Green Space Suitability Analysis Using Evolutionary Algorithm and Weighted Linear Combination (WLC) Method

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Abstract

With current new urban developments, no balance can be found between green spaces and open areas present within urban networks and natural land patterns since urban networks are dominating ecological networks. Accordingly, one of the major tasks of urban and regional planners is the optimal land use allocation to urban green spaces. Therefore, to achieve this goal in this research, locations of new parks(basis on physical, social and economical factors) were analyzed using weighted linear combination (WLC)techniques and evolutionary algorithms. After comparing the results of the two methods, suitable locations for the development of urban green spaces on a local scale were proposed, on the basis of which it was found that heuristic algorithms have good potential to work with spatial data and evaluate land use suitability since they obtain better solutions with greater accuracy and flexibility in less time. Afterwards, suitability analyses of existing local parks(basis on physical, social , economical and ecological factors) were performed using the WLC method and Fragstats software. It was discovered that the existing parks are not on a suitable level based on the study criteria. Therefore, it is suggested that newer parks be established in areas with greater potential and small green spots as well asin the northern parts of the city for improvement.

Keywords: Suitability Analysis, Site Selection, Genetic Algorithm; Local Park, Weighted Linear Combination

1. Introduction

With the increasing population's demand for urban areas, some ecological and environmental functions move towards improving the quality of life (Jim and Chen, 2008). Today, however, no equilibrium is observed between urban networks and natural land patterns in the process of urbanization in terms of urban green spaces and open areas; urban networks are dominating ecological networks(Thaiutsa et al., 2008). This issue by itself has caused the underlying loss of inner-city green spaces and land use changes that might lead to specific global environmental problems such as the formation of urban heat islands(Botequilha Leitão and Ahern, 2002). Meanwhile, green spaces play a decisive role in supporting urban social and ecological systems(Barbosa et al., 2007). Therefore, cities now require that particular attention be given to the revival of urban natures, since the presence of nature in a city based on extent, composition, and necessary and sufficient distribution is a requirement of sustainable development.

This is very important for improving the quality of life in urban areas by making them more ecologically sustainable. One essential task of urban and regional planners is allocating urban land to different uses. In fact, land use planning means the optimal allocation of land resources. Land use as a constructive component of urban spatial structure plays a unique role in the creation and suitability of this structure. Optimal location of urban green spaces with respect to ecological and social functions on different local to regional scales of performance is indispensable. Therefore, because of the importance of urban green space, this land use was selected from among other urban land uses for this study. To assess the suitability and locations of local parks, multi-criteria analysis techniques were employed with the help of Geographical Information System (GIS), ecological status analysis within the Fragstats software environment, and evolutionary algorithms in MATLAB software. A flowchart of the study process is shown in the following figure1.(Fig. 1).

1.1 The use of Weighted Linear Combination (WLC) Method for land use location

Urban land suitability analysis(LSA) makes the basis for urban land use planning(Lianget al., 2007). Suitability analysis is a process to determine whether a land resource is suitable for a particular use. With this method, land is studied by such features as hydrology, topography, geology, etc(Manlun, 2003). Therefore, this method is beneficial for making suitable land use decisions and promoting its social values. The modeling process of this method is shown in the Fig.2 (Malczewski, 2004).

In this context, the mentioned method, known as the weighted linear combination method, was applied to analyze the suitability of local parks and the locations of suitable sites for the development of urban green space systems so as to estimate the potentials of different areas for green space development based on local conditions,

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identify the existing problems by analyzing the suitability of the present parks, and provide suggestions for having a sustainable urban green space system with maximum performance.

