



# GIS-Based Multi-Criteria and Multi-Objective Evaluation for Sustainable Land-Use Planning (Case Study: Qaleh Ganj County, Iran) “Landuse Planning Using MCE and Mola”

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## Abstract

Land evaluation is a key factor in land-use spatial planning, affecting both success and sustainability. This study showcases the value of using the multi-criteria evaluation (MCE) and multi-objective land allocation (MOLA) GIS decision-making tools determine the most favorable spatial development of various land-use types, for Qaleh Ganj County in Iran. Weighted linear combination (WLC) and ordered weighted averaging (OWA) were used to assess the potential of seven land uses based on predefined criteria. MOLA was also used for land-use zoning based on suitability. The results derived from these techniques indicate that the rangeland zone with 30.80% and the ecotourism zone with 22.9% have the highest suitability potential, and aquaculture with 0.26% and tourism with 0.24% have the lowest potential in Qaleh Ganj. Considering the 7 land uses and a lot of defined criteria, MCE and MOLA provided an automatic and flexible way of dealing with qualitative multi-dimensional environmental effects, factors, constraints and objectives. The combination of WLC and OWA helped to manage selection factors differently, as their level of risk and trade-off is different. The result can be considered as optimal suitability maps with an environmental preservation goal which can help to protect the natural environment of this area, and will also allow for continued economic development. The approach described in this study can help developing countries and the sensitive area facing environmental challenges due to rapid development. This approach and its application procedures can be applied to similar territorial contexts, where several territorial factors should be considered and taken into account.

## Article Highlights

- The study illustrates the advantages of using automatic MCE and MOLA methods for spatial planning in Iran with emphasis on environmental preservation vision.
- The offered approach (a combination of WLC and OWA) for suitability land evaluation would help to protect the natural environment of the urban while allowing for continued economic development.
- Considering factors as 2 distinct groups of environmental relevant and cost relevant factors and treat them based on their level of a trade-off for land-use suitability assessment.
- MOLA as an automatic zoning procedure represents a potential solution to the conflict between zoning types of land use and contributes to the optimization of site selection. This helps to minimize subjectivity in land use planning.

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## Introduction

In recent years, spatial planning and development have increasingly focused on environmental protection issues (Tortora et al. 2015; Romano et al. 2015; Memarbashi et al. 2017), where increased economic growth and human activity have continuously impacted on land-use selection and determination (Chen 2014; Jafarian and Kavian 2013). Spatial planning, including land-use development, is known as one policy focus area that plays an influential role in effective natural resource management (Yiannakou and Salata 2017). Land suitability assessment practices are considered as part of the solution for effective land-use allocation and land-use planning (Bocco et al. 2001; Bunruamkaew and Murayama 2012; Briassoulis 2019; Rossiter 1996). Assessing land suitability is a key strategy for promoting sustainable development in land-use planning (Ostovari et al. 2019). The suitability of land for a particular land use varies greatly due to different biophysical qualities and characteristics. Therefore, land suitability evaluation and land-use planning require large amounts of different data (quantitative and qualitative criteria) (Nguyen et al. 2015).

The use of quantitative methods, such as multi-criteria decision making (MCDM), in land-use suitability procedures, allows for the effective use of heterogeneous data (Mosadeghi et al. 2015). According to Malczewski and Rinner (2015), MCE has been used in a variety of applications for spatial decision analysis and management situations. The authors emphasize compensation methods, particularly weighted linear combination (WLC) and ordered weighted averaging (OWA), which is a generalization and extension of the WLC model.

