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Analysis of land suitability for urban development in Ahwaz County in southwestern Iran using fuzzy logic and analytic network process (ANP)

Maryam Malmir · Mir Masoud Kheirkhah Zarkesh · Seyed Masoud Monavari · Seyed Ali Jozi · Esmail Sharifi

Abstract The ever-increasing development of cities due to population growth and migration has led to unplanned constructions and great changes in urban spatial structure, especially the physical development of cities in unsuitable places, which requires conscious guidance and fundamental organization. It is therefore necessary to identify suitable sites for future development of cities and prevent urban sprawl as one of the main concerns of urban managers and planners. In this study, to determine the suitable sites for urban development in the county of Ahwaz, the effective biophysical and socioeconomic criteria (including 27 sub-criteria) were initially determined based on literature review and interviews with certified experts. In the next step, a database of criteria and sub-criteria was prepared.

Standardization of values and unification of scales in map layers were done using fuzzy logic. The criteria and sub-criteria were weighted by analytic network process (ANP) in the Super Decision software. Next, the map layers were overlaid using weighted linear combination (WLC) in the GIS software. According to the research findings, the final land suitability map was prepared with five suitability classes of very high (5.86 %), high (31.93 %), medium (38.61 %), low (17.65 %), and very low (5.95 %). Also, in terms of spatial distribution, suitable lands for urban development are mainly located in the central and southern parts of the Ahwaz County. It is expected that integration of fuzzy logic and ANP model will provide a better decision support tool compared with other models. The developed model can also be used in the land suitability analysis of other cities.

M. Malmir
Department of Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran

M. M. K. Zarkesh (✉)
Department of Remote Sensing and GIS, Science and Research Branch, Islamic Azad University, Tehran, Iran
e-mail: MirmasoudKheirkhah@gmail.com

S. M. Monavari
Department of Land-use Planning and Assessment, Science and Research Branch, Islamic Azad University, Tehran, Iran

S. A. Jozi
Department of Environment, North Tehran Branch, Islamic Azad University, Tehran, Iran

E. Sharifi
Soil Conservation and Watershed Management Research Institute, Karaj, Iran

Introduction

Urbanization and uncontrolled urban growth are the most important issues facing today's societies (Van der Merwe 1997). The physical development of cities is a continuous and dynamic process in which the physical spaces of cities expand quantitatively and qualitatively in horizontal and vertical directions (Lotfi et al. 2009). Uncontrolled and unplanned physical urban development is one of the main problems of urban structure in

developing countries. In Iranian metropolises, including Ahwaz, many changes have been applied in the urban spatial structure due to centralization of industries, services, and facilities, as well as unplanned migration, rapid population growth, increased slum-dwelling, and development of new residential towns on the periphery of metropolitan cities. This kind of urban development leaves adverse effects on ecosystems and the nature and leads to negative socioeconomic and ecological consequences (Liu et al. 2007).

Ahwaz is the capital of Khuzestan Province in southwestern Iran. It is also the seventh largest county in the country. According to the population and housing census in 2012, the county has a total population of 1,395,184 inhabitants; 40 % of dwellers live in the suburbs (SCI 2012). Uncontrolled development of the Ahwaz city is very likely due to the settlement of illegal immigrants in the city border (MRUD 2008). Determining an appropriate pattern of physical development for cities to meet current and anticipated future needs is considered a major problem faced in urban planning, which requires land suitability analyses. Land suitability analysis is a very important issue faced by administrators and urban planners to identify the most appropriate spatial pattern for future land uses (Collins et al. 2001). It can also minimize environmental issues causing tension and conflicts (Eastman et al. 1995).

Land suitability analysis includes a set of physical, socioeconomic, environmental, and ecological viewpoints measured by conventional criteria (McHarg 1981; Collins et al. 2001). The analysis is carried out in accordance with special needs and preferences as well as prediction of certain activities (Malczewski 2004). Expert knowledge, preferences of decision-makers, and public participation are scientifically integrated with real criteria and applied in land suitability analysis. Several methods have been devised and developed for land suitability analysis, one of which is a multi-criteria decision-making technique. This technique is combinations of analytical methods that can help decision-makers solve complex problems (Malczewski 1999; Huang et al. 2011). It reduces costs and is of high potential for spatial decisions (Li et al. 2006; Lotfi et al. 2009).

According to many case studies in the field of urban development, the analytical hierarchy process (AHP) (Liu et al. 2007; Park et al. 2011; Youssef et al. 2011), weighted linear combination (WLC) (Dai et al. 2001),

and ordered weighted averaging (OWA) (Malczewski 2006) are widely-used multi-criteria methods. Since the 1990s, the strategy of integrated multi-criteria decision-making with GIS has received considerable attention from urban planners to solve the problems of spatial planning (Malczewski 2004). The integration of multi-criteria decision-making methods and GIS improves the previous methods and provides a high-performance tool for land suitability mapping or selection of suitable sites for a specific activity (Eastman et al. 1995; Jun 2000; Mendoza 1997; Malczewski 1999; Chakhar and Mousseau 2008).

Literature reviews show that this technique has also been used to evaluate and select suitable sites for urban development (Bantayan and Bishop 1998; Svoray et al. 2005; Dong et al. 2008; Tudes and Yigiter 2010; Youssef et al. 2011). In recent years, instead of AHP, another multi-criteria decision-making technique, analytic network process (ANP), has been greatly promoted in researches worldwide (Jharkharia and Shankar 2007). Despite the complexities of decision-making in the field of locating suitable areas for urban development, which involves considering a variety of criteria and interaction among them, this method compared with the other methods of multi-criteria decision, especially AHP, is used less in site selection studies. It is a general and expanded form of AHP (Saaty 2005) that can be used to model very complex decisions in real-world problems involving multiple interactions and dependencies (Meade and Sarkis 1999). In addition, ANP has a systematic approach to setting priorities and evaluating criteria and goals with the use of a relative scale based on human judgments. ANP can also measure all tangible and intangible criteria and offer a relatively simple and cognitive solution to managers and other decision-makers. Finally, ANP establishes better communication between decision-makers that will lead to a clearer understanding of the issue and the subsequent agreement between them (Saaty 2000).

This outstanding feature of ANP has attracted decision makers in the field of urban planning (Banai and Wakolbinger 2011; Sabri and Yaakup 2008). On one hand, in some multi-criteria decision problems such as land suitability analysis, because of uncertainty and low accuracy of data and also due to the uncertainty in determining decision-making criteria, the use of fuzzy logic theory is highly regarded for standardization of criteria (Donevska et al. 2012; Chang et al. 2008). On the other hand, the integration of fuzzy logic and ANP is

recommended to assign an exact value to each of discrete and continuous data and to obtain correct and reasonable results from spatial analysis in GIS.

The present study was an attempt to analyze the suitability of Ahwaz County for urban development using biophysical and socioeconomic criteria as well as by integration of ANP, fuzzy logic, and WLC in GIS.

