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Research Article

Spatial land use planning based on analytical hierarchy process (AHP) and GIS in Shandiz urban region, Northeast of Iran

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ABSTRACT

Background and objective: Inappropriate land use due to changing requirements and pressures leads to the destruction of land resources and increases poverty and other social problems.
Materials and methods: The present study evaluated the land suitability for the spatial development of the Shandiz urban region, northeast of Iran based on the analytical hierarchy process (AHP) and geographical information system (GIS).
Results and conclusion: On this basis, the land suitability of the study area for spatial development was estimated and revealed that 12 land uses (22.5% of the region) have high and moderate suitability for spatial development. Our results indicated that the regions with higher suitability for the spatial development of the Shandiz urban region are located in the middle and east parts of the study area. In contrast, the north, south, and west parts of the region have low suitability for spatial development. Our study presents a map of land suitability for the spatial development of the region, which will aid in appropriate planning, quick and safe mitigation measures, and future development strategies based on identifying the environmental factors affecting land suitability in the region. We developed a systematic regional planning approach to identify geographic priorities for on-ground natural resource management actions that most cost-effectively meet multiple natural resource management objectives.

1. Introduction

Urbanization is a global phenomenon that can be observed in many countries. Global urbanization has brought about rapid growth in the urban population from 751 million in 1950 to 7.7 billion in 2019 and is projected to increase further to 9.7 billion in 2050 (United Nations, 2019). Rural areas in the suburbs are also developing through the urbanization process. Small towns near many metropolitan areas are important because they play a role in providing rural communities with access to urban services (Rostam et al., 2010; Saleh et al., 2012). They are the drivers of economic

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growth, and to ensure balanced economic growth, regional development strategies have been deployed to address the unbalanced development between urban and rural areas (Saleh et al., 2014). Strong infrastructure can improve access to basic facilities and services in rural areas to provide better access to health, education, water, and electricity. The main drivers for new developments, especially residential and commercial areas, in neighbouring regions and smaller towns (Samat et al., 2019). Inappropriate land use leads to the destruction of land resources and increases poverty and other social problems (FAO, 1976; FAO, 1977; Duc, 2006).

Considering the impact of the user on the land, such problems from improper land use are common. The basic principle of sustainability is to ensure the most appropriate use of the land, taking into account the characteristics of the land and the needs of the users (Prakash, 2003; Mohit and Ali, 2006). The suitability of a country for specific purposes is assessed using a suitability analysis (FAO, 1985; Rossiter, 1996). Suitability analysis aims to determine the future land use pattern that best suits needs and preferences (Hopkins, 1977; Collins et al., 2001; Malczewski, 2004). This analysis is a decision-making process that takes into account not only the natural capacity of the land unit to support a particular use, but also socio-economic and ecological characteristics. In this process, it is becoming increasingly difficult to take relative account of various criteria in determining the appropriate type of land use. Hence, multi-criteria decision-making methods (MCDM) are now used, which facilitate the calculation of the weights of factors affecting the suitability evaluation (Mendoza, 1997; Jankowski et al., 2000; Cengiz, 2003; Prakash, 2003; Duc, 2006). MCDM methods can analyze problems, generate alternative solutions, and evaluate alternatives. The general purpose of these methods is to make it easier for decision-makers to choose the appropriate use among alternatives (Malczewski, 1999; Eldrandaly et al., 2005; Ohman et al., 2007). MCDM methods incorporate qualitative or quantitative weightings to rank or rank criteria and rank usages in single or multiple sentences by importance (Heywood et al., 1995; Jankowski and Richard, 1994).