These two aggregation methods attempt to overcome the lack of sensitivity of traditional Boolean overlay techniques. For instance, in contrast to Boolean suitability aggregation that assumes a crisp boundary and certainty, WLC and OWA allow trade-offs between criteria by weighting the normalized criteria according to their relative importance (Jiang and Eastman, 2000; Hanssen et al. 2018). Several studies demonstrate the potential of the integrated approach in using GIS and MCE (WLC or OWA) for land evaluation (Akbari et al. 2019; Bunruamkaew and Murayama 2012; Chivasa et al. 2019; Comber et al. 2010; Jamil et al. 2018; Karimi et al. 2020; Motlagh and Sayadi 2015; Masoodi et al. 2016b; Zolekar and Bhagat 2015; Zabihi et al. 2019; Sumida and Valente 2019; Shuaibu Kara 2019). These studies showed that these approaches provide more accurate results for land suitability than the Boolean classification, also in some studies, WLC was compared to the OWA aggregation method. In one case, Sumida and Valente (2019) used WLC and OWA

to define land suitability in the south-eastern part of São Paulo, Brazil, and according to their results WLC provided more general and less flexible solutions, but OWA provided a greater number of possible spatial planning scenarios most suitable to the researcher's goals. Other studies (Hajizadeh et al. 2020; Hanssen et al. 2018) have shown OWA to have a high potential for modeling complex decision problems due to a new concept in this method called order weights.

In this study, we used the MCE (a combination of WLC and OWA) method for land evaluation for seven different land uses (objectives), which may lead to conflicting land-use suitability between some of the land uses evaluated, which means that, in some cases (e.g., industrial development and horticulture), the land could only be assigned to one use and not both. In this respect, MOLA is considered as a spatial optimization model that assigns appropriate uses to specific land units subject to multiple objectives/parameters and constraints (Dai and Ratick 2014; Song and Chen 2018). Thus, there is no overlap or conflict between defined zones in the final land-use suitability (zonation) maps. MOLA is known as a solution to resolving objective conflict (Eastman 2003; Ichwani et al. 2018).

Surprisingly, through searching the scientific literature we found few publications on the zoning of terrestrial environments for multiple land uses using MOLA (Fataei and Mohammadian 2015; Hajehforooshnia et al. 2011; Mehri et al. 2018; Mahmoodzadeh et al. 2019; Shaygan et al. 2013; Sitko and Scheer 2019) which focus mainly on the natural environment or protected areas but not on the mixed environment of urban and natural areas (peri-urban to rural) land-use planning. The integration of MCE with GIS and MOLA has significantly advanced conventional map overlay approaches (Zhang et al. 2013). MCE and MOLA allow one to assess the relative priorities of a region based on criteria and indicators for that region and provide a framework for solving multi-objective land allocation problems in cases of conflicting objective cases (Hajehforooshnia et al. 2011). No research on the MCDM approach has been conducted so far, in particular using the OWA and MOLA method for multiple land-uses zoning town environments in Iran, which will be discussed in this paper.

## Research Objective

The main aim of this study was to apply MCE with a fuzzy approach and Analytical Hierarchy Process (AHP), integrated with GIS, to evaluate the area of Qaleh Ganj, Iran, for the optimal spatial mix of seven land-use types (aquaculture, arable land, horticulture, rangelands, industrial

development, tourism, and ecotourism), based on optimum potential suitability, with a focus on environmental preservation. This included using an automatic MOLA model to minimize subjectivity in defining the zonation of specific land uses across the county.

Specifically, we investigate:

- How can be solved the WLC problem (complete trade-off between factors) by using a GIS-based OWA method with a multi-criteria approach?
- -How can the critical factors, through their relative weights imported into GIS-based MCE capabilities, help decision-makers in land-use planning now and in the future?
- How can the MOLA model contribute to zoning multiple land uses and contribute to solving land suitability conflicts in the urban environment?

## Materials and Methods

### Study Area

Qaleh Ganj (a.k.a. Ghaleh Ganj) County (27° 31' 25" N and 57° 52' 52" E) is located in the south of Kerman Province in south-eastern Iran (Fig. 1), with an area of approximately 10,440 km<sup>2</sup>.

It is situated in a region with a low elevation to sea level (350–1000 m), low rainfall, and extensive sandy deserts. It should be noted that the protected area MARZ is situated in Qaleh Ganj County with a total area of 213,578 ha (Fig. 1).

