GIS- based Land Suitability Analysis Using AHP for Public Parks Planning in Larkana City

Imtiaz Ahmed Chandio (Corresponding author)
PhD Student, Department of Civil Engineering, Universiti Teknologi Petronas
Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia
Tel: 60-12-279-6324 E-mail:imtiazutp@gmail.com

Abdul-Nasir Matori
Associate Professor, Department of Civil Engineering, Universiti Teknologi Petronas
Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia
Tel: 60-12-437-1617 E-mail:nasrat@petronas.com.my

Dano Umar Lawal
PhD Student, Department of Civil Engineering, Universiti Teknologi Petronas
Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia
Tel: 60-17-736-6200 E-mail:bblawaldano@gmail.com

Soheil Sabri
PhD Student, Department of Urban and Regional Planning, Universiti Teknologi Malaysia
81310, Skudai, Johor, Malaysia
Tel: +60127798025 E-mail: Soheilsabri@gmail.com

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Abstract

Optimal locations for public facilities such as public parks are significant issues in the urban planning of Larkana city. Therefore, specifically, Larkana city of Pakistan is selected as the study area where the land suitability model was applied to determine suitable land for public parks. This study was carried out within the framework of an Analytic Hierarchy Process (AHP) as a multi-criteria evaluation approach by integrating it with the Geographic Information System (GIS). Decision support system software called Expert choice 11.5 was used to calculate the weights based on three alternative scenarios. Computed composite weights were inserted into the spatial analysis function of GIS and produced three scenarios of suitability maps, i.e.: (a) land availability, (b) land value and (c) population density. Hence, based on the analysis and findings made in this research, finding suitable locations using the land suitability model for future park development is highly helpful. Results can be useful in the planning of public facilities and future land use planning in Larkana city.

Keywords: GIS, AHP, Expert choice, Land suitability, Optimal locations

1. Introduction

A built environment represents a high level of interference in the ecological system, changing the landscape and intervening with natural processes permanently. Parks are classified into two major categories, such as provision of recreation, services to society and conservation of natural values (Maruani and Amit-Cohen, 2007). Keeping in view, parks and green spaces control the rising temperature in urban areas and provide a healthy urban environment (Barbosa et al. 2007). In addition, less attention is paid to protect the urban parks (Thompson, 2002) and their sustainability (Chiesura, 2003). Uncontrolled human activities have increased tremendously. As a result, the existing parks and open spaces are encroached into a built environment in developing countries like Pakistan's cities (Adeel, 2010). Hence, the main objective of this paper is to identify and evaluate the existing public parks in Lankana City by finding the most suitable site to locate the public park based on an integrated GIS multi-criteria evaluation technique. There are various methods used in GIS in evaluating land suitability, e.g. Murrey, 2003 applied a location model; Graymore et al., 2009, produced an index of regional sustainability spatial decision support system; Saaty, R.W., 2003 and Abadi, 2007, used an analytic network process; and Mohit and Ali, 2006 integrated an analytic hierarchy process with GIS. In this study, a GIS-based AHP was used to determine land suitability for parks, which has been a very useful method over the years. GIS plays a vital role in planning for many decades of land-use suitability mapping and modelling (Malczewski, 2004 and Malczewski, 2006). This paper addresses a scientific approach to determine suitable land for healthy urban development. This approach will help in revision of policy and preparation of development plans in the study area and for other cities as well.

2. Study area

The study covers the locations of public parks for Larkana city of Pakistan. Larkana is the most important settlement in upper western Sindh; located at 27º 33´-north latitudes and 68 º 12´-east longitudes. The average population growth rate of Larkana experienced an increase of about 3.0% to 3.2% per year in the period of 1951 to 1998. Assuming the same growth rate, the population of Larkana will increase from 270,283 in 1998 to 400,550 in 2010 and 544,200 in 2020 (Larkana development plan, 2000-2020). The location map of Larkana city is shown in Fig. 1.