However, the exclusive use of these methods has limitations in terms of geographical dimensions (Malczewski, 1999) since conventional multi-criteria decision-making techniques do not take into account spatial differences in the terrain under consideration, and estimate mean values or sums of integers. (Jankowski and Richard, 1994; Tkach and Simonovic, 1997). This deficiency is largely remedied by the application of the multi-criteria spatial analysis technique, which offers the possibility of making an assessment taking into account the heterogeneity within the area. This technique accounts for differences indicated by area criteria and alternative values (Ascough et al., 2002; Prakash, 2003). The integrations of GIS and MCDM methods is a widely used decision support technology that enables spatial identification in land use analysis. Together, the GIS and MCDM methods address the shortcomings in integrating geographic information with subjective values and preferences (Mohit and Ali, 2006). The integration of GIS and spatial multi-criteria decision-making (SMCDM) as a means of decision support is now widely used to solve problems in different sectors (Carver, 1991; Jankowski, 1995; Foote and Lynch, 1996; Eldrandaly et al., 2005; Bello-Pineda et al., 2006; Fusco Girard, & De Toro, 2007). GIS is a powerful tool for spatial and attributes data input, storage and query, manipulation and analysis, and output (Marble et al., 1984; Duc, 2006).

It also allows the mapping of the data obtained (Mohit and Ali, 2006). Therefore, GIS is efficient in the spatial decision-making process. The integration of AHP, a multi-criteria analysis method, with GIS in land suitability analysis is amenable to many studies (Malczewski, 1996; Thirumalaivasan et al., 2003; Aly et al., 2005; Banai, 2005; Hill et al., 2005; Cengiz and Celem, 2006a, 2006b; Gloria et al., 2007; Li et al., 2007; Ying et al., 2007) as AHP facilitates the balancing of factors affecting soil suitability and has a high ability to integrate heterogeneous data (Prakash, 2003). The method, which allows to evaluation group decisions with a logical and systematic approach, is used to select the best alternative among those identified for a specific purpose, taking into account several criteria (Saaty, 1977, 1980; Saaty and Vargas, 2001). Urban land use planning and management is a volatile mutation around the world. With the aim of sustainability, the use of indicators for area testing and monitoring is increasingly in demand. Classical approaches build basic sets of indicators by selecting the most relevant items from exhaustive lists. More recently, some structured research approaches consider the set of indicators as a whole, following system concepts, and thus highlighting the spatial strengths and weaknesses of the sets.

Several studies have developed techniques for integrated regional planning, including land use planning and information systems (Ive, et al., 1989), a multi-criteria decision support tool for integrated land-use planning (Recatala et al., 2000), and a relational indicator set model (RIM) to design a set of spatial and non-spatial indicators for cities (Repetti and Desthieux, 2006). Other studies have also shown that integrated and quantitative spatial planning can achieve multiple natural resource management objectives in areas such as environmental management (Hill et al., 2005; Crossman et al., 2007), forestry (Bettinger et al., 2005) and agricultural resource management (Hayashi, 2000). Land use patterns are based on and influenced by a variety of factors and processes in different sectors, such as B. natural site conditions and urban site selection. They all change over time due to technical possibilities (Bartel, 2000).

Urban land use patterns are defined as a framework of spatial relationships between areas of different use and are thus also an expression of a spatial functional configuration that is being investigated within the framework of the model-based research project. The integration of land assessment and GIS can provide an improved basis for approaching the spatial suitability assessment of land. Analytic Hierarchy Process (AHP) is a decision-making approach that uses multiple goals and criteria to arrive at a scale of preference among a set of alternatives (Saaty, 1980; Saaty & Vargas, 2001). AHP has found wide application in site selection, suitability analysis, regional and urban planning, and natural hazard assessment. The present study aimed to assess the suitability of areas for sustainable urban development in the urban region of Shandiz, one of the most important tourist centers in northeastern Iran.

2. Materials and Methods

2.1. Geographic position of the study area

The study area is located in the northern part of Binaloud mountainous zone, Northeast Iran (Fig. 1).