Material and methods

Study area

Ahwaz County, with an approximate area of 687,469.23 ha, is located in Khuzestan Province in southwestern Iran between the longitudes 48° 2′–48° 41′ E and the latitudes 30° 54′–31° 7′ N . The county has a dry and hot desert climate. The average annual rainfall, average relative humidity, and average annual temperature are 206.43 mm, 46.5 %, and 25.46 °C, respectively. There is a relatively flat and fertile plain in the northern and central parts, as well as sandy dunes along the eastern and western borders stretched parallel to the Zagros Mountains from the northwest to the southeast direction. In the southern and southeastern county, there is an arid barren plain, which is rich in oil and gas. The topography of this area is generally similar to the terrain feature of Khuzestan Plain. The slope varies between 0.04 and 0.06 %.

Materials

The data used in this study include digital maps of topography (1:50,000) from National Geography Organization of Iran, digital geological maps (1:100,000) from Geological Survey of Iran, digital maps of land capability (1:250,000) from Water and Soil Research Institute, digital elevation model (DEM), satellite image of Landsat 8 (OLI-TIRS) in 2013, data on wells in the area from Khuzestan Water and Power Authority, hardcopy maps of Ahwaz Urban Development Master Plan from the Ministry of Housing and Urban Development, Ahwaz City boundary map for 2012, and the map of residential areas from the Statistical Center of Iran.

The software used in this research include Super Decision for paired comparisons and weighting criteria and sub-criteria effective in site selection of suitable areas for urban development using ANP method and ARC GIS 9.3 software to prepare map layers, process the input data, and perform fuzzification and overlay analyses. Then, the Map Comparison Kit (MCK) version 3.2 was used to compare the final land suitability map with the comprehensive plan of Ahwaz County.

Methodology

Determination of criteria and sub-criteria

Various stages of this study are shown in Fig. 1. The determination of criteria is a technical activity based on theory, empirical researches, or common sense. It should be noted that there is no comprehensive and global framework for the determination of a set of criteria to assess land suitability for urban development. Therefore, in this study, the determination of criteria was done based on literature reviews, case studies, relevant government documents (including laws and regulations related to urbanization), and ideas and experiences of a group of experts from different disciplines related to the subject, after compliance with the conditions of Iran.

For this purpose, after initial investigations, a total of 45 sub-criteria were selected for primary screening by Delphi method. The Delphi method in this study was conducted using a semi-closed questionnaire. The survey questionnaires were filled out by 12 experts proficient in urban development, environment, civil engineering, and urban planning and development who were quite familiar with the area under study. The questionnaire was designed in a way that enables the experts to grade the importance of each of the listed sub-criteria using a scale range between 0 and 10. They were also asked to add new criterion to the list if necessary. In order to evaluate the sub-criteria, the importance chart of the sub-criteria was plotted in which they were sorted by their degree of importance. The horizontal axis shows the importance of each sub-criterion and the vertical axis gives the degree of its importance. Those criteria that earned at least half the numerical value of each axis were involved in the site selection analysis. According to the chart, out of all the listed sub-criteria, only 27 sub-criteria were selected for the site selection analysis.

The percent and degree of importance of each criterion were calculated using Eq. 1 (Daheshvar et al. 2013):

$$\frac{W}{\sum x_i} = \text{Adjusted weighted coefficient} \qquad (1)$$

$$z_{i=y_i\,n_i}$$

wherein z_i is the weighted score of the ith criterion

$$y_i = \frac{W}{\sum x_i}$$

in which, the y_i is the adjusted weight

$$A = \frac{W}{\sum x_i}\ \max(n_i)\max(x_i)$$

where A is the maximum achievable score

$$\text{Percentage of criteria importance} = \frac{\sum z_i}{A}\ 100$$

$$\text{degree of criteria importance} = \frac{\sum (x_i\,n_i)}{N}$$

In all of the abovementioned equations, x_i is the primary weight, n_i is the number of panelist scored to each degree of importance, N is the number of respondents, and W is the maximum adjusted weight.

Criteria, in this research, are divided into two main groups of biophysical criteria (including geological, water resources, natural disasters, climatologic, and biological) and socioeconomic criteria (including accessibility, infrastructures, and land use). Geological criterion in the biophysical group consists of land capability, soil

Fig. 1 Flow chart of methodology
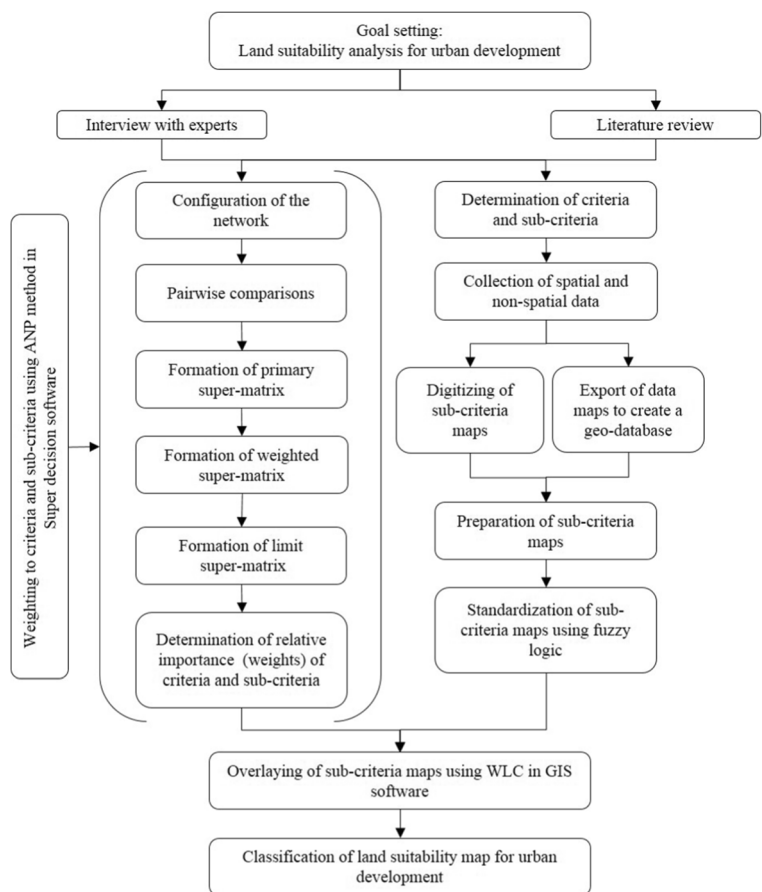
erosion, geological formations, slope, aspect, and elevation. Distance from rivers and streams, distance from wells, and depth of groundwater are the sub-criteria of water resources.

The criterion of natural disasters includes the sub-criteria of distance from faults, seismicity risk, and distance from flood plains. Climate criterion is composed of the sub-criteria of average annual rainfall, average annual temperature, percent of relative humidity, and speed of prevalence wind. Distance from protected areas and land cover density constitutes the biological criterion.

Accessibility criterion in socioeconomic group includes the sub-criteria of distance from residential areas, distance from roads, and distance from airport. Furthermore, the sub-criteria of distance from gas transmission lines, distance from power transmission lines, distance from waste disposal centers, distance from wastewater treatment plants, and distance from industrial areas were classified under the category of infrastructure criterion.

Preparation of map layers

In this study, maps of slope, aspect, and elevation were prepared from DEM by the Surface Analysis command in the Spatial Analyst of GIS software. Digital geological maps were prepared from Geological Survey of Iran at the scales of 1:100,000 and 1:250,000. The map layers of streams and rivers, floodplains, roads, gas and power transmission lines, airport, and residential areas were generated from topographic maps (1:50000) and field visits.