### Data Collection and Preparation Using GIS

Data used in this study were collected from a variety of sources (Table 1); layers showing land-use and access routes were corrected using a satellite image (Landsat ETM+,

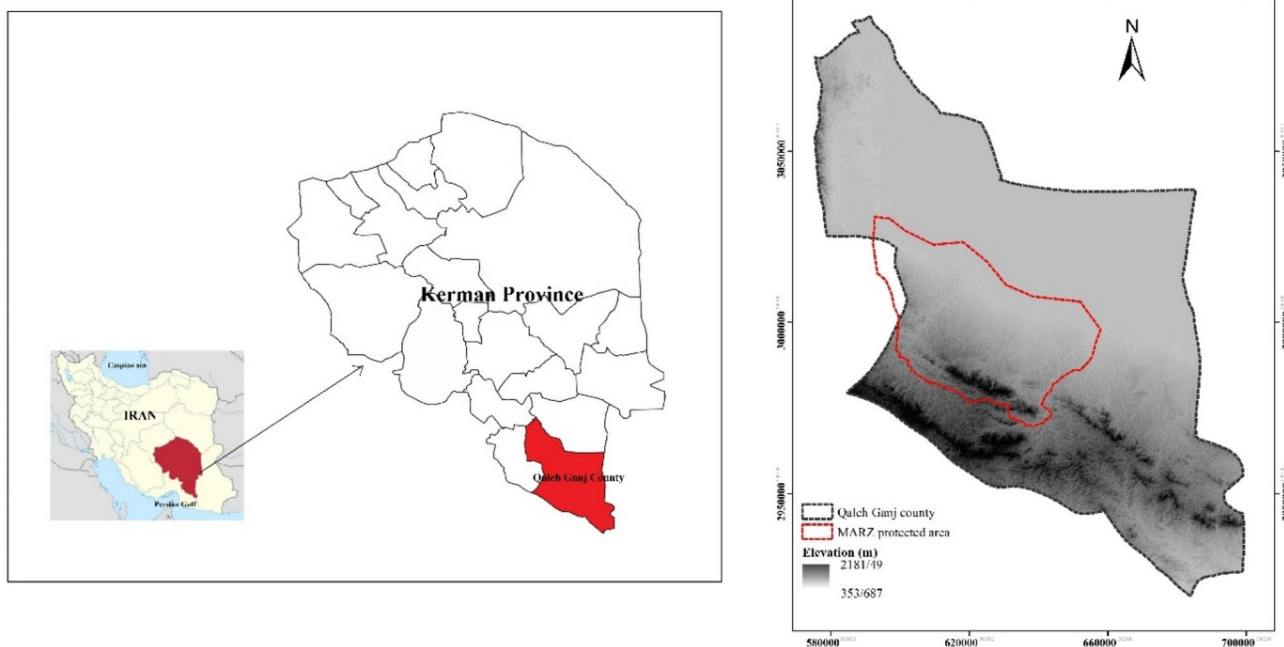


Fig. 1 Location of Qaleh Ganj County town in southern Iran

**Table 1** List of data and sources (data acquisition) for land-use planning of Qaleh Ganj County, Iran

Data	Source
Digital elevation model (DEM), original boundary, topographic map (1:25,000)	Iran National Cartographic Center
Vegetation cover, land use, land capability	Forests, Range and Watershed Management Organization of Iran
Soil and geology maps	Geological survey and mineral exploration of Iran
Climatic data and maps	Iran Meteorological Organization

2018), and control points were determining by field surveys. Existing land-use map of study is shown in Fig. 2.

**Methodology**

In this research, we use land suitability analysis to determine the optimal position for different land uses by combining GIS and MCDM techniques. This consists of two main steps: (1) evaluation of land suitability for different land uses using multi-criteria evaluation (MCE), (2) zoning using multi-objective land allocation (MOLA) (Fig. 2).