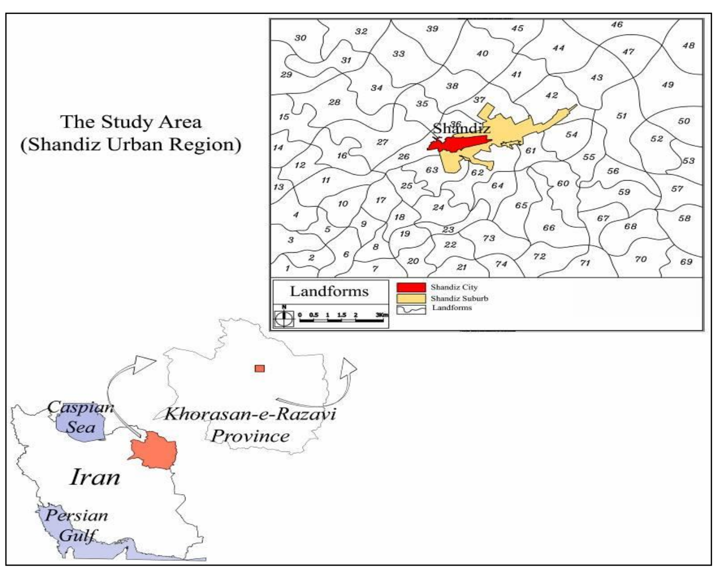

Fig. 1. The position of the study area

The topographical features are complex and varied and are dominated by mountains and hills from 1000 to 1600 meters above sea level. The study site lies between latitude 36° 19' N to 36° 26' N and longitude 59° 13' E to 59° 23' E with a total area of about 173 Km2 which located in the northern part of Binaloud mountainous zone, Northeast Iran (Fig. 1). The study area is covered mainly by Alluvial Terraces and Phylitic formations. The area includes several fault systems southward of Shandiz City. The main land-use form in the study area is semi-compact pasture lands, irrigated farmlands, and gardens, respectively. More than one-third of the study area has steep slopes over 15°. The pattern of settlement in the study area has focused on Shandiz City with a total population of about 10000 people. The city has had quick spatial development from 589 ha to 1340 ha over the recent decade.

2.2. Procedure and methodology in land suitability

The integration between the geographic information system (GIS) and the Multiple Criteria Decision Making (MCDM) methods can create a dynamic land use model. Criteria to be considered when analyzing the suitability of land use (Rad & Haghyghy, 2014). MCDM techniques should be used in conjunction with GIS tools to obtain concrete research results, based on various criteria established depending on the context of the study (Rusydiana & Devi, 2013). Established criteria are generally in the form of parameters or standards that can be measured in decision-making. Criteria analysis and scoring are performed to obtain a set of measurements and are used as a tool to compare the best criteria in the study. The procedure of spatial land suitability evaluation for urbanization applied in our study has been shown in Fig. 2. In this process determining environmental factors by the AHP approach are essential for evaluating spatial land suitability for different land uses of the study area. Each factor layer can be organized in the form of one map layer in GIS. The overlay of these map layers in GIS produces a composite map of land uses. The spatial land suitability analysis process is demonstrated in Fig. 2.