3. Methodology

The GIS- based land suitability analysis using AHP (Joerin et al., 2001) approach as the multi-criteria decision analysis (MCDA) was used in this research study. It allows integrated GIS-based land suitability modelling for site suitability (Mendoza, 1997). It is a logically ordered procedure that works by breaking down a problem into its smaller and smaller elements which helps decision makers all the way (Saaty, 1985). The AHP is a systematic method to guide decision-makers in making decisions to solve the problems based on priorities (Miller et. al., 1998). However, AHP manages the several criteria/factors of a problem into a hierarchy related to a tree form arrangement. The goal level is the uppermost level, which defines the problem. The second level is the level of criteria/factors comprising three aspects: land availability, accessibility and socio-economic. The third level consists of various sub-criteria/parameters. Figure 2 depicts the hierarchy structure of almost all the decision factors based on the expert's discussions, which were applied in this study. The relevant factors of the land suitability analysis were selected based on literature surveys and discussion with experts. Further factors were categorized into relevant parameters. Keeping in view, the alternatives (Scenarios) based on the criteria and parameters were determined using the pair-wise comparison matrix as shown in Table 4, 6, and 8.

3.1 Data collection

The spatial and non-spatial data was collected from the department of Town Planning, Hyderabad, and municipal authorities of Larkana, Sindh (Pakistan). The obtained data is shown in Table 1. It was easy to get data through formal requests. There were some limitations, e.g. time constraint and sensitive area information.

3.2 GIS data base development

GIS data base development of this study was developed by using criteria and sub-criteria that is indicated in Table 2. The base map of Larkana city was scanned and fixed geo-referencing to change it into earth coordinates, then it was digitized in ArcGIS 9.2 software to develop data layers.

3.3 Development of the pairwise comparison matrix

Matrixes of pairwise comparisons were created by the experts on condition that judgments are evaluated to find suitable alternatives to estimate associated absolute numbers from 1 to 9, the fundamental scales of the AHP (Saaty, 2007) exhibited in Table 3. Three alternative scenarios were produced by using AHP in the suitable site selection of parks. The AHP is the rational planning process in locating public facilities (Banai-Kashani, 1989).

3.4 Computation of the pairwise comparison matrix

Table 2 exhibits the criteria and sub-criteria, considered in land suitability analysis to create three alternatives (scenarios) by using the ArcGIS 9.2 spatial analysis tool, which includes (1) land availability, (2) land value and (3) population density.

The weights of factors and parameters were successfully calculated easily for land suitability with the Expert Choice 11.5 software (Lee and Chan, 2008), keeping in view the consistency ratio (CR). If CR is satisfactory, it does not exceed the desired range, i.e. >0.10. If the CR value is in an undesirable range, the obtained judgement matrix is needed to be reviewed till these values have improved and are satisfactory. The AHP software, Expert Choice can calculate automatically. Indeed, it was a time consuming procedure to compute the pairwise comparison matrix manually or in MsExcel. Therefore, Expert Choice is a multi-objective decision support tool based on AHP (Saaty, 2003).

Later on, to compute composite weights, Eastman et al., 1995 stated two procedures for multi-criteria evaluation: the concordance discordance analysis and the weighted linear combination. The function of a weighted linear combination (WLC) procedure where each factor and parameter (Vi) are multiplied by the weight of the suitability parameters (Wi) to get composite weights and then summed as shown in Table 4, 6 and 8. WLC is a straight forward linear method calculating composite weights. Similarly, the results of composite weights based on alternatives (scenarios) were used in a weighted sum spatial analysis function. This function multiplies and sums up the layers to produce scenarios suitability maps for parks which are presented in Fig. 3, 4 and 5.

Therefore, the weighted linear technique (Mendoza, 1997; Mohit and Ali, 2006) was applied to yield a suitability map by the following formula:

$$E = \sum_{i=1}^{n} wi * vi \quad (1)$$

Where: Wi = relative importance or weight of factors/parameters i,

Vi = relative weight of parameters i,

and n = total number of parameters related to the study.

4. GIS based Land Suitability Analysis

The land suitability analysis was performed in the raster format. The raster data model is the more suitable technique because the structure of raster data is grid cell based, which can easily delineate suitable sites. Raster data facilitates the user in carrying out a weighted overlay on numerous layers. Suitability maps were created under a raster GIS environment, based on various scenarios. The suitability for each land use was analyzed in ArcGIS 9.2 to locate suitable areas for parks.