The maps of the position of wells and ground water depth were prepared according to data obtained from Khuzestan Province Water and Power Authority. To produce the map of groundwater depth, the interpolate function in the GIS software was used. Maps of rainfall, temperature, humidity, and prevalence wind speed were prepared by the interpolate function based on the data from weather stations in the region during the period from 1980 to 2010. To produce seismicity risk and fault maps, the relevance hardcopy maps in the Master Plan of Ahwaz County (MRUD 2008) were digitized.

Digital maps of land use and land cover were derived from Landsat 8 (OLI-TIRS) satellite images dated back to 2013. Waste disposal site and water treatment plant were positioned and mapped using field visits and GPS. The maps of county boundary in 2012 and residential areas were prepared from the Statistical Center of Iran (SCI 2012).

The map layer of the protected areas was obtained from the Department of Environment. To prepare the maps of distance from rivers and streams, wells, floodplains, roads and highways, faults, gas and power transmission lines, airport, industrial zones, waste disposal site, wastewater treatment system, residential areas, and protected areas, the Euclidean distance function in the GIS software was used. Finally, all the maps were prepared with the same cell size (30×30 m) and geo-reference system. Accordingly, a spatial database was formed from the abovementioned map layers in Arc GIS software, version 9.3.

Standardization of maps

After preparing the criteria maps, the standardization process was used to unify measurement scales and to convert them to comparable measurement units (Eastman 2006). More precisely, to overlay different layers of criterion maps, their scales should be proportionate to each other. There are several approaches to provide comparable and standardized criterion maps, including deterministic, probabilistic, and fuzzy methods. In this study, the fuzzy method was used to standardize the data. Fuzzy logic is a form of reasoning for solving those complex problems that are difficult to solve through conventional methods (Zadeh 1968). Fuzzy logic differs from conventional dichotomous logic because it permits objects to belong partially to multiple sets and can have intermediate values (Donevska, et al. 2012)

The standardization process in the fuzzy method is through reconfiguration of values in the form of a fuzzy set membership. S-shaped, J-shaped, and linear functions are the most commonly used functions in fuzzy set (Burrough et al. 1992). In this study, the standardization of the map layers was done using expert opinion and based on criteria and standards in the field of urban development in Iran and other resources listed in Table 1. In this study, the sub-criterion maps were standardized according to the expertise opinion and knowledge of relationships between the sub-criteria, using increasing or decreasing linear functions and with formulation by the Raster Calculator tool in GIS software. Accordingly, the values of the map layers were converted to comparable measurement units between zero and 255 (Eastman 2006).

Table 1 Criteria and standards for the sub-criteria used in the analysis of land suitability for urban development

Sub-Criteria	Very low suitability	Low suitability	Medium suitability	High suitability	Very high suitability	Reference
Distance from faults (m)	0-500	500-1000	1000-1500	1500-2000	> 2000	(Lotfi et al. 2009), (Xu et al. 2011)
Distance from flood plains (m)	0-50	50-100	100-150	150-200	> 200	(Bathrellous et al.,2012)
Seismicity risk	High	High	Medium	Low	Low	Expert group
Percent of relative humidity (%)	-	-	-	-	60-80	(Makhdom, 2003)
Average annual rainfall (mm)	-	-	-	-	500-800	(Makhdom, 2003)
Average annual temperature (°C)	-	-	-	-	18-24	(Makhdom, 2003)
Speed of prevalence wind (km/h)	> 50	-	35-50	-	< 35	(Makhdom, 2003)
Distance from rivers (m)	<200	200-500	500-1000	1000-2000	>2000	(Zhang et al. 2013)
Distance from wells (m)	<10	-	10	-	> 10	(Ahsan 2003)
Depth of groundwater (m)	<1	1-3	3-6	6-12	> 12	(Amous 2013)
Soil erosion	Class 1	Class 2	Class 3-4	Class5	Class5	(Tudes and Yigiter 2010)
Land capability	Water bodies	Heavy soil texture, shallow to deep and semi-deep soil	Moderate to heavy soil texture, shallow to semi-deep soil or moderate to heavy texture soil, semi-deep to deep soil	Light-textured deep soil or Moderate textured shallow to semi-deep soil	Moderate to heavy textured deep soil or Relatively heavy textured deep soil	Expert group
Geological formations	-	-	Silt, clay silt, sandy silt (Quaternary sediments)	Sandy limestone (Aghajari Formation)	-	Expert group
Aspect	Southern, Western	-	Northern	-	Eastern	(Makhdom, 2003)
Elevation (m)	>173	130-173	80-130	30-80	0-30	Expert group
Slope (°)	>15	8-15	5-8	2-5	0-2	(Amous 2013)
Distance from protected areas (m)	0-1000	-	-	> 1000	> 1000	(Xu et al. 2011)
Land cover density	-	Planted forests	Rangelands with a density of 10 to 25 %	Rangelands with a density less than 10 %	No rangeland	Expert group
Distance from airport (m)	0-3000	-	-	-	> 3000	(Star and Estes 1991)
Distance from residential areas (m)	> 2000	1500-2000	1000-1500	500-1000	0-500	(Maktav et al. 2011), (Xiang et al., 2008)
Distance from roads (m)	> 3000	2500-3000	1500-2500	1000-1500	150-1000	(Zhang et al. 2013), (Ahsan 2003)
Distance from gas transmission lines (m)	0-250	-	-	-	> 250	(Ahsan 2003)
Distance from industrial areas (m)	0-1000	1000-2000	2000-3000	3000-5000	> 5000	(Maktav et al. 2011), (Xiang et al., 2008)
Distance from waste disposal center (km)	0-20	-	-	-	> 20	(Abdoli 2006)
Distance from power transmission lines (m)	0-90	-	> 1000	-	90-1000	(Mozaffari and Olazadeh 2009)
Distance from wastewater treatment plants (m)	0-6000	-	-	-	> 6000	(Ahsan 2003)
Land use	Water bodies	Planted forests	Agricultural lands	Poorly vegetated regions	Urban	Expert group

In this case, the maximum value that represents the greatest suitability belongs to the maximum membership of 255 and the minimum value that represents the lowest suitability belongs to the least membership value of zero in the fuzzy set. For further analysis, different sub-criteria maps were rasterized, because calculations in raster formats are less complex than vector format. A number of standardized maps are depicted in Fig. 2.

Weighting of criteria and sub-criteria using ANP

ANP is the extended and general form of AHP. This method was proposed in 1996 by Thomas L. Saaty, which recently gained more popularity. In the AHP method, the underlying assumption is based on independent performance of groups in the upper levels of hierarchy from all parts in the lower levels (Chung et al. 2005), while many of the decision issues cannot be presented in a hierarchical structure due to dependencies between criteria, sub-criteria, and alternatives in the same level, as well as dependencies between the upper and lower levels of a hierarchy. This led Saaty to develop the ANP.