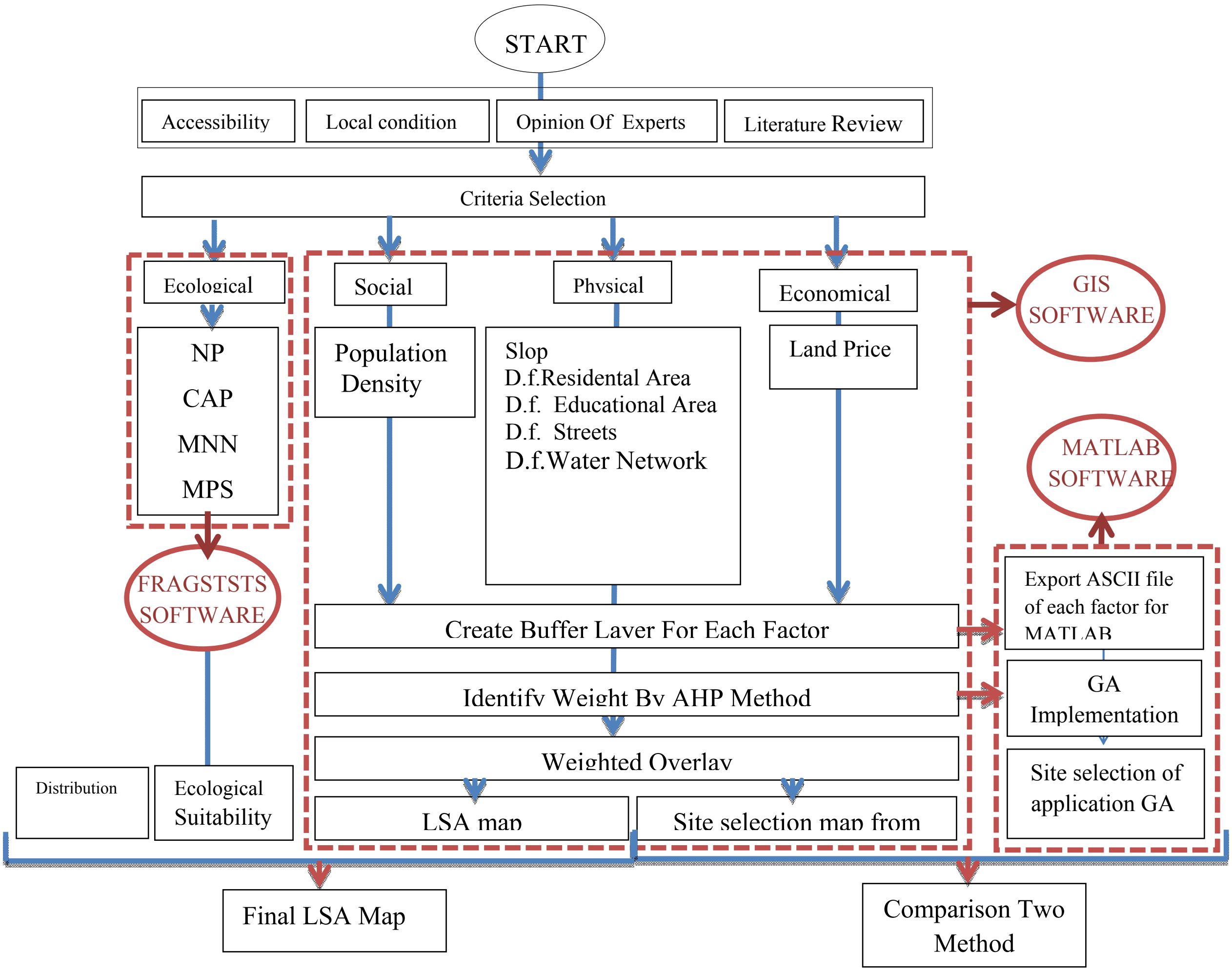

Fig. 1. Research flowchart.(Source:The Authors)

Recent advances in information technology, especially the Internet and artificial intelligence(AI), have led to the development of new approaches to land use suitability analysis based on GIS(Collinset al., 2001; Yang et al., 2007). In this article, evolutionary algorithms were utilized as the second method of locating local parks in order to determine this method's efficiency in the study issue by comparing its results with results obtained with the WLC technique.

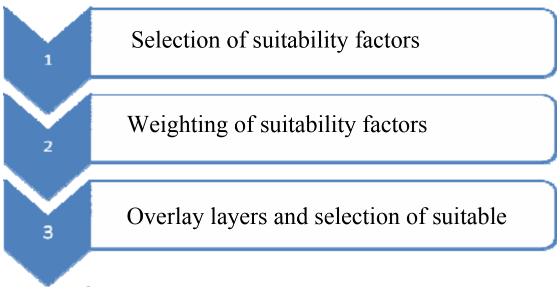

Fig. 2.The process of weighted linear combination (WLC) Method. (Source:The Authors)

1.2 The use of heuristic algorithms for land use location

There is a growing movement towards using artificial intelligence (AI) tools for land use location and identification based on GIS and modeling applications(Collins et al., 2001). This research is directed towards a foundation for the development of AI technology to solve land use planning and suitability problems. Heuristic search techniques include algorithms created via inspiration by physical and biological processes in nature. Unlike classical methods, these methods are random-based, doing space searching in parallel, and only use the fitness function to guide the search.

Genetic algorithms are a family of heuristic algorithms optimized based on random search. The main component of evolutionary algorithms is the chromosome, representing a solution in the search space of an optimization problem. Each chromosome consists of genes, each of which describes a problem parameter. large-scale combinational problems(Jaramillo et al., 2002), and their success in doing so has led to a selection of algorithms for solving such problems(Eldrandaly, 2010). Work stages for a genetic algorithm are as follows: generation of random initial population, calculation of objective function value for each element of population, selection of next generation members, use of the original operators of crossover and mutation algorithms to multi-objective land use optimization. Li andYeh (2005)investigated a combination of genetic algorithms and GIS to search for an optimal location.

(Ponjavic and Karabegoviv,2006)employed GIS and a genetic algorithm to determine land multi-criteria value in a spatial planning. (Matthews and et al, 2006) applied computer-based and genetic algorithm methods for multi-objective land use planning.(Ducheyne and et al, 2006) investigated a spatial approach to forest management optimization with linking GIS and multi-objective genetic algorithms.(Datta ,2007) studied multi-objective land use planning to locate resources and manage land use using genetic algorithms.To see recent works in this field, the following can be noted: (Zhanget al., 2010; Caoet al.,

These algorithms are powerful tools for solving complex

produce the next generation, and repetition of the solution process until the stop of the algorithm conditions(Goldberg, 1989).