5. Results and Discussion

The AHP method was used to evaluate the priority weight of each factor and sub-criteria (parameters). AHP and the Geographic Information System (GIS) are an integrated technique used to assess suitable land for public parks in Larkana City (Thapa, 2008). The derivation of relative composite weights of land suitability factors and parameters based on land availability scenario 1 was calculated as presented in Table 4. In a similar way, scenario 2, land value; and scenario 3, population density, were also analyzed and mentioned in Table 6 and Table 8. The cell size was (5x5) and total grid cells were (388,377) for this study area. The land suitable for public parks based on AHP by using GIS in scenario 1 results in; out of 388,377 grid cells, 383,39(10% or 95.8 hectares) are potential land, 246,353 (63% or 615.8 hectares) are least potential land and 103,685(27% or 259.2 hectares) are constraint; this is depicted as degree of land suitability scenario1 in Table 5. Fig. 3 shows the potential areas for different land uses based on scenario 1 in the city.

In degree of land suitability scenario 2: 247,692(64% or 619.2 hectares) of the grid cells are potential land, 56,763(15% or 141.9 hectares) are least potential land and 83,922(21% or 209.8 hectares) are constraint; this is shown in Table 7. Potential land based on the land value scenario in the city is presented in Fig. 4. Finally, 270,033(69% or 675 hectares) are potential land, 100,778(26% or 251.9 hectares) are least potential land and 17,566(5% or 43.9 hectares) are constraint out of 388,377 grid cells as illustrated in Table 9 degree of land suitability scenario3. Fig. 5 shows the potential areas based on the land density scenario in the city.

5.1 Evaluation of potential land based on scenarios

All three scenarios were combined to determine potential land. As stated in Table 10, 256,698 grids (66% or 641.7 hectares) are potential land, 58,185 grids (15% or 145.4 hectares) are least potential land and 73,494 grids (19% or 183.7 hectares) are constraint for parks development. Fig. 6 illustrates the potential land map for parks in Larkana City.

5.2 Evaluation of most suitable land for parks based on scenarios

It is shown in Table 11 that 4,543 grids (1.2% or 11.3 hectares) are most suitable, 514 grids (0.2% or 1.2 hectares) are least suitable and 383,320 grids (98% or 958.3 hectares) are not suitable for parks planning. Furthermore, Fig. 7 shows the most suitable land for parks.

GIS-based AHP as a multi-criteria evaluation approach was applied in the present study. The main advantage of this appraoch is that it can be done quickly utilizing the data processing and capabilities of GIS in the land use decision making process (Store, 2001). Therefore, the results of this study will be useful with GIS-based land suitability analysis modelling in land-use planning and development plans in the future. The development plans can be successful if this study methodolology is included in the planning process.

6. Conclusion

This study has focused the use of integrated multi-criteria AHP with GIS to determine the suitability of the land for parks in the city of Larkana. The sustainable planning approach has not been considered before in urban development that is needed essentially for growth of the city. However, GIS-based AHP as MCDA in the land suitability analysis approach can be useful to determine suitable land in urban development. Planning standards of optimal locations are not the only important consideration in the planning process, but also sustainable distances from facilities to people should also be considered. The results show that scenario 3 (Population density) obtained the highest percentage of potential land (69%), while scenario 2 (land value) obtained 64% and scenario1 (Land availability) 10%.

This study can provide a framework for the planning process by using GIS and the multi-criteria decision analysis making (MCDM) approach for Larkana city planning. Therefore, this study presented the advantages of integrated GIS-based land suitability analysis and a solution for such complicated decisions. It can also provide an important guidance for future land use changes and cost effective solutions in the cities, where conditions are similar as in Pakistan.