In the ANP method, the decision-making problem is presented in a network of criteria and alternatives categorized into clusters. All components of the network within and between clusters are somehow related to each other. Network structure and pairwise comparisons are the two main elements of ANP to represent the decision problem and to establish relationships within the structure, respectively, by which complex settings could be modeled accurately and interdependency among the elements will be handled. This would be possible by the supermatrix: a two-dimensional matrix assigning the relative importance weights of individual pairwise comparison matrices. The overall supermatrix is made up by eigenvector values of the adjusted relative importance weights (Aragonés-Beltrán et al. 2010). The ANP method includes the following steps:

(i)   Identification of the network components and their relationships

In the network structure, first of all, the purpose of the study is raised clearly and then a logical system is created in the form of a simple network including a number of clusters consisting of a number of elements. In this research, the structure was implemented using expert judgment in the Super Decision software shown in Fig. 3. The ANP, in this study, included three types of dependencies: first, the hierarchy controlling the dependency between the criteria and the sub-criteria network; second, the relationships between clusters and elements; and third, feedback between the different clusters and the elements within a cluster.

As the figure suggests, elements within a cluster, in some cases, are associated with one or all of the elements in other clusters (influenced by them or over them). These relationships (external dependency) are shown by the arrows. In cases of bilateral dependency between the two groups, the arrow is double-headed. Furthermore, elements within a cluster are interrelated among themselves (interdependence) that these relationships are shown as a bow attached to the cluster.

(ii)   Pairwise comparisons of the elements using ratio scales

Similar to the AHP method, in this study, the elements within each of the clusters were compared pairwisely based on their importance in relation to the control criteria. In other words, the weights of the elements were determined by averaging the experts' scores on the questionnaires about the relative importance of various elements. The clusters were also compared pairwisely based on their role and their impact on achieving the research goal.

Moreover, the interdependencies of the elements within a cluster were compared pairwisely. Similar to AHP, the relative importance of the elements were determined based on Saaty's nine-point scale so that the number 1 represents that the two elements are equally important and number 9 shows extraordinary importance of an element to the other element. The value of a_{ij} in pairwise comparison matrix shows the relative importance of the component in i^{th} row compared to that of in the jth column. In other words, $a_{ij} = w_i / w_j$.
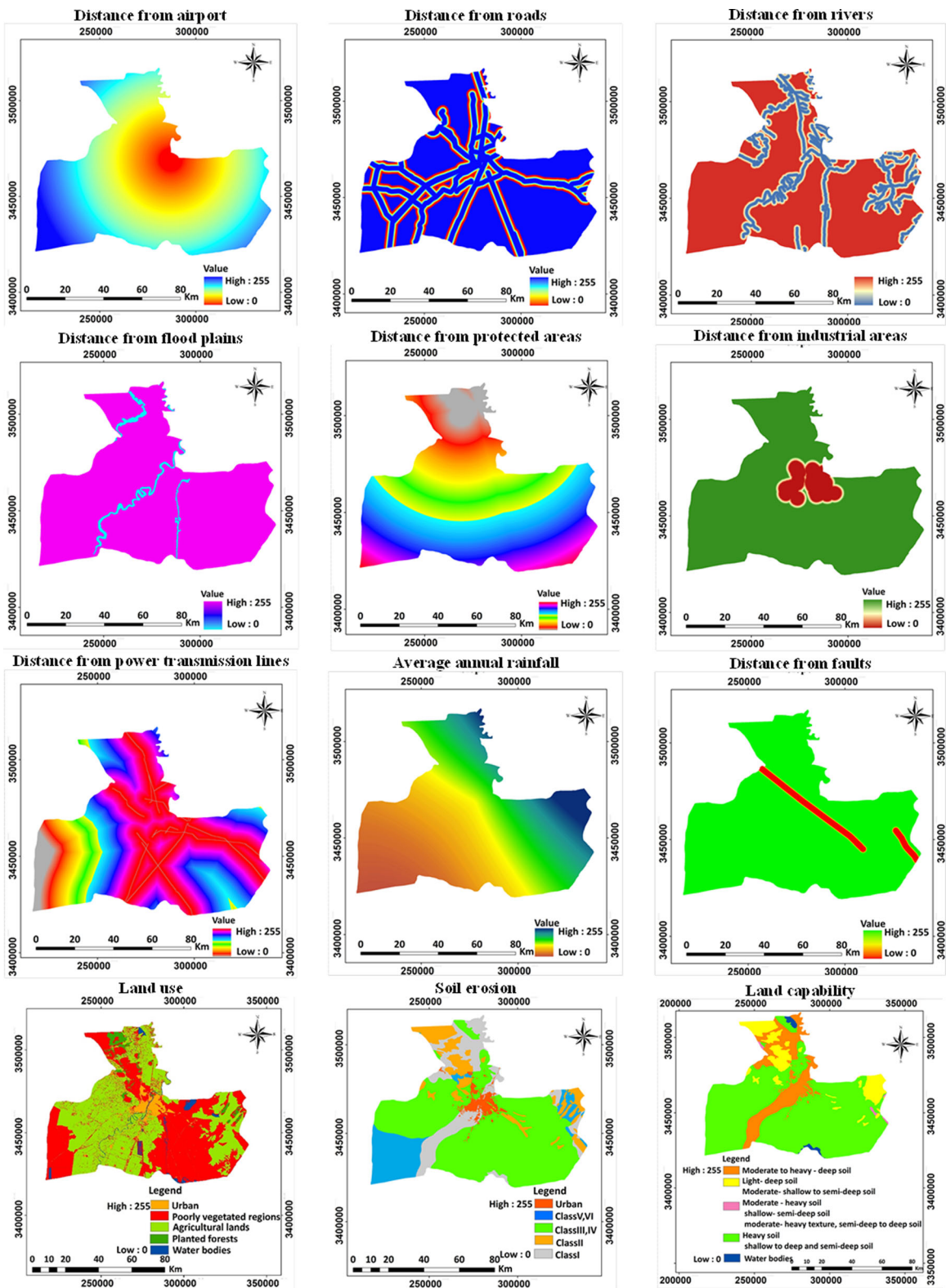
Fig. 2 A number of standardized maps used in land suitability analysis for Ahwaz County's urban development
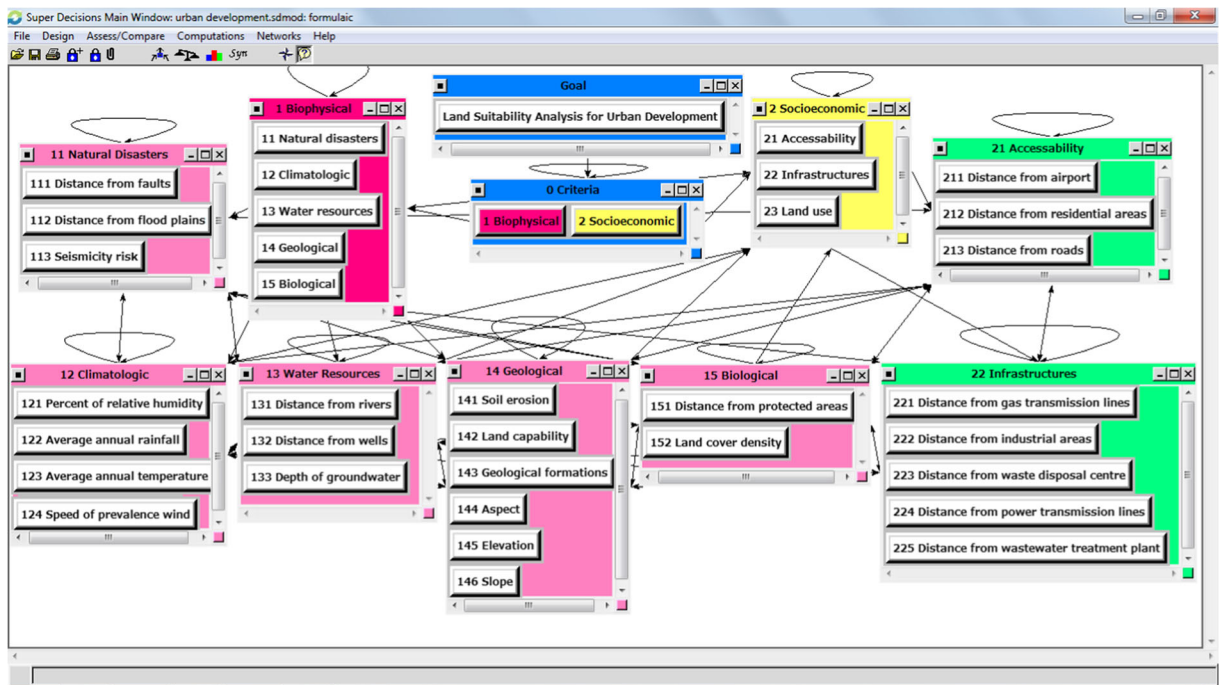
Fig. 3 Network model of land suitability analysis for urban development