Applications of GA in GIS-based land suitability analysis have become greatly popular in recent years(Krzanowskiet al., 2001), some research of which are noted as follows. In 2001, Matthew addressed the issue of evolutionaryalgorithms in a 2012; Liuet al., 2014; Stewart and Janssen, 2014; Shayganet al., 2014; Liu et al., 2015).

According to the information presented in this study, local parks in the city of Birjand were located using genetic algorithm capabilities based on physical, social and economical factors. The results were compared with the results of the WLC technique to determine accuracy.

2. Materials and Methods

2.1 Site description

South Khorasan Province is located in the northeast margin of Dasht-e-Lut in the east of Iran(Fig.3).

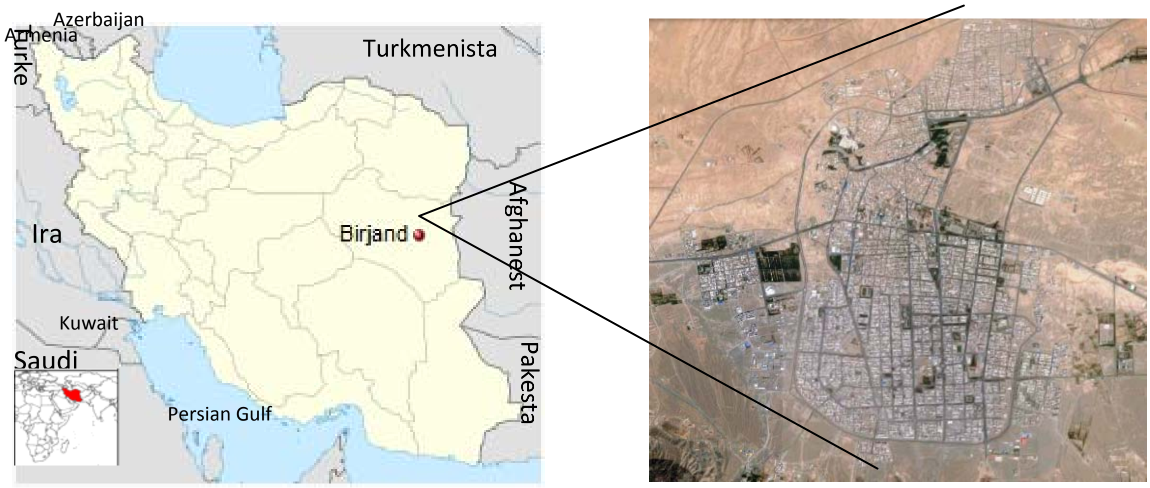

Fig. 3.Location of Birjand city. (Source:The Authors)

Birjand City as its capital has an area of 14,265 km^2 located within the coordinates of 32˚ 53' north latitude and 59˚ 12' east longitude. The city is located near the center of the Birjand Plain and is surrounded by mountain ranges. According to the 1390 population and housing census, 259,506 people live in this city. Generally, it can be said that it has a cold and dry climate with a high day and night temperature difference(-15 to 42 °C), low relative humidity(18.8-57.7), and low rainfall(0.9-92.4mm). More than 90% of the water needed for the area is supplied by underground water reserves. Consequently, the sources of water for irrigation are wells in Birjand. The information relevant to the present green spaces is mentioned in Table1.T wenty-two local parks exist in the city, the locations of which are shown on Fig.4 .

3.

Fig. 4 .Location of local parks in Birjand City
(Source:The Authors)

3.Research methodology

3.1. Land suitability analysis and site selection using WLC method

Site information can be analyzed using GIS based on land suitability analysis(Krzanowski et al., 2001). LSA is supported by GIS spatial analysis functions through the following steps:

- Selection of suitability criteriaThe keys for land suitability analyses and sit selection are the criteria for appropriately assessing the different study

Table 1
Areas of different types of green spaces

Type	Area(m²)
Areas of different types of street green spaces	910642.44
Areas of planted forests	417081.9
Areas of private gardens	1866501
Areas of children's playing spaces in public parks	34478.85
Per capita of urban public parks	3.95
Per capita of total urban green space	11.16
Urban green belt area	70000

(Source:The Authors)

Table 2
The criteria for site selection and the suitability analysis of urban parks