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Table 1. Data types and sources

Data	Types	Sources
Base map (Land- uses)	Spatial	Town planning department, Hyderabad
Land value	Non-spatial	Market survey, Municipal authority
Population density	Non-spatial	Development plan of Larkana city (2000-2020)
Income level	Non-Spatial	Development plan of Larkana city (2000-2020)

Table 2. Criteria and sub-criteria/parameters (Vi)

Criteria/Factors	Sub-criteria(Parameters)		
Land Availability	Vacant land	Public	
		Private	
	Existing Parks		City Parks
			Mohalla Parks
Land Price/Value	Land value (sq. ft)		High
			Medium
			Low
Accessibility	Roads	Major Roads	
		Local Roads	
Socio-Economic	Population Density	High	
		Medium	
		Low	
	Income group/level	High	
		Middle	
		Low	

Table 3. AHP Scale of Relative Importance

Intensity of relative importance	Definition	Explanation
1	Equal Importance	Two activities combine equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favour one activity over another.
5	Essential or strong importance	Experience and judgment strongly favour one activity over another.
7	Demonstrated importance	An Activity is strongly favoured and its dominance is demonstrated in practice.
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed.
Reciprocals of above non-zero numbers.	If an activity has one of the above numbers (e.g. 3) compared with a second activity, then the second activity has the reciprocal value (i.e.1/3) when compared to the first.	

Source: Saaty (1985)

Table 4. Derivation of Relative Composite Weight of Land Suitability Factors and Parameters based on Land availability Scenario (Wi)

Criteria/ Factors	**Sub-criteria(Parameters)**		**Composite weight (Wi)**	**Weight (Wi)**
Land Availability	Vacant land	Public	0.28	28
		Private	0.06	6
	Sub-total		0.34	34
	Existing Parks	City Parks	0.07	7
		Mohalla parks	0.04	4
	Sub-total		0.11	11
Land Price/Value	Land Value (sq/ft)	High	0.02	2
		Medium	0.04	4
		Low	0.07	7
	Sub-total		0.13	13
Accessibility	Roads	Major Roads	0.05	5
		Local Roads	0.12	12
	Sub-total		0.17	17
Socio-Economic	Population Density	High	0.08	8
		Medium	0.05	5
		Low	0.03	3
	Sub-total		0.16	16
	Income group/level	High	0.03	3
		Middle	0.04	4
		Low	0.02	2
	Sub-total		0.09	9
Total Weight age(∑wi=1.0)			1.00	100

Table 5. Degree of Land suitability scenario1 (Land availability)

Degree of Suitability	**Scenario1**		
	Grid Cell Nos.	Area (Hectares)	Percentage
Potential	38,339	95.8	10
Least potential	246,353	615.8	63
Constraint	103685	259.2	27
Total	388,377 (100)	970.9	100

Table 6. Derivation of Relative Composite Weight of Land Suitability Factors and Parameters based on Land value Scenario (Wi)

Criteria/Factors	**Sub-criteria(Parameters)**		**Composite weight (Wi)**	**Weight (Wi)**
Land Availability	Vacant land	Public	0.14	14
		Private	0.02	2
	Sub-total		0.16	16
	Existing Parks	City Parks	0.06	7
		Mohalla Parks	0.04	4
	Sub-total		0.1	10
Land Price/Value	Land Value (sq. ft)	High	0.05	5
		Medium	0.17	17
		Low	0.29	29
	Sub-total		0.51	51
Accessibility	Roads	Major Roads	0.03	3
		Local Roads	0.07	7
	Sub-total		0.1	10
Socio-Economic	Population Density	High	0.03	3
		Medium	0.05	5
		Low	0.01	1
	Sub-total		0.09	9
	Income group/level	High	0.01	1
		Middle	0.02	2
		Low	0.01	1
	Sub-total		0.04	4
Total Weight age (∑Wi=1.0)			1.00	100

Table 7. Degree of Land suitability scenario 2 (Land value)

Degree of Suitability	**Scenario 2**		
	Grid Cell Nos.	Area (Hectares)	Percentage
Potential	247,692	619.2	64
Least potential	56,763	141.9	15
Constraint	83,922	209.8	21
Total	388,377 (100)	970.9	100

Table 8. Derivation of Relative Composite Weight of Land Suitability Factors and Parameters based on population density scenario (Wi)