**Evaluation of Land Suitability by MCE**

The purpose of MCE is to investigate options among several possibilities from multiple criteria and multiple objectives (Mensour et al. 2019). In this method, multiple criteria are aggregated into a single evaluation score for each decision alternative. The mathematical model of multi-criteria land suitability evaluations is expressed as Eq. 1 (Mendoza 2000):

$$S = f(x_1, x_2, \dots, x_n), \tag{1}$$

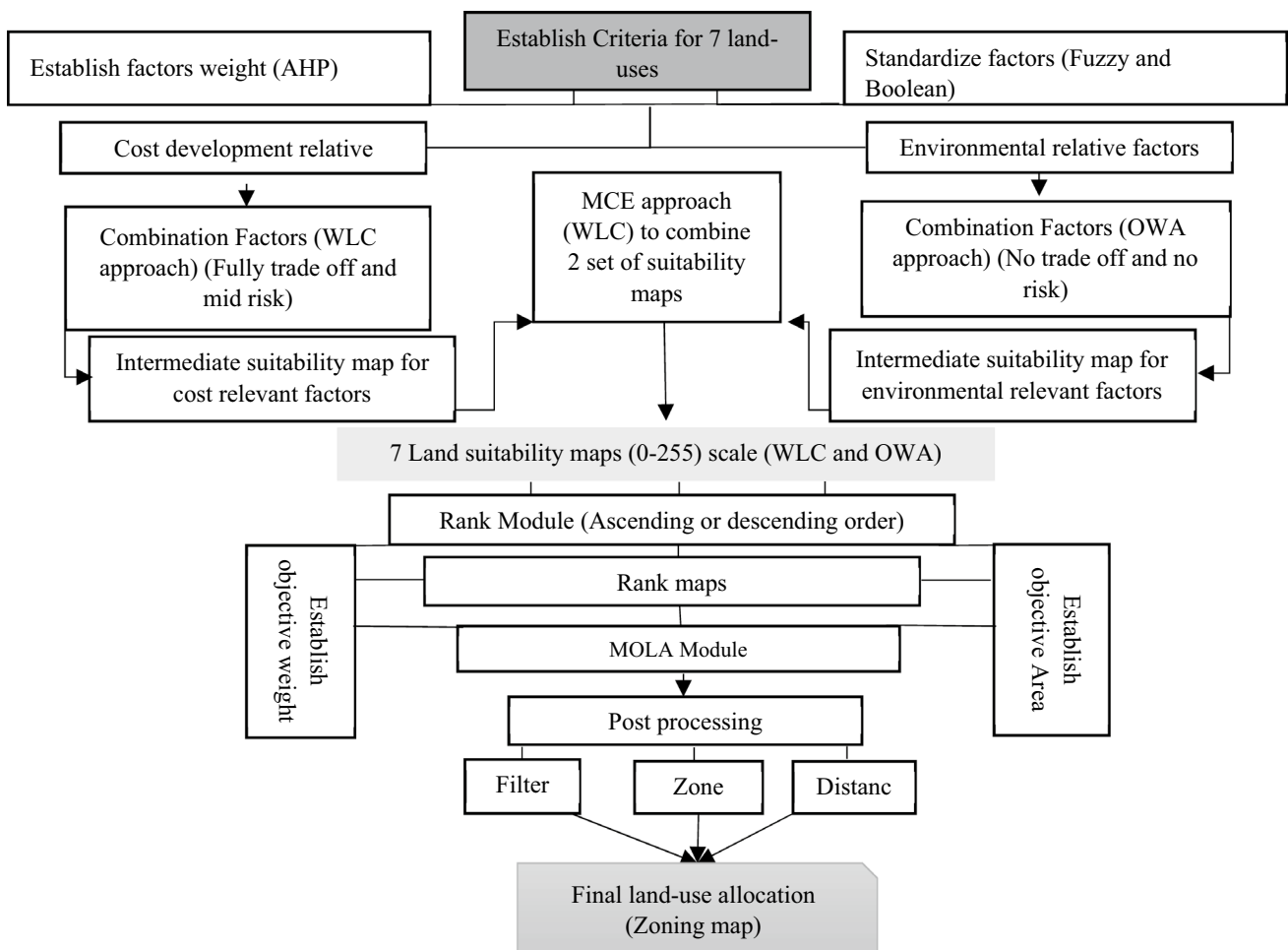
where  $S$  represents land suitability measures, and  $x_1, x_2, \dots, x_n$  are the criteria affecting the suitability of the land.