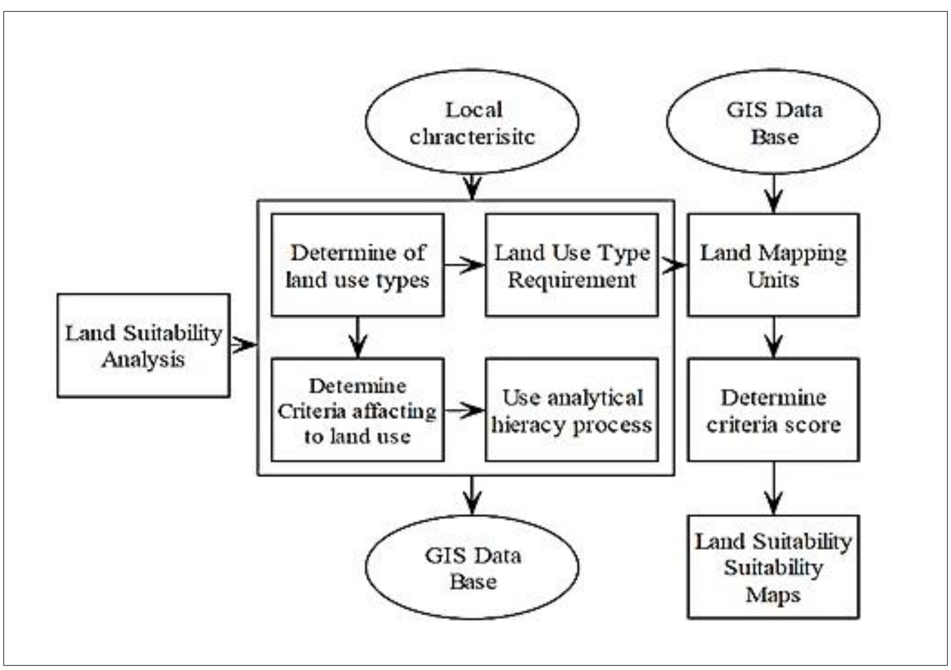

Fig. 2. Spatial land suitability analysis process (Chanhda, et al., 2010)

2.3. AHP approach in land suitability evaluation

The Analytic Hierarchy Process (AHP), one of the MCDM techniques, is used in this study over other techniques because it requires precise numerical values to express the strength of expert selection in decision-making for the results of the analysis of land use. The AHP developed by Saaty (1980) considers a one-level weighting system through a pairwise comparison matrix between the parameters as described by Saaty (1990, 1994) and Saaty and Vargas (1991, 2001). The method employs an underlying nine-point recording scale to rate the relative preference on a one-to-one basis of each criterion (Malczewski, 1999). For better map presentation purposes, a scale assigns linguistic expression to each corresponding numerical value (Table 1).

Table 1. Pair-wise comparison nine-point rating scale

Importance	Definition	Explanation
1	Equal importance	Contribution to objective is equal
3	Moderate importance	Attribute is slightly favored over another
5	Strong importance	Attribute is strongly favored over another
7	Very strong importance	Attribute is very strongly favored over another
9	Extreme importance	Evidence favoring one attribute is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

When using this approach, it is commonly accepted that taking numerical values and assigning them such linguistic expressions that translate into imprecise terminology creates a vast area of ambiguity about the results. The numerical values are quantified translations useful for calculating factor weights and the validity of the numerical values may best be judged by the factor weights and the consistency of the calculation process (Ayalew et al., 2004). Pair-wise comparison, however, is subjective and the quality of the results is highly dependent on the expert's judgment. The weights of factors are calculated from the pair-wise comparison matrix undertaking specific values and vector calculation. The sum of criteria weights should be equal to 1. The complete pair-wise comparison matrix contains many multiple paths by which the relative importance of factors can be assessed; therefore, it is also possible to determine the degree of consistency that has been used in developing the judgments. In the construction of the matrix of paired comparisons, the consistency of the judgments should be revealed because this matrix is a consistent matrix. In the AHP approach, an index of consistency, known as the consistency ratio (CR), is a ratio between the matrix's consistency index and random index. CR is used to indicate the probability that the matrix judgments were randomly generated (Malczewski, 1999).

$$CR = \frac{CI}{RI} \quad (1)$$

Where RI is the average of the resulting consistency index depending on the order of the matrix given by Malczewski (1999) and CI is the consistency index and can be expressed as

$$CI = \frac{\lambda max - n}{n - 1} \quad (2)$$

Where, λmax is the largest or principal specific value of the matrix and can be easily calculated from the matrix, and n is the order of the matrix. CR ranges from 0 to 1. A CR close to 1 indicates the probability that the matrix's rating was randomly generated. A CR of 0.10 or less is a reasonable level of consistency (Malczewski, 1999). A CR above 0.1 requires revision of the judgments in the matrix. In this case, the CR of the matrix of paired comparisons between the 10 influential factors in our land suitability assessment is 0.096 which seems logical. The weights should add up to a sum of 1.0, as the linear weighted combination calculation requires.

$$\sum_{j=1}^{n} w_j = 1 \qquad (3)$$

The results of the pair-wise comparison matrix and the factor weights are shown in Table 2.