Criteria/Factors	Sub-criteria(Parameters)		Composite weight (Wi)	Weight (Wi)
Land Availability	Vacant land	Public	0.12	12
		Private	0.02	2
	Sub-total		0.14	14
	Existing Parks	City Parks	0.04	4
		Mohalla parks	0.02	2
	Sub-total		0.06	6
Land Price/Value	Land value (sqft)	High	0.01	1
		Medium	0.1	10
		Low	0.1	10
	Sub-total		0.21	21
Accessibility	Roads	Major Roads	0.03	3
		Local Roads	0.05	5
	Sub-total		0.08	8
Socio-Economic	Population Density	High	0.19	19
		Medium	0.11	11
		Low	0.05	5
	Sub-total		0.35	35
	Income group/level	High	0.02	2
		Middle	0.05	5
		Low	0.09	9
	Sub-total		0.16	16
Total Weight age (∑Wi=1.0)			1.00	100

Table 9. Degree of Land suitability scenario 3 (Population density)

Degree of Suitability	Scenario 3		
	Grid Cell Nos.	Area (Hectares)	Percentage
Potential	270,033	675	69
Least potential	100,778	251.9	26
Constraint	17,566	43.9	5
Total	388,377 (100)	970.9	100

Table 10. Land suitability for Public parks

Land for parks development.	Grid Cell Nos.	Area(Hectares)	Percentage
Potential	256,698	641.7	66
Least potential	58,185	145.46	15
Constraint	73,494	183.7	19

Table 11. Most suitable land for Parks

Land for Parks development	Grid cell nos.	Area(Hectares)	Percentage
Not suitable	383,320	958.3	98.6
Least suitable	514	1.2	0.2
Most suitable	4,543	11.3	1.2

