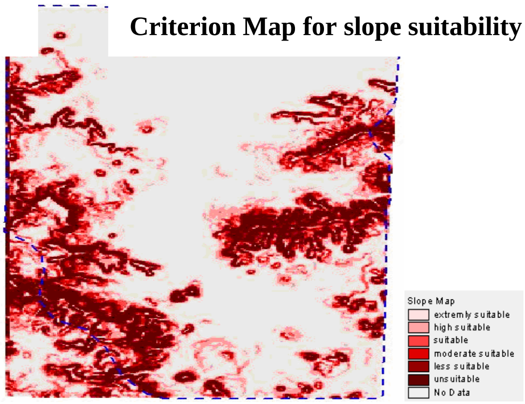
Criterion Map for Aspect suitability



Criterion Map for elevation suitability



Criterion Map for slope suitability



Criterion Map for landuse suitability

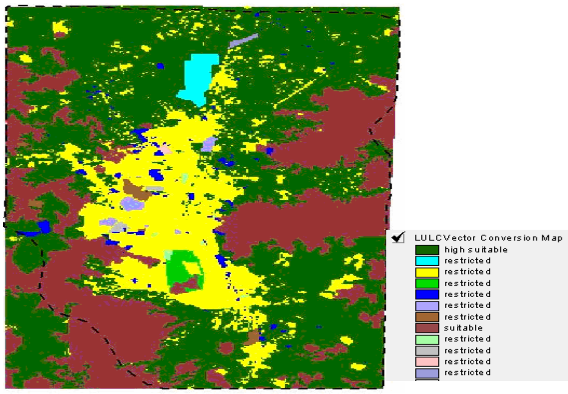
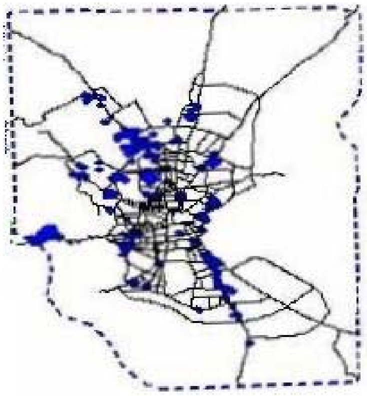
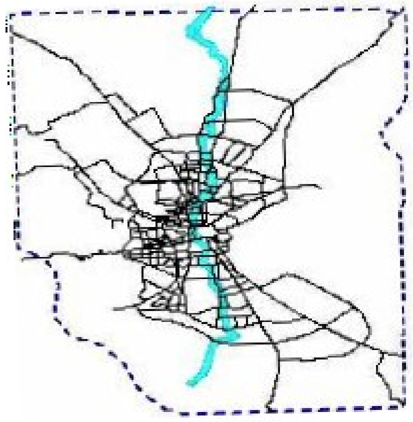