Table 2. The hierarchy weight values of evaluation factors

CR=0.096											**Factor weights**
Elevation	1.00										0.03
Slope	3.00	1.00									0.16
Physical dev.	6.00	0.33	1.00								0.11
Road network	8.00	2.00	1.00	1.00							0.20
Env. hazards	4.00	1.00	1.00	1.00	1.00						0.16
Vegetation	5.00	0.33	0.50	0.50	0.50	1.00					0.10
Drainage	0.50	0.13	1.00	0.14	0.17	0.17	1.00				0.03
Lithology	3.00	3.00	1.00	0.33	0.50	1.00	3.00	1.00			0.11
Soil infiltration	1.00	0.20	1.00	0.25	0.33	0.25	3.00	0.33	1.00		0.04
Soil erodibility	5.00	0.25	0.20	0.33	0.33	0.50	3.00	0.50	3.00	1.00	0.06

Then, the category class of each evaluation factor was determined as shown in Table 3.

Table 3. The category scores given to environmental factors

Env. factors	category	Scores
Elevation	< 1400 m	1
	> 1400 m	0
Slope	< 15%	1
	> 15%	0
Physical development	Permanent settlement	1
	No settlement	0
Road network	Roads accessibility	1
	No accessibility	0
Environmental hazards	Landslide, Flooding	0
	No hazard	1
Vegetation	Pastures, Farms	1
	Gardens	0
Drainage	High density drainage	0
	Low density drainage	1
Lithology	Sediments, Sand stone, Granite	1
	Phylitic Shale, Marn	0
Soil infiltration	Low Infiltration	1
	High Infiltration	0
Soil erodibility	Low erodibility	1
	High erodibility	0

When restrictions were imposed on a particular land use, the class index value assigned was zero, which indicated that it was unsuitable. The determination of the spatial land suitability was done using the index sum method. This method sums up the product of weight values and category scores for each land use by the following equation:

$$F = \sum_{k=1}^{n} w_{ik} \times U_{ik} \qquad (4)$$

Where F is the sum total of fraction values for every evaluation unit, W_{ik} is the weight value of the k evaluation factor for the i-evaluation unit, U_{ik} is the index value of the k evaluation factor for the i-evaluation unit, and n is the number of evaluation factors. An IDW interpolation function in ArcGIS ver.10.7 was applied to map the spatial land suitability of the study area.

3. Results and discussions

The systematic regional planning method we present employs a land suitability analysis framework for spatial development. A database is produced by digitizing the data from field observations and environmental factor maps in GIS environment (Fig. 3). The AHP method is a measurement theory based on priority values obtained from pairwise element comparisons. By using the AHP method, the criteria for choosing a model can be clearly defined and the problem can be systematically structured. AHP facilitates the hierarchical structuring of goal-oriented decisions as it allows the combination of strategies and activities. This approach allows decision-makers to compare and check suitability criteria. Because the method measures the inconsistencies in the ratings, it can measure the logical relationship of the values given in the qualitative factors and therefore minimizes the rating errors within its mechanism. Specialists can meet and discuss land potential and issues in terms of the weighting of all evaluation criteria.

This application significantly reduces the time and effort required for land use decisions and can contribute to creating more complete data about the area under consideration and building an infrastructure for future planning. The quantitative relationship between affecting factors and spatial development of the Shandiz urban region was achieved by the Analytic Hierarchy Process (AHP) method to produce the land suitability map. With this method, the effect of the categories of the data layer and the effective value related to each factor is quantitatively determined. It has been shown that the use of the AHP method produces a practical and realistic result to define the factor weights in the land suitability evaluation. Based on the AHP method, it has been revealed that Road network, slope, and Environmental hazard are important parameters for land suitability in the region. The resultant land suitability evaluation map divided the study area into four zones, with a suitability index of high (<0.50), moderate (0.50-0.60), low (0.60-0.70), and negligible (> 0.70) suitability. The area and percentage distribution of the land suitability indices in the study area were determined as a result of an analysis showing the effects of each land use (Table 4).