Figure 1. Location map of Larkana city

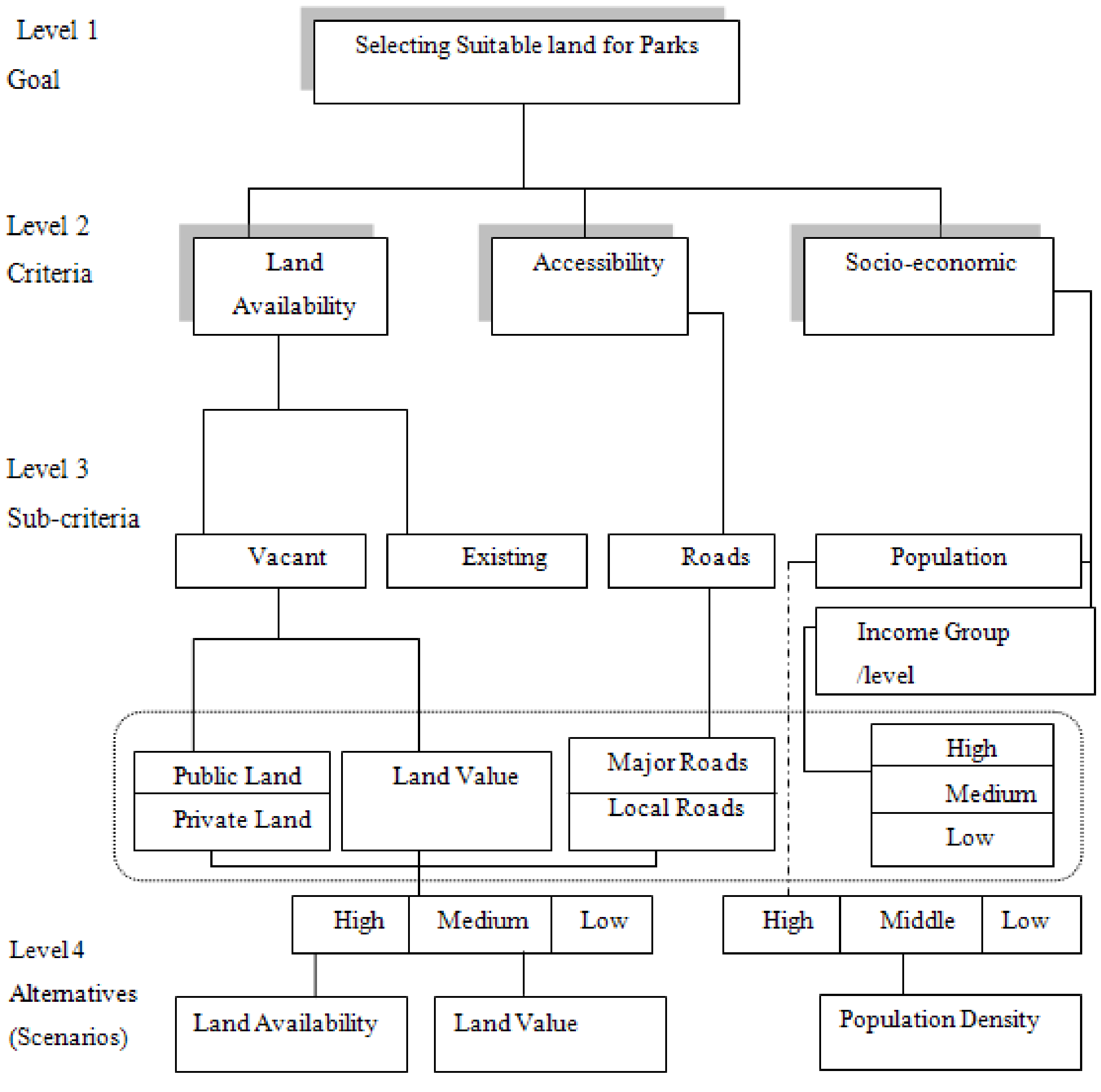

Figure 2. Hierarchical Structure Model of Selecting suitable Land for Parks

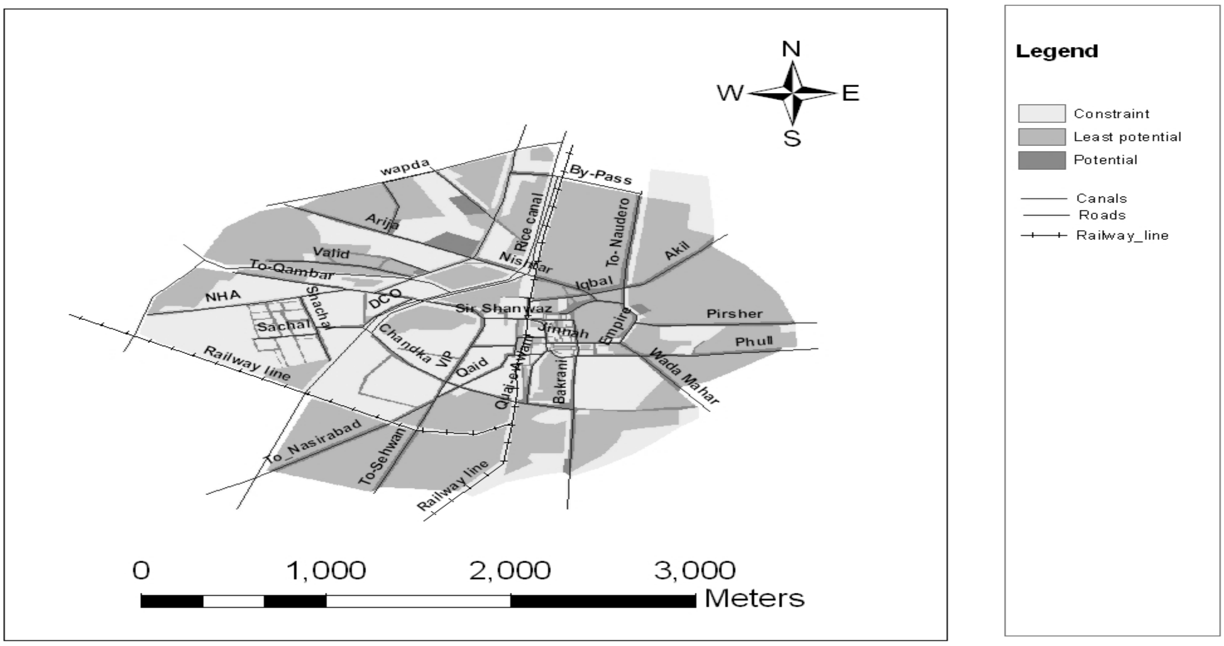

Figure 3. Scenario1 (Land availability)