Criteria	Factor		Description
Criteria for suitability analysis of urban parks / Criteria for site selection of urban parks	Physical factors	D.f.water supply network	Proximity to sources of irrigation water to reduce transfer costs is essential for locating urban parks, especially in Birjand City, which is an arid area facing water shortages and for which the need for further proper management is felt.
		Slope	The most appropriate slope for building a park is 2-15%.A gradient of 0-2 % is not suitable due to drainage problems. In general, the limiting factors are not serious, because the slope can be properly used by suitable designs to add more beauty to parks.
		D.f.the main street	Easy access to parks and the possibility of monitoring them and maintaining their security for citizens will be required in addition to the passersby's aesthetic use of park nature and services.
		D.f. cultural and educational centers	The main objective is to ensure their proximity and high compatibility with each other, while creating a healthy environment for students and employees and for visitor revitalization at these centers.
		D.f.residential areas	Residential land use account for the most important urban land use on which living facilities are required to be based, and parks should be established close to them for relaxation and recreation.
	Economical factors	Land price	Due to the impact of land prices on urban parks, it is necessary to pay attention to their economic aspects.
Criteria for suitability analysis of urban parks	Social factors	Population density	Access to this sort of land use by a greater number of citizens and focus on the crowded places can be considered as a measure.(Schipperijn et al., 2010)
	Ecological factors(Botequilha Leitão and Ahern, 2002)	CAP	Class area proportion: The percentage of each land use or cover is assessed by the landscape.
		NP	Number of Patch:The number of spots for specific land use.
		MPS	Mean Patch Size: Average spot size calculates the average size of a spot from among a class of patches.
		MNN	Mean Nearest Neighbor :Average nearest-neighbor distance calculates the average distance between 2 similar spots.
	Distribution	Area effected by local park	It is necessary to consider the proper distribution of parks and green spaces in the city determined by the level of service provided.

(Source:The Authors)

areas(Daizhi, 2009). Each factor is presented by a GISthematic map. Usually, Suitable sites for specific land use are selected based on literature review, local condition(Baycan-Levent and Nijkamp, 2009), opinion of experts and accessibility.

After the literature was reviewed(Botequilha Leitão and Ahern, 2002; Imaoka et al., 2005.; Zucca et al., 2008)and data access, local condition and opinion of experts was considered, the criteria for site selection and the suitability analysis of urban parkswere collected as shown in Table 2.

- **Map preparation for each of the determined criteria**

Buffer maps were prepared for each of the parameters of distance from residential areas, distance from water supply network, distance from access network, and distance from cultural and educational centers. Maps of

- **Weighting of suitability factors using AHP technique**

population, land price, and slope were also prepared (Fig. 5 to Fig. 11), for use in the final suitability map (The numbers of buffer loops and classes must be equal. Here, 6 loops were considered).