The multi-criteria analysis based on GIS was carried out using three methods: Boolean overlay, weighted linear combination (WLC), and ordered weighted averaging (OWA). In addition, the analytical hierarchy process has been applied to determine the weighting of the criteria.

The Boolean overlay led to the identification of suitable sites and the elimination of others without taking into account the level of suitability, and these drawbacks can be solved by weighting the factors and aggregating them with procedures based on the weighted average (WLC and OWA methods).

Therefore, in this research, we applied these two later methods for land suitability.

WLC compensatory decision rules are a widely used GIS-based decision support tool (Malczewski, 2006). This method involves a multi-stage process of (1) defining objectives, (2)



**Fig. 2** Multi-criteria and multi-objective flowchart in this study for land-use planning in Qaleh Ganj County

choosing the criteria to measure the objectives, (3) specifying alternatives, (4) assigning weights to the criteria, and (5) applying the appropriate mathematical algorithm for ranking alternatives (Masoodi et al. 2016a). The OWA procedure is the same as the WLC procedure, but only OWA requires additional weights, called order weights, and determines the combination of factor weights. Seven chosen land uses (objectives) included aquaculture, arable land, horticulture, rangelands, industrial development, tourism, and ecotourism. It should be noted that these land uses are the most conventional land uses that are suitable or acceptable for Iran's environmental conditions (Makhdoum 2001). The applicable criteria for the suitability of these seven land uses were chosen based on a literature review (Feizizadeh and Blaschke 2013; Hajehforooshnia et al. 2011; Makhdoum 2001; Masoodi et al. 2016a; Eastman 2010; Salmanmahiny et al. 2014). Makhdoum (2001) identified the most important criteria for different land uses (including arable land, horticulture, rangeland, aquaculture, industrial development, tourism, ecotourism) which are compliant and consistent with Iran's environmental condition. These factors serve to support or reject suitability for a specific area (Jiang and Eastman 2000). The criteria are shown in Table 3.

### Weighting Criteria by AHP

To take into account the judgments of stakeholders and to make a joint decision on the preferred alternatives, the analytical hierarchy process (AHP) approach was used for prioritization, as it is relatively easy to handle multiple criteria and can balance both qualitative and quantitative data (Gorsevski et al. 2006; Hanssen et al. 2018).

AHP extracts the weights from a pairwise analysis of the relative value of the parameters. By taking the eigenvector corresponding to the largest eigenvalue of the matrix, the AHP calculates the weighting for each criterion ( $w_i$ ) and then normalizes the sum of the components to unity as:

$$\sum_{i=1}^n w_i = 1. \quad (2)$$

A scale of significance for these comparisons is proposed (Table 2) (Saaty 2000).

However, decision makers sometimes make inconsistent (subjective) judgments, in which case the mentioned consistency is not always satisfied. Therefore, after obtaining the weight values it was important to test the accuracy of the matrix. AHP provides measures to assess this mathematically. The consistency is measured according to a consistency ratio (Eq. 3)

$$CR = \frac{\lambda_{\max} - n}{(n - 1)RI}. \quad (3)$$

Hereby the random index (RI) is the average of the resulting consistency index,  $\lambda_{\max}$  is the largest or principal

**Table 2** Scale for pairwise comparisons proposed by (Saaty 2000)

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	The strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
Reciprocals	Values for inverse comparison

eigenvalue of the matrix, and  $n$  is the order of the matrix. In the present study, AHP weights and consistency ratios for each zone are shown in Table 3.