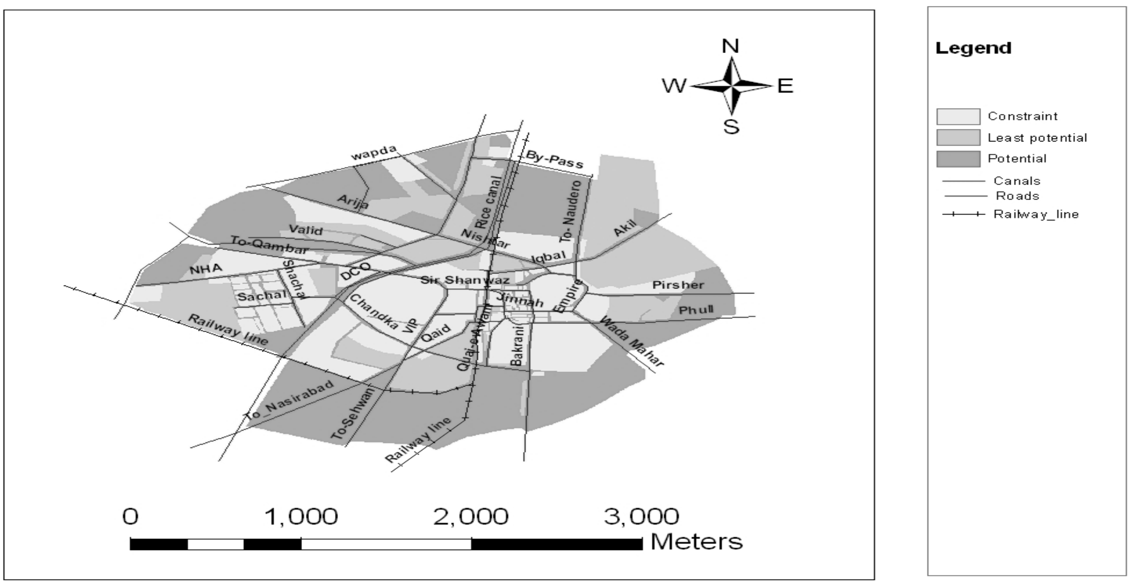

Figure 4. Scenario 2 (Land value)

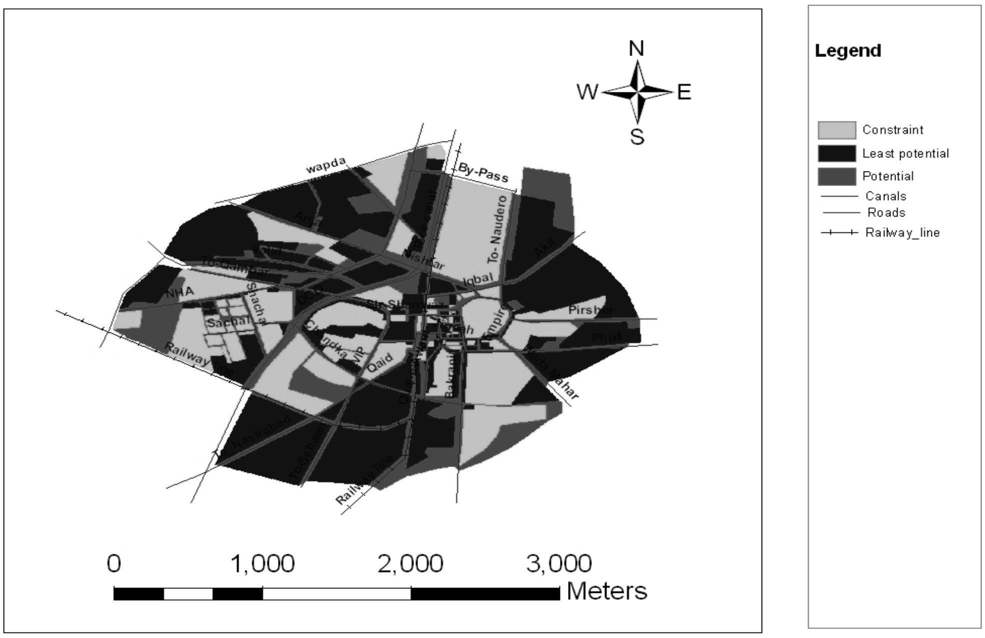

Figure 5. Scenario 3 (Population density)