After the formation of the pairwise comparison matrix, in order to calculate the relative weight of each element (w) and to determine the local priority vector, the eigenvector method was used in accordance with Eq. 2 in which A is pairwise comparison matrix, W is eigenvector, and λ_{max} is the greatest eigenvalue in the matrix A:

$$AW = \lambda_{\max} w \tag{2}$$

Consistency ratio (CR) checks the consistency of judgments for each pairwise comparison based on Eq. 3 It indicates the seriousness of consistency violations and the extent of trust to the judgments. The values ≤0.1 mean that the judgments are acceptable; otherwise, re-judgments would be required (Saaty and Vargas 2006):

$$CR = \frac{CI}{RI} \tag{3}$$

where CI is the consistency index of the pairwise comparison matrix that is estimated using Eqs. 4 and 5 based on the largest

eigenvector (λ_{max}) value and the size of matrix (n), and RI is the random consistency index calculated by a reciprocal matrix:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4}$$

(iii) Creation of unweighted supermatrix

The concept of supermatrix is similar to the process of Markov chain (Saaty 1996). To achieve the global priorities in a system with interdependent influences, local priority vectors are inserted in the appropriate columns of a matrix known as supermatrix. In other words, a supermatrix is a categorized matrix in which each part illustrates the relationship between the elements and clusters in a system. If the element in the left column of the matrix has no effect on the elements in the top rows, then the corresponding value will be considered zero at the supermatrix. In this phase, the resulting relative importance weights (eigenvectors) were placed in the pairwise comparison matrices within the supermatrix to create the unweighted supermatrix, which is shown in Table 2.

Table 2 Unweighted supermatrix

Cluster	Element	Goal	Criteria		Biophysical					Socioeconomic			Natural disasters
		0	1	2	11	12	13	14	15	21	22	23	111
Goal	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria	1	0.250	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2	2.750	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biophysical	11	0.000	0.416	0.000	0.000	0.458	0.474	0.531	0.469	0.405	0.404	0.405	0.000
	12	0.000	0.050	0.000	0.077	0.000	0.065	0.075	0.068	0.053	0.050	0.053	0.000
	13	0.000	0.174	0.000	0.289	0.173	0.000	0.256	0.166	0.169	0.177	0.169	0.000
	14	0.000	0.274	0.000	0.490	0.289	0.336	0.000	0.297	0.280	0.278	0.280	0.000
	15	0.000	0.086	0.000	0.144	0.079	0.125	0.138	0.000	0.092	0.090	0.092	0.000
Socioeconomic	21	0.000	0.000	0.400	0.400	0.400	0.400	0.400	0.400	0.000	0.667	0.667	0.000
	22	0.000	0.000	0.200	0.200	0.200	0.200	0.200	0.200	0.500	0.000	0.333	0.000
	23	0.000	0.000	0.400	0.400	0.400	0.400	0.400	0.400	0.500	0.333	0.000	0.000
Natural disasters	111	0.000	0.000	0.000	0.571	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	112	0.000	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500
	113	0.000	0.000	0.000	0.286	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500
Climatologic	121	0.000	0.000	0.000	0.000	0.212	0.000	0.000	0.000	0.000	0.000	0.000	0.212
	122	0.000	0.000	0.000	0.000	0.269	0.000	0.000	0.000	0.000	0.000	0.000	0.269
	123	0.000	0.000	0.000	0.000	0.410	0.000	0.000	0.000	0.000	0.000	0.000	0.410
	124	0.000	0.000	0.000	0.000	0.109	0.000	0.000	0.000	0.000	0.000	0.000	0.109
Water resources	131	0.000	0.000	0.000	0.000	0.000	0.644	0.000	0.000	0.000	0.000	0.000	0.655
	132	0.000	0.000	0.000	0.000	0.000	0.085	0.000	0.000	0.000	0.000	0.000	0.095
	133	0.000	0.000	0.000	0.000	0.000	0.271	0.000	0.000	0.000	0.000	0.000	0.250
Geological	141	0.000	0.000	0.000	0.000	0.000	0.000	0.290	0.000	0.000	0.000	0.000	0.286
	142	0.000	0.000	0.000	0.000	0.000	0.000	0.417	0.000	0.000	0.000	0.000	0.412
	143	0.000	0.000	0.000	0.000	0.000	0.000	0.469	0.000	0.000	0.000	0.000	0.165
	144	0.000	0.000	0.000	0.000	0.000	0.000	0.054	0.000	0.000	0.000	0.000	0.057
	145	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.036
	146	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.044
Biological	151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.800	0.000	0.000	0.000	0.800
	152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.200
Accessibility	211	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.097	0.000	0.000	0.097
	212	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.570	0.000	0.000	0.570
	213	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.000	0.333
Infrastructures	221	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.111	0.000	0.111
	222	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.471	0.000	0.471
	223	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.224	0.000	0.224
	224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.000	0.153
	225	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.000	0.041

	Natural disasters		Climatologic				Water resources			Geological			Natural disasters
	112	113	121	122	123	124	131	132	133	141	142	143	144
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 2 (continued)