### Standardization of Criteria

We used the fuzzy membership function (FMF) to standardize the factors. Application of the fuzzy set membership in criteria standardization was suited to this study as it provides strong logic for the process of standardization (Jiang and Eastman 2000) and a useful means of dealing with uncertainty as a result of imprecise boundaries between suitability classes (Hoseini 2019). Eastman (2012) suggested the standardization of factors using a range of fuzzy set membership functions to either a 0–1 real number scale or a 0–255-byte scale. Determining the shape and type of membership functions and threshold values of variables (effective range) are essential to implement fuzzy sets for standardizing criteria maps. Fuzzy sets used in this study were monotonically increasing, monotonically decreasing, and symmetric functions in linear and user-defined shapes (Table 4). The thresholds for the best suitability and least suitability for these criteria are given based on published literature (Makhdoum 2001; Eastman 2010; Salmanmahiny et al. 2014). The method to quantify fuzzy graphs is a linear scale conversion method based on maximum and minimum values as scaling points (Mahini and Gholamalifard 2006). This method is based on Eq. 4 (Eastman 2003). Table 4 summarizes fuzzy membership defined in this study for different criteria and land use.

$$x_i = (R_i - R_{\min}) / (R_{\max} - R_{\min}) \times \text{standardized\_range}, \quad (4)$$

where  $R$  is the raw score.

### Overlaying Map Layers

In this study, we used an integrated WLC and OWA approach to overlay the map with the software Idrisi Selva. WLC is described by a complete trade-off and average risk, midway between operations of “AND” and “OR,”

**Table 3** Analytical hierarchy process (AHP) weights of defined criteria for land suitability assessment in Qaleh Ganj County, Iran

Factor	AHP weight						
	Arable land	Aquaculture	Industrial development	Horticulture	Rangeland	Tourism	Ecotourism
Spring/aqueduct	0.164	0.11	0.21	0.18	0.164	0.146	0.13
Distance to surface water	0.074	0.23	0.026	0.17	0.095	0.146	0.32
Distance to well	0.141	0.11	0.2	0.098	0.085	0.06	0.1
Microclimate	0.019		0.02	0.09	0.037	0.052	–
Temperature	0.014	0.11	0.014	0.09	–	0.052	–
Precipitation	0.016	0.11	0.021	0.09	–	–	–
Land-use	0.049	0.04	0.032	0.02	0.099	0.027	0.05
Geology and soil	0.218	0.06	0.198	0.08	0.1	0.1	0.172
Elevation	0.056	0.02	0.027	0.016	0.02		
Slope	0.063	0.11	0.135	0.16	0.02	0.239	0.038
Aspect	0.014	–	0.046		–		–
Cover	0.023	0.01	0.031	0.05	0.097	0.057	0.09
Land unite	0.103	–		–	0.24		–
Distance to village	0.032	0.02	0.034	0.014	0.028	0.022	–
Distance to road	0.014	0.03	0.016	0.019	0.015	0.019	–
Natural and cultural attractions	–	–	–	–		0.08	0.1
Inconsistency	0.04	0.05	0.06	0.03	0.05	0.06	0.02

i.e., neither extreme risk aversion nor extreme risk taking (Fig. 3) Due to the risk built into this method of hiding a limiting factor between the high values of the other criteria, the WLC method is not always suitable for spatial planning. Similarly, in complex territorial analysis, non-compensatory methods may prove to be restrictive because they only take into account the restrictive factors or the predominant factors (Romano et al. 2015), but with the OWA approach, we can control trade-off and risk by order weight (Malczewski 2006; Purnamasari et al. 2019). In our study, there are two different types of factors: variables relevant to development costs and variables relevant to environmental concerns, which generally do not have the same degree of trade-off.

Factors relevant to development costs can be weighed in full against each other, but environmental factors are not easily trade-off. To address this discrepancy, we treated our factors as two separate sets with different trade-off levels. So the WLC method was used to combine cost-relevant factors (e.g., road, land use, elevation, etc.) which allow them fully trade-off. On the other hand, for the second group of environmental factors (e.g., water resource, soil, cover, etc.), we applied the OWA method to control the risk and trade-off of these variables. In this study we applied a low level of risk and no trade-off reorder weight for environmental factors, so the first environmental factor is assigned weight 1 and for the rest factors weights 0 was applied (1, 0, 0.0.0) (Rinner and Malczewski 2002; Drobne and Liseć 2009; Zabihi et al. 2019). With this approach, we prevent environmental factors

are compromised or trade-off by cost-relevant factor and also by each other.