Table 4. Land suitability index for each land use

Land suitability	Number of land uses	Area (Km^2)	Percent of the study area (%)
High	2	3.4	2.0
Moderately	10	35.6	20.5
Low	23	53.8	31.1
Negligible	39	80.2	46.4

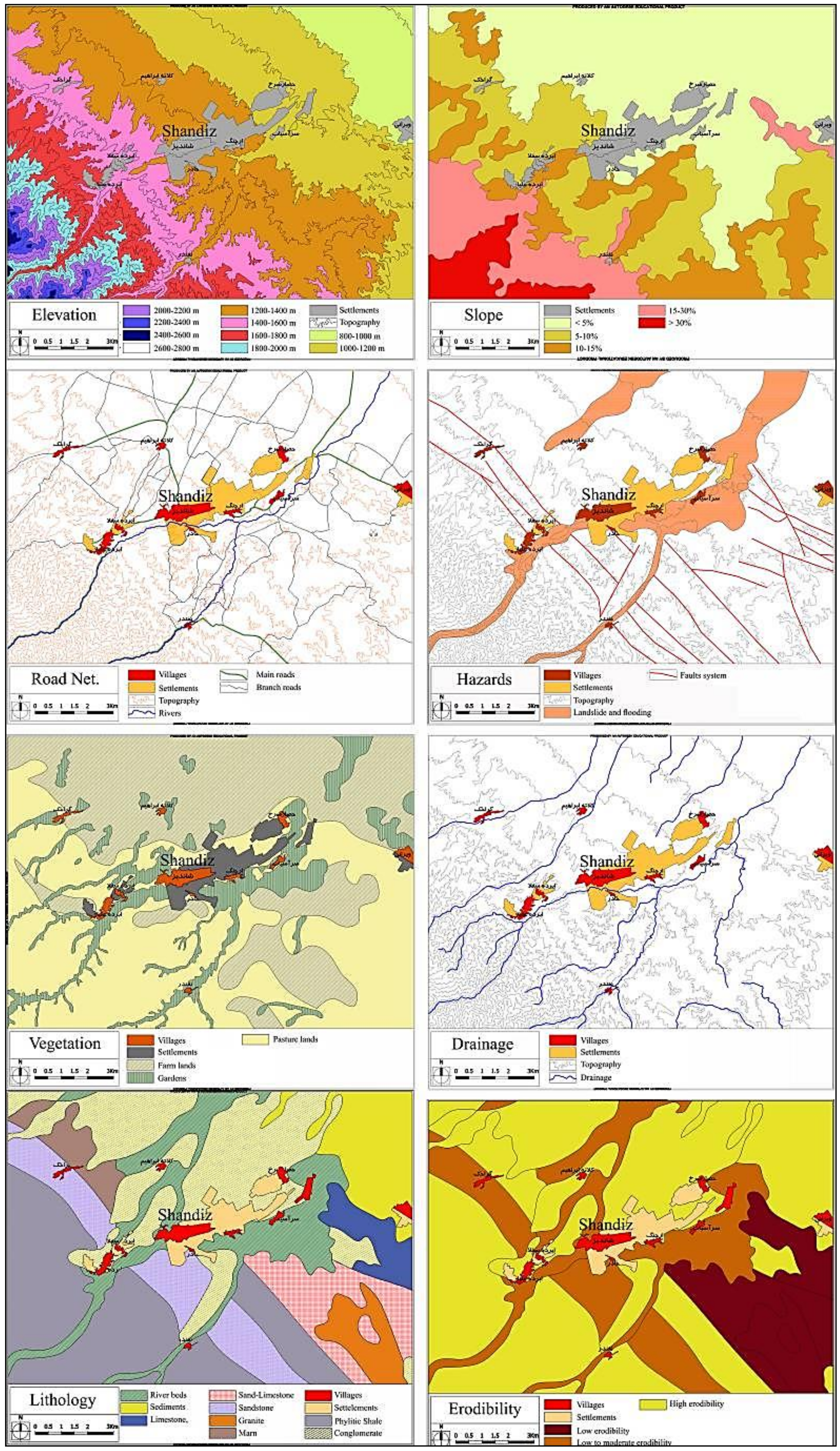

Fig. 3. The environmental factor maps

According to the result of the analysis, the suitability of the study area by colors is as follows; 46.4% (80.2 km2) is negligible (red), 31.1% (53.8 km2) is low (yellow), 20.5% (35.6 km2) is moderate (green) and 2.0% (3.4 km2) is high (blue). About 77.5% of the study area including 62 land uses has a low and negligible suitability to the spatial development of the Shandiz urban region, while 22.5% of the region including 12 land uses falls into the high and moderate categories. According to the land suitability evaluation map, future spatial developments are also predicted for all areas in the middle to the north that are in some proximity to slopes lower than 15° which corresponds well with observed pasture lands (Fig. 4).