	Natural disasters		Climatologic				Water resources			Geological			
	112	113	121	122	123	124	131	132	133	141	142	143	144
Biophysical	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Socioeconomic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Natural disasters	0.667	0.667	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	0.000	0.333	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
	0.333	0.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
Climatologic	0.212	0.212	0.000	0.297	0.297	0.297	0.212	0.212	0.212	0.212	0.212	0.212	0.212
	0.269	0.269	0.267	0.000	0.540	0.540	0.269	0.269	0.269	0.269	0.269	0.269	0.269
	0.410	0.410	0.540	0.540	0.000	0.163	0.410	0.410	0.410	0.410	0.410	0.410	0.410
	0.109	0.109	0.163	0.163	0.163	0.000	0.109	0.109	0.109	0.109	0.109	0.109	0.109
Water resources	0.655	0.655	0.655	0.655	0.655	0.655	0.000	0.750	0.857	0.655	0.655	0.655	0.655
	0.095	0.095	0.095	0.095	0.095	0.095	0.250	0.000	0.143	0.095	0.095	0.095	0.095
	0.250	0.250	0.250	0.250	0.250	0.250	0.750	0.250	0.000	0.250	0.250	0.250	0.250
Geological	0.286	0.286	0.286	0.286	0.290	0.286	0.286	0.286	0.286	0.000	0.514	0.339	0.302
	0.412	0.412	0.412	0.412	0.417	0.412	0.412	0.412	0.412	0.554	0.000	0.487	0.447
	0.165	0.165	0.165	0.165	0.169	0.165	0.165	0.165	0.165	0.256	0.296	0.000	0.166
	0.057	0.057	0.057	0.057	0.054	0.057	0.057	0.057	0.057	0.082	0.078	0.000	0.052
	0.036	0.036	0.036	0.036	0.035	0.036	0.036	0.036	0.036	0.050	0.052	0.048	0.033
	0.044	0.044	0.044	0.044	0.035	0.044	0.044	0.044	0.044	0.058	0.052	0.048	0.052
Biological	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Accessibility	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570
	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333
Infrastructures	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111
	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471
	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224
	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153
	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041

	Geological		Biological		Accessibility			Infrastructures				
	145	146	151	152	211	212	213	221	222	223	224	225
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 2 (continued)

	Geological		Biological		Accessibility			Infrastructures				
	145	146	151	152	211	212	213	221	222	223	224	225
Biophysical	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Socioeconomic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	1.000	1.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Natural disasters	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
Climatologic	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212
	0.269	0.269	0.269	0.269	0.269	0.269	0.269	0.269	0.269	0.269	0.269	0.269
	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410
	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109
Water resources	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655
	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290
Geological	0.301	0.301	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417
	0.449	0.449	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169
	0.162	0.162	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
	0.052	0.054	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
	0.000	0.036	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biological	0.800	0.800	0.000	1.000	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
	0.200	0.200	1.000	0.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Accessibility	0.097	0.097	0.097	0.097	0.000	0.333	0.333	0.196	0.196	0.196	0.196	0.196
	0.570	0.570	0.570	0.570	0.667	0.000	0.667	0.493	0.493	0.493	0.493	0.493
	0.333	0.333	0.333	0.333	0.333	0.667	0.000	0.311	0.311	0.311	0.311	0.311
Infrastructures	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.000	0.194	0.156	0.150	0.091
	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.549	0.000	0.576	0.538	0.531
	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.231	0.447	0.000	0.259	0.237
	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.166	0.293	0.219	0.000	0.141
	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.054	0.065	0.049	0.053	0.000

Table 3 Weighted supermatrix

	Goal	Criteria		Biophysical					Socioeconomic			Natural disasters
	0	1	2	11	12	13	14	15	21	22	23	111
Goal												
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria												
1	0.250	0.000	0.442	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.750	0.558	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biophysical												
11	0.000	0.184	0.000	0.037	0.255	0.240	0.253	0.257	0.070	0.077	0.106	0.000
12	0.000	0.022	0.000	0.138	0.096	0.033	0.036	0.037	0.009	0.010	0.014	0.000
13	0.000	0.077	0.000	0.234	0.161	0.000	0.122	0.091	0.029	0.034	0.073	0.000
14	0.000	0.121	0.000	0.069	0.044	0.171	0.000	0.163	0.048	0.053	0.024	0.000
15	0.000	0.038	0.000	0.137	0.160	0.064	0.066	0.000	0.016	0.017	0.000	0.000
Socioeconomic												
21	0.000	0.000	0.223	0.069	0.080	0.146	0.137	0.157	0.000	0.360	0.493	0.000
22	0.000	0.000	0.112	0.137	0.160	0.073	0.069	0.079	0.243	0.000	0.246	0.000
23	0.000	0.000	0.223	0.102	0.000	0.146	0.137	0.157	0.243	0.180	0.000	0.000
Natural disasters												
111	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
112	0.000	0.000	0.000	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.111
113	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.111
Climatologic												
121	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.007
122	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.009
123	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.014
124	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Water resources												
131	0.000	0.000	0.000	0.000	0.000	0.082	0.052	0.000	0.000	0.000	0.000	0.068
132	0.000	0.000	0.000	0.000	0.000	0.011	0.075	0.000	0.000	0.000	0.000	0.010
133	0.000	0.000	0.000	0.000	0.000	0.035	0.030	0.000	0.000	0.000	0.000	0.026
Geological												
141	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.000	0.000	0.000	0.000	0.055
142	0.000	0.000	0.000	0.000	0.000	0.000	0.075	0.000	0.000	0.000	0.000	0.080
143	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.000	0.032
144	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.011
145	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.007
146	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.008
Biological												
151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.047	0.000	0.000	0.000	0.045
152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.011
Accessibility												
211	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.014
222	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.127	0.000	0.061
223	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.060	0.000	0.029
224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.000	0.020
225	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.005

	Natural disasters		Climatologic				Water resources			Geological			
	112	113	121	122	123	124	131	132	133	141	142	143	144
Goal													
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria													
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biophysical													

Table 3 (continued)

	Natural disasters		Climatologic				Water resources			Geological			
	112	113	121	122	123	124	131	132	133	141	142	143	144
Socioeconomic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Natural disasters	0.000	0.000	0.000	0.210	0.210	0.000	0.210	0.000	0.210	0.210	0.210	0.000	0.210
	0.149	0.149	0.105	0.083	0.083	0.105	0.083	0.083	0.083	0.105	0.083	0.083	0.083
	0.000	0.074	0.053	0.041	0.041	0.053	0.041	0.053	0.041	0.041	0.041	0.053	0.041
	0.074	0.000	0.053	0.041	0.041	0.05.	0.041	0.053	0.041	0.041	0.041	0.053	0.041
Climatologic	0.007	0.007	0.000	0.009	0.009	0.012	0.007	0.008	0.007	0.007	0.007	0.008	0.007
	0.009	0.009	0.012	0.000	0.017	0.021	0.008	0.011	0.008	0.008	0.008	0.011	0.008
	0.014	0.014	0.021	0.017	0.000	0.006	0.013	0.016	0.013	0.013	0.013	0.016	0.013
	0.004	0.004	0.006	0.005	0.005	0.000	0.003	0.004	0.003	0.003	0.003	0.004	0.003
Water resources	0.068	0.068	0.077	0.000	0.088	0.079	0.061	0.061	0.077	0.061	0.061	0.061	0.073
	0.010	0.010	0.011	0.009	0.011	0.023	0.000	0.013	0.009	0.009	0.011	0.009	0.009
	0.026	0.026	0.029	0.023	0.023	0.029	0.069	0.029	0.000	0.023	0.023	0.029	0.023
Geological	0.055	0.055	0.054	0.043	0.043	0.054	0.043	0.000	0.077	0.064	0.045	0.045	0.045
	0.080	0.080	0.078	0.062	0.078	0.062	0.078	0.062	0.083	0.000	0.092	0.067	03.067
	0.032	0.032	0.031	0.025	0.025	0.031	0.025	0.031	0.025	0.038	0.044	0.000	0.025
	0.011	0.011	0.011	0.008	0.008	0.011	0.008	0.011	0.008	0.012	0.013	0.015	0.000
	0.007	0.007	0.007	0.005	0.005	0.007	0.005	0.007	0.005	0.007	0.008	0.009	0.005
	0.008	0.008	0.008	0.007	0.005	0.008	0.007	0.008	0.007	0.009	0.008	0.009	0.008
Biological	0.045	0.045	0.051	0.041	0.041	0.051	0.041	0.051	0.041	0.041	0.041	0.051	0.041
	0.011	0.011	0.013	0.010	0.010	0.013	0.010	0.013	0.010	0.010	0.010	0.013	0.010
Accessibility	0.014	0.014	0.015	0.012	0.012	0.015	0.012	0.015	0.012	0.012	0.012	0.015	0.012
	0.061	0.061	0.062	0.049	0.049	0.062	0.049	0.062	0.049	0.049	0.049	0.062	0.049
	0.029	0.029	0.030	0.023	0.023	0.030	0.023	0.030	0.023	0.023	0.023	0.030	0.023
	0.020	0.020	0.020	0.016	0.016	0.020	0.016	0.020	0.016	0.016	0.016	0.020	0.016
	0.005	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.004	0.004	0.004	0.005	0.004