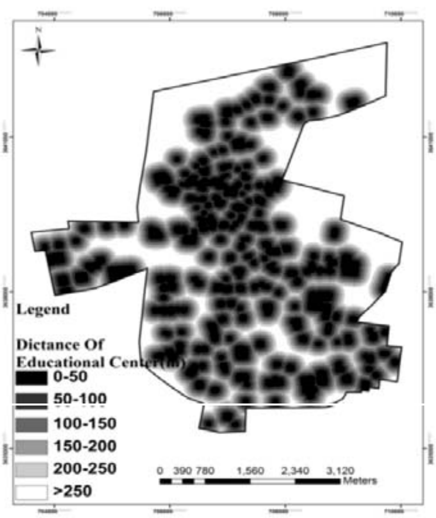

Fig. 5. Distance of cultural and educational centers

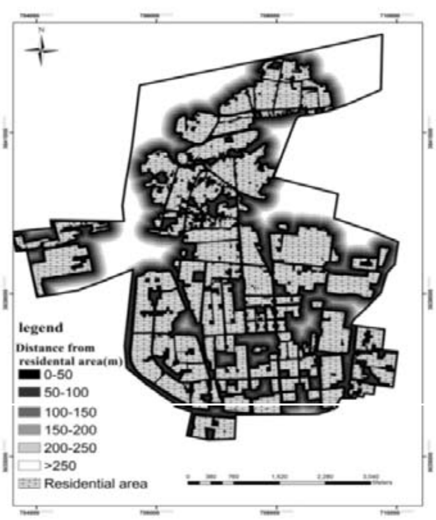

Fig. 6 .Distance of residential areas

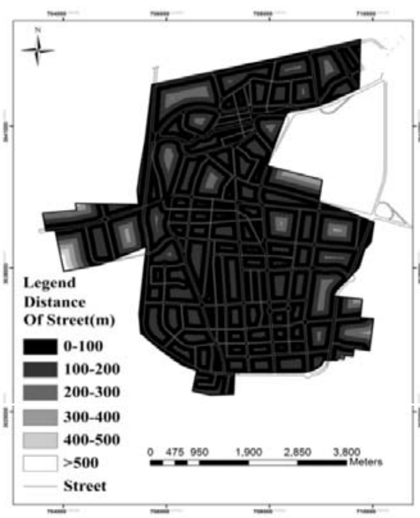

Fig.7.Distance of streets

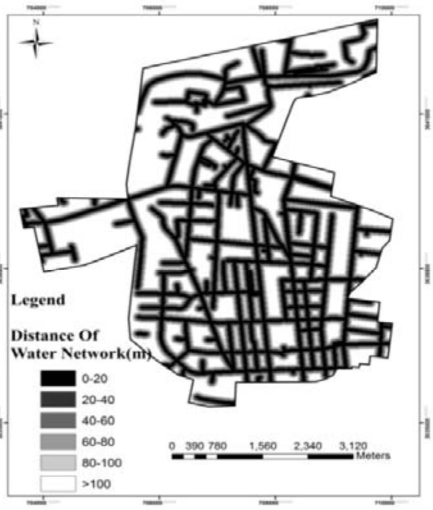

Fig.8.Distance of water network

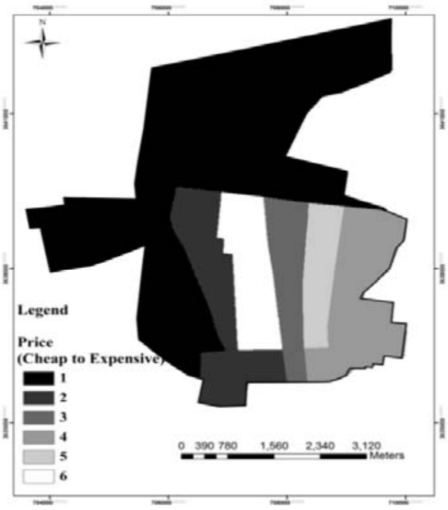

Fig.9.Price land

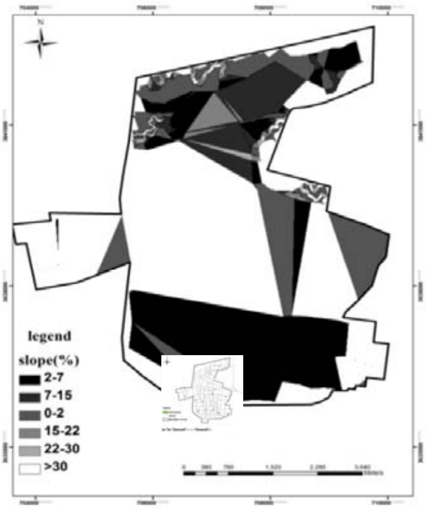

Fig.10.Slop

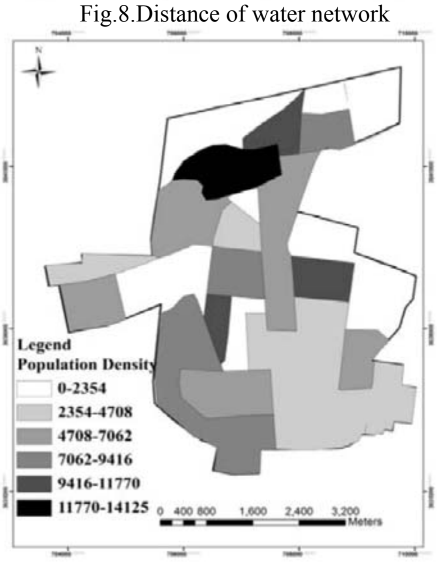

Fig. 11.Density population

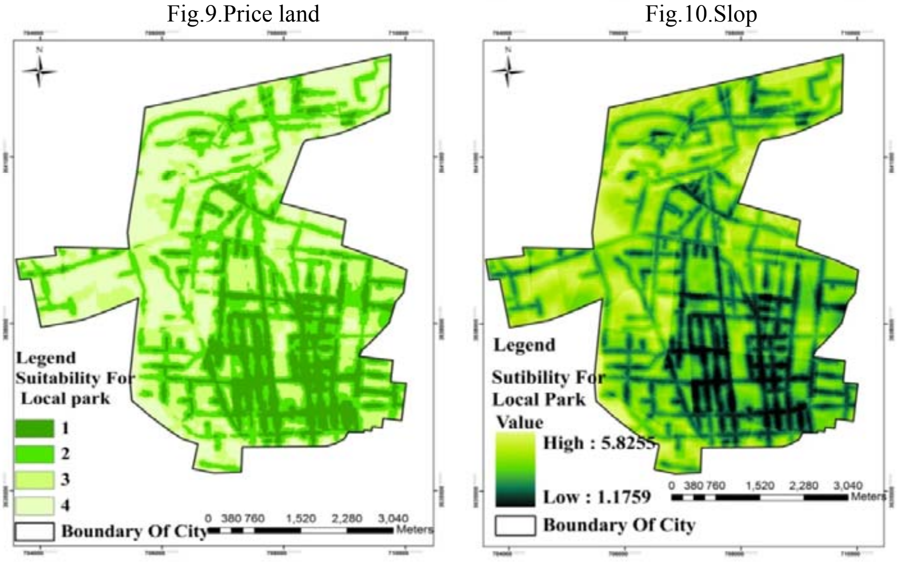

Fig. 12.Suitability maps for local park(classified and integrated map)

After the map needed for raster multiplication was prepared, eachfeature weight was determined using the AHP (Analytical Hierarchy Process) technique(Saaty, 1980). To this aim, several questionnaires were prepared and 15 experts (2 academic groups and green space executive directors) were asked to assign a weight to each factor based on their desired priorities for this ground. After collecting data from the questionnaires, the mean of the total votes was calculated and then computations, the weight of each factor was obtained. Their order of priority was: distance from water supply network(0.3019), distance from cultural and educational centers(0.1888), population(0.176), land price(0.1641), proper slope(0.1161), distance from the main road(0.0349), and distance from residential areas(0.0183). For CR(Consistency Ratio), zerowas obtained. Therefore, the results were acceptable.