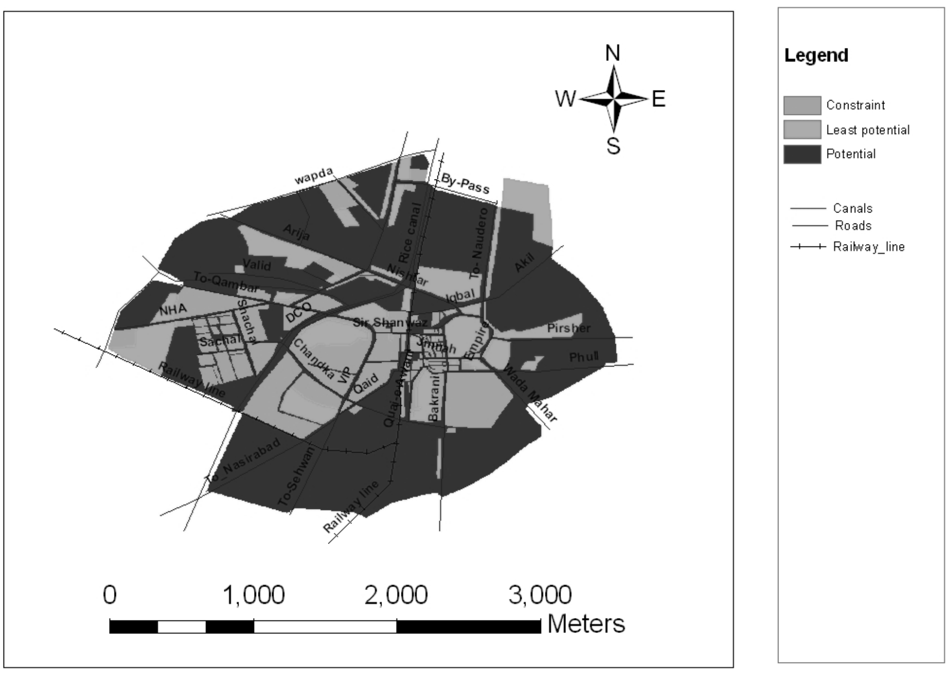

Figure 6. Potential land for parks in Larkana City

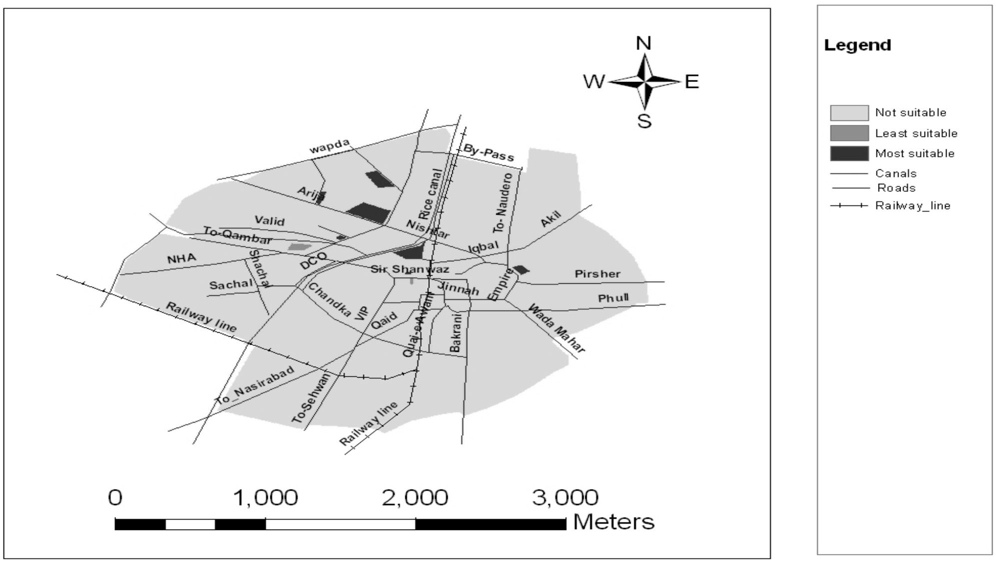

Figure 7. Most suitable land