Moderate Land suitability is identified for areas comprising the gardens covered most of the hills and valleys. Land use change resulted from the distribution of urban activity, with central areas serving economic, political, institutional, and cultural functions (Rodrigue, 2020). The results of this study indicate that road networks are an important factor contributing to land use change in Shandiz district. The development of a systematic transportation system, especially the development of highways, plays an important role in influencing the pattern and flow of future development (Yaakup, 2008; Masumi et al., 2014; Ghane Ezabadi et al., 2021).

There were also significant changes in the agricultural land use (vegetation). The pattern of changes in agricultural land use that used to mature gradually has now become more planned (Amir, 2004). Changes in land use and development direction in the Shandiz district require a local authority to Plan, manage and monitor development effectively to maintain the overall quality of the landscape and its ecological system.

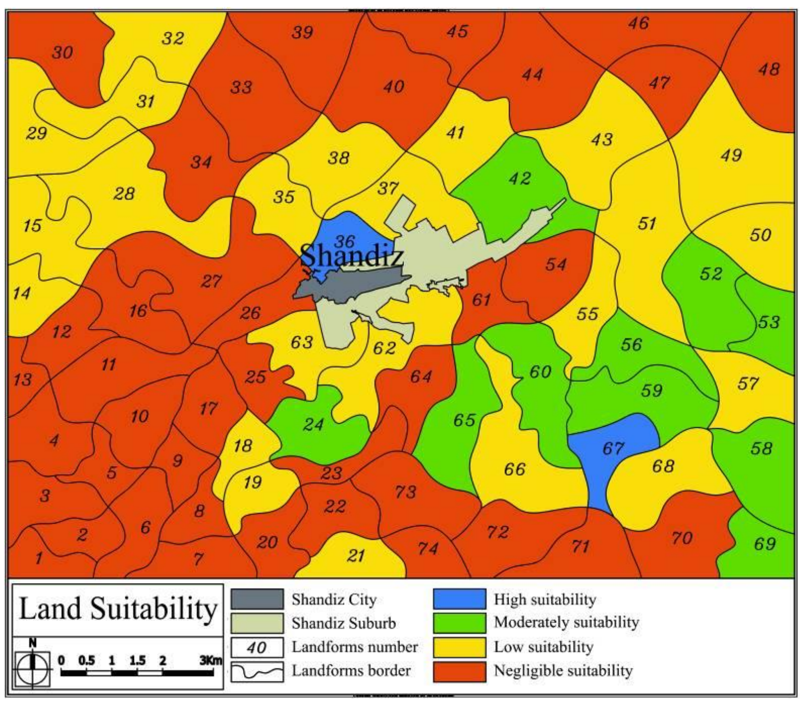

Fig. 4. Land suitability evaluation map of the study area

4. Conclusion

The pattern of change and land use suitability is a phenomenon that needs to be studied to construct a comprehensive scenario of suburban/urban land use in rural areas. Measurement of parameters that may contribute to land-use change also needs to be accurately determined to more effectively assess the factors driving land-use change. In the present study, we applied the analytic hierarchy process (AHP) and GIS analysis to produce a Land suitability evaluation map for spatial planning of the Shandiz urban region, northeast of Iran. A database is produced by digitizing the data from field observations and environmental factor maps in GIS environment. Based on the AHP method, it has been revealed that Road network, slope, and Environmental hazard are important parameters for land suitability in the region. The resultant map divided the study area into four zones, with a suitability index of high, moderate, low, and negligible. Our results revealed that about 22.5% of the region is prone to moderate and high suitability for spatial development.

Declarations

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Conflict of Interest /Competing interests (The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript)

Availability of Data and Material (Data are available when requested)

Consent to Publish (Authors consent to publishing)

Authors Contributions (All co-authors contributed to the manuscript)

Code availability (Not applicable)

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