- Integration of data layers and selection of suitable zones

With the advent and rapid development of GIS, land suitability analysis is widely utilized in urban planning and site selection for special uses since it can improve efficiency assessments. One of the main functions of spatial analysis in GIS is the overlaying procedure associated with land suitability analysis, etc., to evaluate multiple factors. Overlaying was done for local park uses after calculating the weight of each factor and the map of suitability, by which the final fitness was obtained.

3.2- Location of local parks using genetic algorithm

To implement the algorithm on a region, it was described as a two-dimensional grid so that every unit location was given as (i, j). In this study, Birjand City was created as a grid form of 10 m accuracy with 752 × 642 columns and rows of cells, respectively. Then, each layer of location factors was converted to an ascii file and imported into the MATLAB environment. The weights obtained by AHP to represent the importance of each factor are among the other components needed to implement the algorithm. For each of the effective factors, the mathematical form can be shown so that each cell value in proportion to its suitability, which was encoded from 1 to 6 in this study, is put in the relevant factor matrix to create the local parks. Decision variables are the same suitability classes.

$$\text{LSA} = \begin{bmatrix} lsa11 & \cdots & lsa1n \\ \vdots & \ddots & \vdots \\ lsa1m & \cdots & lsamn \end{bmatrix} lsa \in \text{LSA}$$

$$lsa = \{1,2,3,4,5,6\}$$

In this work, to perform the genetic algorithm, a population size of 100, a generation number of 2000, a combined rate of 0.9, and a mutation rate of 0.1 were considered. Each chromosome consisted of 25 genes or pixels. To find the fitness value of the points, each point was regarded within a pixel range of 10 × 10 m. With regard to the assumption that the minimum necessary area for the local parks was 10000 m^2 and based on an area of 100 m^2 designated for each cell, the algorithm was asked to select 10 pixels in the x direction and 10 pixels in the y direction based on the desired central cell to evaluate each cell and calculate the sum of the objective functions all together. Areas of less than this value could not be used for local parks. In order to shorten the running time of the program, the actual coding method was used instead of binary coding.

The objective function was defined as the suitability maximization of each cell to create local parks based on physical, social and economical factors. A site's suitability can be interpreted as fitness for a certain use(Steiner, 2012). Fitness or suitability can be explained by a wide range of factors(Koomen et al., 2007; LaGro, 2011). In this research, the total suitability of each parcel was calculated for urban green space land use using the following formula:

$$\text{Maximizing Land Use Suitability}= \text{ min}, \sum_{j=1}^{10} \sum_{i=1}^{10} \sum_{i=1}^{n} wi\text{Si},$$

where j is vertical pixel, i is horizontal pixel, n is the number of parcels, Si is the fitness of parcel i to create a local park, and wi is the weight and importance of each parameter. n is the number of efficient parameters in urban green space suitability, which was equal to 7 in this study, representing the seven factors : distance from educational centers, distance from residential centers, distance from the water supply system, distance from the access network, slope, land price, and population. The objective function is the sum of the values of the layers in a way that, after successive generations of new populations, the best chromosomes are the answers in which the above-mentioned objective function would be minimal for their genes and their surrounding pixels.

4. Results

The overall results of this study can be divided into the following two parts:

4.1. Comparison of the two methods of WLC and GA algorithm for locating local parks

- The result of local park site selection based on WLC method

With regard to the weights obtained and the classified maps for each factor,suitability map (Fig. 12) was achieved based on weighted overlaying technique. According to this map, suitable and unsuitable sites for locating local parks could be discovered in the future such that if a park lay in a lower class (darker site in the picture), it would have a higher suitability.

-The result of local park site selection based on genetic algorithm

GIS software is a very powerful tool for spatial analysis, but it has a weakness in modeling. Therefore, in this research, a combination of GIS software and MATLAB was used so as to have a strong work based on both local and spatial data, programming, and modeling. The following figures shows the best answer found in each generation. Given the fact that the target was minimization, the best generation should have had a lower suitability value. Moreover, as seen in the Fig.13, it is clear that after producing about 1,000 generations, the best answer does not undergo much change; thus, it can be said that the algorithm has almost converged. After 58 seconds, the algorithm produced 2000 generations and ultimately provided the best answers in the form of 25 locations with sizes of 100 × 100 m as appropriate responses to create local parks in the city of Birjand (see Fig.14).