	Geological		Biological		Accessibility			Infrastructures				
	145	146	151	152	211	212	213	211	222	223	224	225
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biophysical	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3 (continued)

	Geological		Biological		Accessibility			Infrastructures				
	145	146	151	152	211	212	213	211	222	223	224	225
Socioeconomic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.210	0.210	0.000	0.210	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Natural disasters	0.106	0.083	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111
Climatologic	0.041	0.041	0.053	0.042	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
	0.041	0.041	0.053	0.041	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	0.008	0.008	0.011	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
	0.013	0.013	0.016	0.013	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
	0.003	0.003	0.004	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Water resources	0.057	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068
	0.009	0.011	0.008	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	0.023	0.023	0.028	0.022	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
Geological	0.055	0.044	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
	0.067	0.079	0.063	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
	0.024	0.024	0.032	0.025	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
	0.008	0.008	0.010	0.008	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	0.000	0.005	0.007	0.005	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	0.005	0.000	0.007	0.005	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Biological	0.041	0.041	0.000	0.052	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
	0.010	0.066	0.000	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Accessibility	0.012	0.012	0.015	0.012	0.014	0.014	0.014	0.000	0.025	0.020	0.019	0.012
	0.049	0.049	0.062	0.049	0.061	0.061	0.061	0.071	0.000	0.074	0.069	0.068
	0.023	0.023	0.030	0.023	0.029	0.029	0.029	0.030	0.058	0.000	0.033	0.031
	0.016	0.016	0.020	0.016	0.020	0.020	0.020	0.021	0.038	0.028	0.000	0.018
	0.004	0.004	0.005	0.004	0.005	0.005	0.005	0.007	0.008	0.006	0.007	0.000

Table 4 Limited supermatrix

Table 4 Limited supermatrix

		Goal	Criteria		Biophysical					Socioeconomic			Natural disasters
		0	1	2	11	12	13	14	15	21	22	23	111
Goal	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biophysical	11	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
	12	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	13	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
	14	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
	15	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Socioeconomic	21	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
	22	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	23	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
Natural disasters	111	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
	112	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
	113	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
Climatologic	121	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	122	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	123	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	124	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Water resources	131	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
	132	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
	133	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Geological	141	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	142	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
	143	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
	144	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
	145	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	146	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Biological	151	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
	152	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Accessibility	211	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
	212	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
	213	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
Infrastructure	221	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
	222	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
	223	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
	224	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
	225	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

	Natural disasters		Climatologic				Water resources			Geological			
	112	113	121	122	123	124	131	132	133	141	142	143	144
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4 (continued)

	Natural disasters		Climatologic				Water resources			Geological			
	112	113	121	122	123	124	131	132	133	141	142	143	144
Biophysical	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Socioeconomic	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
Natural disasters	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
Climatologic	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Water resources	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Geological	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Biological	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Accessibility	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
Infrastructure	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

	Geological		Biological		Accessibility			Infrastructures				
	145	146	151	152	211	212	213	221	222	223	224	225
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Criteria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4 (continued)

	Geological		Biological		Accessibility			Infrastructures				
	145	146	151	152	211	212	213	221	222	223	224	225
Biophysical	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Socioeconomic	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
Natural disasters	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
Climatologic	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Water resources	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Geological	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Biological	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Accessibility	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
Infrastructure	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012

Table 4 (continued)

	Geological		Biological		Accessibility			Infrastructures				
	145	146	151	152	211	212	213	221	222	223	224	225
	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

(iv) Creation of weighted supermatrix

The blocks of the unweighted supermatrix were weighted using the corresponding priorities of the clusters to create the column-stochastic weighted supermatrix. Columns in the supermatrix are composed of several eigenvectors of sum of vectors. The sum of each of which is equal to one. It is possible that the sum of each column in the primary supermatrix is more than one (proportional to the eigenvectors that exist in each column). Therefore, in order for the sum value in each column be equal to 1, it is required to standardize each column of the matrix by factorizing the elements of the column based on their relative weight. As a result, a new matrix called weighted matrix is obtained in which the sum of each column will be equal to one. This is similar to Markov chain in which the stochastic sum of all conditions is equivalent to 1. The weighted matrix is provided in Table 3, which is obtained from multiplying the data of the cluster matrix by the unweighted supermatrix and normalizing the resulting matrix.

(v) Formation of limit matrix

In the next step, the weighted supermatrix is raised to limiting powers in order to converge the matrix elements until the values in the matrix rows are equal to each other (Eqs. 4 and 5). The resulted matrix is presented in Table 4.

$$w = \lim_{k \to \infty} W^k \tag{5}$$

Results and discussion

After conducting the steps mentioned, the weight of each of the sub-criteria (map layers) was calculated using the ANP method shown in Table 5. The weighted map layers were later combined using WLC as the simplest commonly used multi-criteria decision-making method (Eastman 2001). The combination was done based on Eq. 6 by the Raster Calculator command in GIS software:

$$S = \sum_{i=1}^{n} W_i X_i \tag{6}$$

where S is the suitability degree, n is the number of factors (sub-criteria), W_i is the weight of the factor i, and X_i is the fuzzy value of the factor i.