Figure (5) The constraint factors Maps

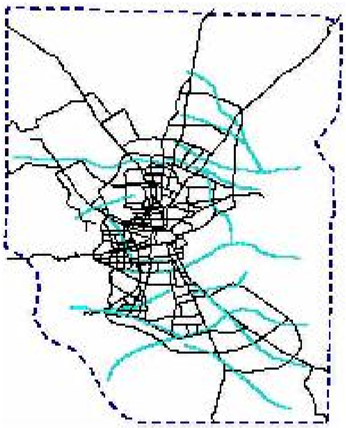
Industry buffer grid Map



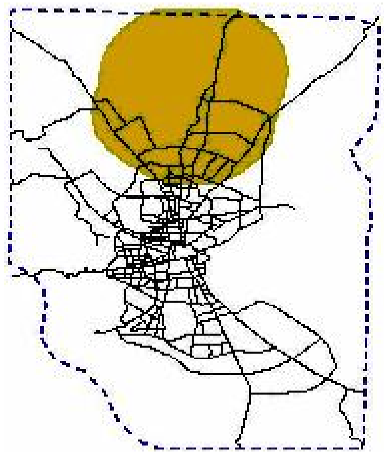
Wadi Sailah Grid Buffer Map



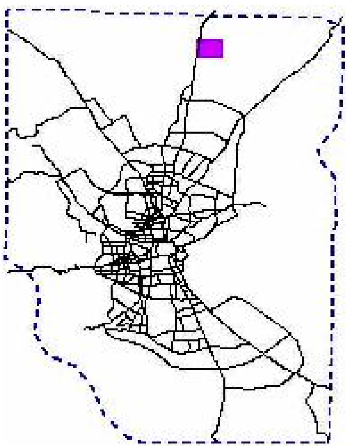
Canal buffer grid Map



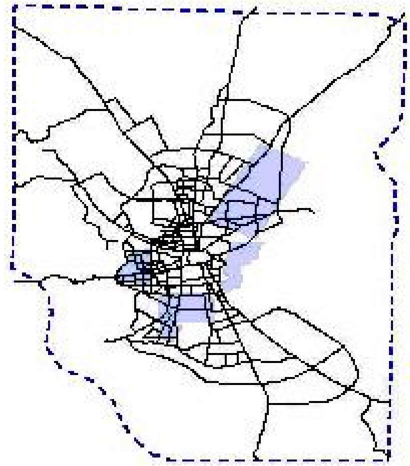
Airport buffer grid Map



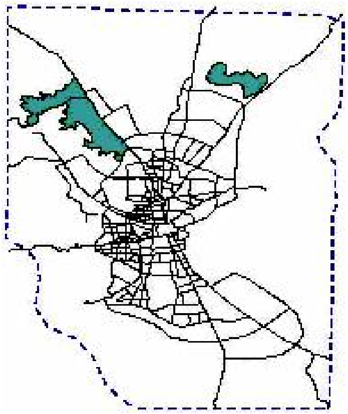
Wastewater station buffering map



Groundwater basin Map



Proposed Green Ares reservation map **Military comps buffering map**



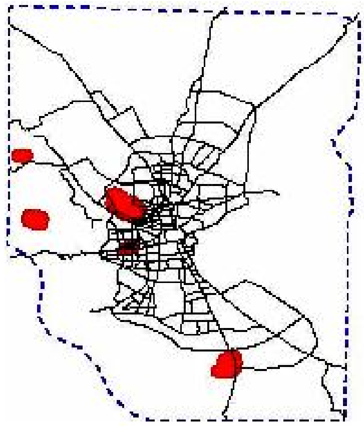
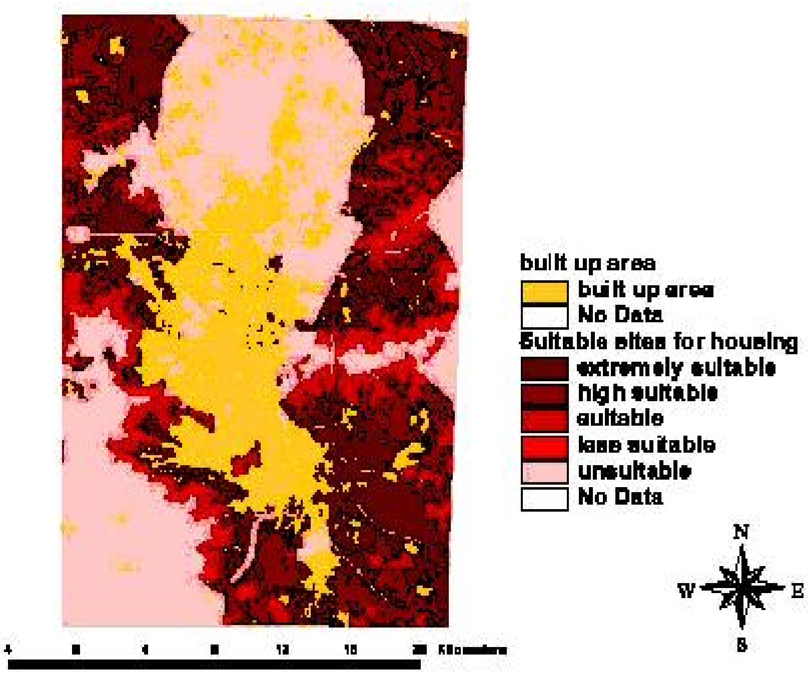


Figure (6) Land Suitability Map for Housing



CONCLUSION

Site selection is a crucial, multifaceted process that could significantly impact the profit and loss of capital investments. The proposed process includes four steps: establishment of suitability criteria, site screening, establishment of the AHP evaluation criteria, and site Evaluation. An integrated system was developed to aid the analyst in finding the optimum site for the facility sought. The system integrates two major tools (GIS and AHP) in a manner that reach the correct solution to assist the decision maker in determining appropriate values for the physical suitability criteria. The system was successfully tested in determining the optimum land suitability for housing.

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