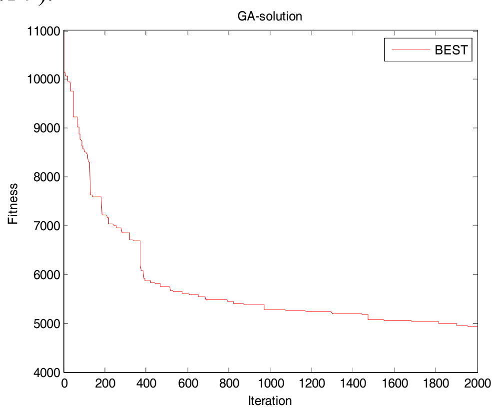

Fig.13 .The best response during different generations algorithm (Source:The Authors)

To compare the results of implementing the algorithm with the map obtained from Weighted Linear Combination, the overlaying procedure was followed. Based on the results obtained, it can be stated that these responses are exactly on a suitable level of locations acquired through the analyses of GIS software and the WLC method, except that in a very short time,a more detailed search was carried out on the suitable sites of class 1, from which more appropriate spots were selected.

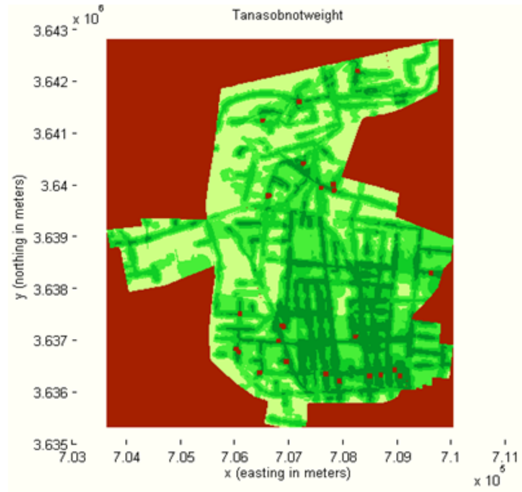

Fig.14 .Result of the implementation of the algorithm After 2000 iterations. (Source:The Authors)

3.2. Suitability analysis of existing local parks Suitability analysis of local parks based on physical, social and economical factors

Fig. 15 was obtained based on the weight overlaying technique. Using this map, suitable and unsuitable sites could be identified for the location of future local parks, and the suitability analysis of the current statuses of the parkswas dealt with by overlaying the layer of existing local parkson the mentioned map.Fig. 15.Existing local parks status basis on suitability value(classified and integrated map) It was found that no scientific studies had been done to locate the existing local parks, and the states of the present parks were not suitable in terms of the suitability level based on Fig15.

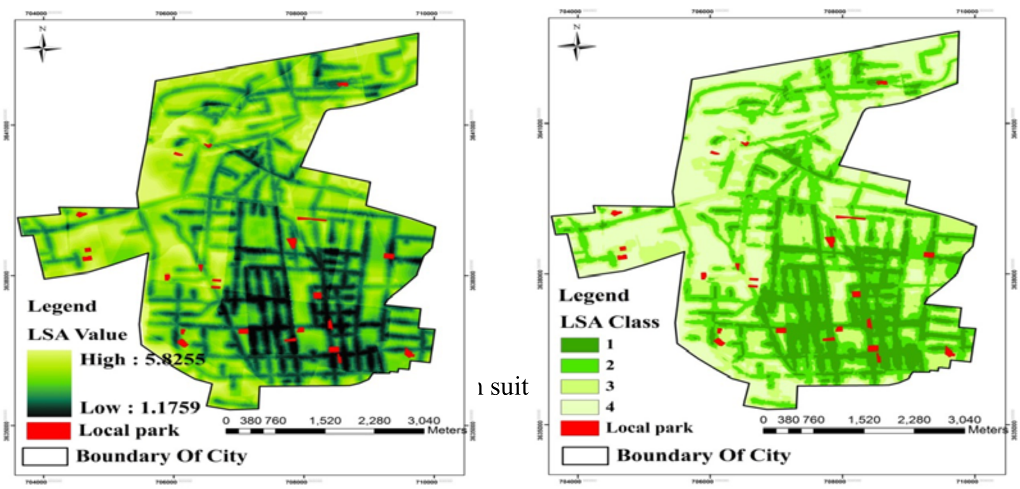

Fig. 15. Existing local parks status basis on suitability value (classified and integrated map)

(Source:The Authors)

Furthermore, the current parks were uniformly distributed in the four suitability classes, and the shares of the first and second classes were not to a maximum degree. These issues are displayed in the following diagram(Fig.16).

- Suitability analysis of local parks based on ecological factors

In this research, the Fragstats program was employed to calculate landscape metrics. To start using this application, two input data sets were required: 1) green space layer in the city; and 2) divider network, according to which the whole town was divided into 25

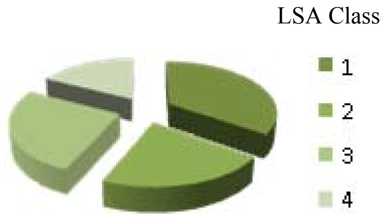

Fig. 16.The share of each class of suitability in the location of parks

cells of 100 ha. After entering the data into the Fragstats software, four metric values were computed for each of the 25 cells. Since the landscape metrics could not indicate ecological suitability or unsuitability alone, all the metrics were evaluated together in the ecological status analysis. To this goal, Fig.17 was prepared, in which the MPS ,MNN,NP and CAP metrics were focused on together.