Table 5 Weights of sub-criteria (map layers) determined by ANP method in Super Decision software

Sub-criteria	Weights	Sub-criteria	Weights
Distance from faults	0.074	Elevation	0.005
Distance from flood plains	0.041	Slope	0.006
Seismicity risk	0.042	Distance from protected areas	0.032
Percent of relative humidity	0.005	Land cover density	0.010
Average annual rainfall	0.007	Distance from airport	0.032
Average annual temperature	0.010	Distance from residential areas	0.100
Speed of prevalence wind	0.003	Distance from roads	0.069
Distance from rivers	0.048	Distance from gas transmission lines	0.012
Distance from wells	0.008	Distance from industrial areas	0.046
Depth of groundwater	0.021	Distance from waste disposal center	0.023
Soil erosion	0.040	Distance from power transmission lines	0.016
Land capability	0.055	Distance from wastewater treatment plant	0.004
Geological formations	0.024	Land use	0.078
Aspect	0.008		

Land suitability maps for urban development will be derived after applying the abovementioned equation, according to which the weights were multiplied by the relevant fuzzified map layers. Then, the weights of the map layers were added together to get an initial output map. The output is a raster map with a value range between 0 and 255. Higher values (close to 255) indicate more suitability of land for urban development, while lower values (close to zero) show the lands with poor suitability for urban development. The output map was converted to vector format and re-classified into five suitability classes of very high, high, medium, low, and very low. This map shows the classification of suitable lands for urban development in the county of Ahwaz shown in Fig. 4. The proportion of each suitability class is given in Table 6.

According to the obtained results, out of the entire study area (687,469.23 ha), the suitability of 40,901.13 ha (5.95 % of the study area) is very low for urban development. The low and medium suitable lands extend over an approximate area of 121,311.36 ha (17.65 %) and 265,481.55 ha (38.61 %), respectively. Highly suitable lands occupy 219520.98 ha (31.93 %), scattered mainly in the southern parts of Ahwaz County. Areas with very high suitability cover an area of 40,254,21 ha (5.86 %) within the central and eastern parts

Fig. 4 Final land suitability map for the physical development of Ahwaz County

Table 6 Area of suitability classes for the physical development of Ahwaz County

Suitability class	Area (ha)	Area (%)
Very low	40,901.13	5.95
Low	121,311.36	17.65
Medium	265,481.55	38.61
High	219,520,98	31.93
Very high	40,254,21	5.86

of the county. The final land suitability map indicates suitable and prioritized lands for urban development.

Subsequently, in order to ensure the accuracy of the final land suitability map, it was compared with the land suitability map of the comprehensive plan of Ahwaz County dated back to the year 2007 (Fig. 5). The comparison has been made by MCK software based on kappa coefficient. The kappa coefficient of 0.54, which falls within the acceptable range of 0.4–0.6 showed moderate and acceptable compliance of these two maps.

In this study, the analysis of land suitability for urban development in the county of Ahwaz was carried out with the help of a set of decision-making rules including fuzzy logic techniques and ANP in GIS software. The results of this study showed that the integration of GIS with ANP, due to involving all effective criteria and sub-criteria as well as experts' opinion in the site selection process, could provide a suitable framework to solve complex urban planning and management issues. In particular, the GIS is capable of managing many relevant spatial data and integrating data of several map layers to provide a comprehensive spatial database of available suitable lands for development, which in turn helps in problem solving.

Since the creation of the database in GIS software needs accurate information, the input data must have the proper resolution and decision-making criteria are carefully chosen. GIS, due to being fast, precise and

Fig. 5 Final land suitability map extracted from comprehensive plan of Ahwaz County

operational, is a capable and efficient tool for analyzing data and providing valid results for presenting appropriate patterns of urban development. So, the system would be an effective and important tool for sustainable planning and management of natural and human resources. It could also adjust interaction between these resources with the urban development of Ahwaz County.

In addition, the combination of ANP and fuzzy logic in this study overcomes many of the deficiencies and drawbacks of previous methods and leads to increased accuracy of the final decision. Reviewing the relevant literature, it was found that many of these studies have been conducted based on the conventional site selection methods such as Boolean models, overlapping, and AHP. Accordingly, the use of new models such as ANP and considering greater number of criteria and sub-criteria in land suitability analysis are what distinguish the present study from other similar studies.

The use of less important criteria and ignoring the more important items is another drawback observed in some of the studies. In this study, attempts were made to shortlist to an extent possibly the most important and influential biophysical and socioeconomic criteria according to previous studies and local conditions. Moreover, the use of expertise opinion in selecting and weighting of criteria and sub-criteria based on their experience and knowledge on the subject and also the local conditions had an important role in achieving the desired results.
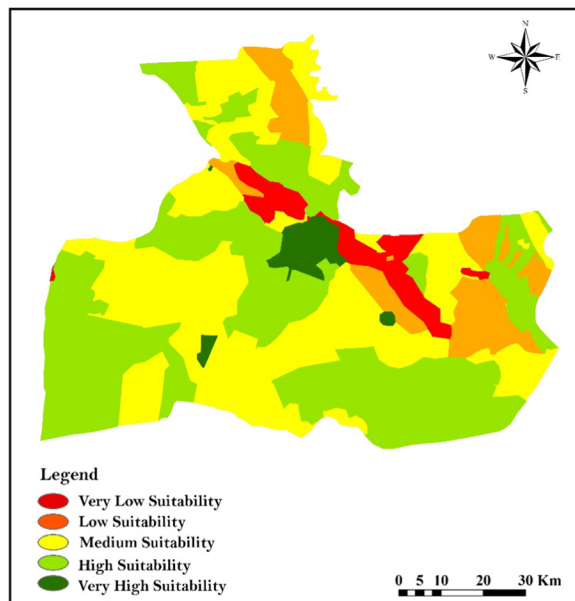
Conclusion

In this study, the analysis of land suitability for urban development in the county of Ahwaz was carried out with the help of a set of decision-making rules including fuzzy logic techniques and ANP in GIS software.

The results of this study indicated that ANP is a more powerful and more realistic technique than are other methods used in relevant studies. Because ANP, in addition to the features of AHP method such as flexibility, simplicity, and the use of qualitative and quantitative criteria simultaneously, considers the interaction of different levels of decision relative to each other, as well as internal interrelationships and dependencies of decision criteria within a level, which are ignored practically in other methods of decision-making.

Complexity and structure of feedback from locating suitable areas for urban development has revealed the

necessity of using this method in prioritizing them. However, the structural development of decision support model involving identification of all relationships between clusters and elements and the expression of various expert opinions in relation to the decision objectives in the ANP method is more difficult than in the AHP method. The results of this method at this level of scale and scope are greatly satisfying. Obviously, the accuracy of the final map is largely dependent on the accuracy of base maps and pixel sizes. If greater accuracy is desired, assessment should be done in a smaller area, with a larger scale and smaller pixels.

The results could also assist planners and experts to formulate an appropriate plan for sustainable development of the study area. Therefore, the development of appropriate strategies and guidance of residential centers toward suitable lands can prevent the spread of settlements in unsuitable areas and better preserve the environmental resources of the study area.

This study is a supplement of the previous paper on change detection in the county conducted Malmir et al. (2015). It is also expected that with slight changes on the model, it is used for other cities and provinces with similar conditions.

In the end, in order to avoid scattered urban sprawl and harmonize the physical development of cities, centralized management of cities is strongly recommended. It is also suggested to create a database of different land uses in the city to control unplanned constructions regardless of environmental considerations. Also, in order to achieve sustainable urban development, the development patterns should be proportionate to the lands surrounding the Ahwaz County. It is also recommended to develop appropriate and local criteria and use applicable models such as the multi-criteria evaluation model.

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