Class1:NP<20,CAP>20%, MPS> 20000 $m^2$and MNN<100m

Class2:20<NP<40,10%<CAP<20% , 20000m^2<MPS<5000 m^2, 200m<MNN<100m

Class3: NP> 40,CAP< 10%,MPS< 5000 m^2, MNN> 200 m

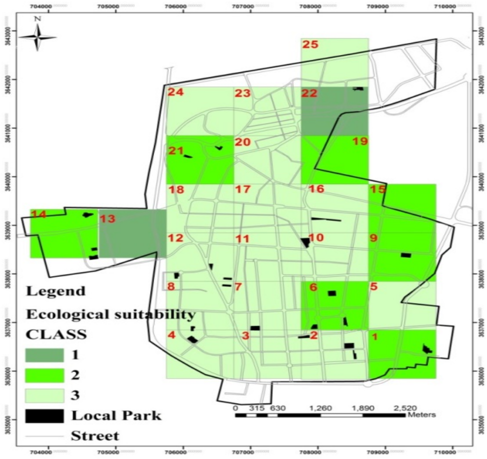

Fig.17.The ecological suitability status of existing parks
(Source:The Authors)

Based on the prepared map (Fig.17), each local park located ecologically within more stable cells was in a better and more sustainable condition. Moreover, in cells 3 and 6 with high NPs, it was better to use a combination

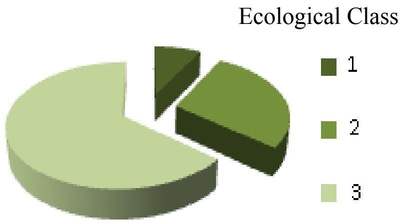

Fig. 18. The share of each ecological class in Birjand city

of existing spots for the location of new parks and to attempt to reduce the number of patches to create further suitability since the mentioned cells had higher potential for creating a park because of having green spots.

Based on ecological suitabilitymap (Fig.17), the share of each ecological class in Birjand City is shown in the following diagram(Fig.18)

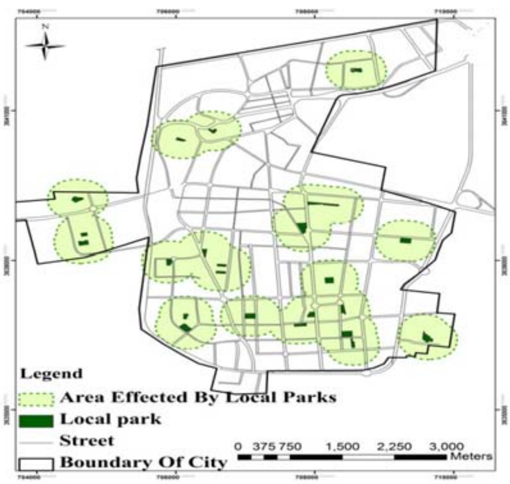

Fig. 19.Distribution of local parks
(Source:The Authors)

- Suitability analysis of local parks based on distribution

Distribution map (Fig.19) represents local parks distribution and their range of influence.The scopes of which were influenced to be 350 m or about 10 minutes walking. Accordingly, it is clear that the density of these sites was higher in the southern part of the city such that their functioning ranges interfered with each other in some areas. In the northern part of the city, however, there were too few of these types of parks. It can be said that more than 75% of Birjand's local parks appear in the southern half of the city and less than 25% of them in the northern half. This is indicative of improper distribution. Of course, for better interpretation and a more realistic conclusion, the neighborhood, and regional parks should be considered in addition to local parks along with their functional scopes since their locations in low-density areas proportional to the local parks may be such that they compensate for their shortages or at least make their presence less important.

5. Discussion

Physical developments of cities are regarded as a dynamic and continuous process. If this trend quickly occurs with no program, it leads to an improper combination of urban spaces. As a result, urban systems will face many problems. Urban green spaces have a key role in improving the environmental quality, viability, and sustainability of a city while providing many advantages on local and national levels and on the economic and social quality of urban life. For this reason, this research studied suitability and site selection of urban green spaces (basis on physical, social and economical factors)on a local scale using the WLC technique and heuristic algorithm. The main objective of selecting these methods was comparing artificial intelligence techniques with a very strong scientific support and the traditional methods with empirically proven efficiencies. After comparing the results of the two methods, it was concluded that the genetic algorithm is highly efficient for solving the problems of land use and working with spatial data with more accurate responses. In addition to higher precision, greater flexibility and easier entering of conditions and constraints can be mentioned as benefits of using this algorithm for the problems of suitability analysis. For example, in the weighted linear combination method, equal numbers of classes should have existed for each factor. Thus, the unclassifiable factors such as the limits of faults could not be used to create a suitability map, though they were also important for location. Such restrictions can be removed when working with algorithms. Furthermore, constraints such as minimum or maximum area of a park and the like can be utilized for a more accurate suitability analysis. After performing the suitability analysis of the existing parks, it was found that they were not at a suitable level in terms of the study criteria. Therefore, to improve this condition, it is proposed that newer parks be established in areas with higher potential and small green spots as well as in the northern part of the city.

Acknowledgments

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