The WLC and OWA combination operator for the  $j$ th location (point or pixel) is defined as follows (Eastman 2012; Romano et al. 2015).

$$\text{WLC} = \sum W_i X_i \pi C_j, \quad (5)$$

where  $S$  is the suitability,  $W_i$  is the the weight of factor  $i$ ,  $X_i$  is the the fuzzy value of factor  $i$ ,  $C_j$  is the constraint  $j$ ,  $\pi$  is the product.

$$\text{OWA}_j = \sum_{i=1}^n \left( \frac{u_i v_i}{\sum_{i=1}^n u_i v_i} \right)^{z_{ij}}, \quad (6)$$

where  $u_i$  is the reordered  $i$ th criterion weight ( $w_i$ );  $v_i$  is the  $i$ th element of a set of order weights  $V = (v_1, v_2, \dots, v_n)$  such that  $v_i \in [1, 0]$  and  $\sum_{i=1}^n v_i = 1$ ;  $z_{ij} \geq z_{2j} \geq \dots \geq z_{nj}$  is obtained by reordering the criterion values  $x_{1j}, x_{2j}, \dots, x_{nj}$ .

The result consists of two intermediate suitability maps, one of which is the result of the combination of five cost-relevant factors and the other the result of the combination of environmental factors. Using a third MCE operation, we then combined these two intermediate suitability maps. (For comparison we have also combined both groups of factors (cost-relevant and environmental-relevant factors) using the WLC approach, to illustrate how the outcome will change in this case if there is no control over trade-off and risk).

**Table 4** Standardization of factors and constraints with Fuzzy Set Membership and Boolean logic for land suitability assessment in Qaleh Ganj

Criteria	Land-use (Fuzzy Membership)						
	Arable land	Horticulture	Rangeland	Aquaculture	Industrial development	Tourism	Ecotourism
1 Proximity to surface water resource							
2 Proximity to spring and aqueduct							
3 Proximity to Well							
4 Geo	User-defined	User-defined	User-defined	User-defined	User-defined	User-defined	User-defined
5 Land-use	User-defined	User-defined	User-defined	User-defined	User-defined	User-defined	User-defined
6 Proximity to main roads							
7 Aspect	Plain = 1, North = 0.6 East = 0.7, South = 0.4 West = 0.6	Not used	Not used	North = 0.7, East = 1, South = 0.2, West = 0.2	North = 0.7, East = 1, South = 0.2, West = 0.2	North = 1, East = 0.8, South = 0.4, West = 0.3	Not used
8 Proximity to Settlement							
9 Vegetation cover	User-defined	User-defined	User-defined	User-defined	User-defined	User-defined	Not used

Table 4 (continued)

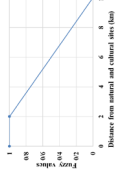
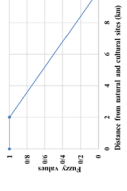
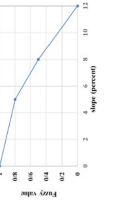
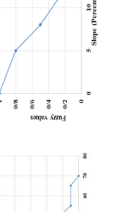
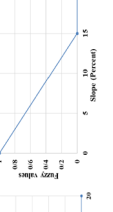
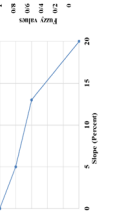
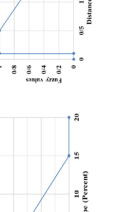
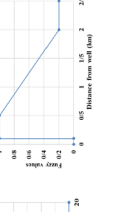
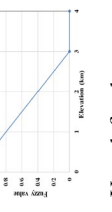
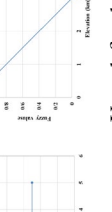
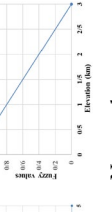
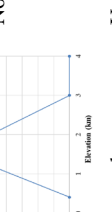
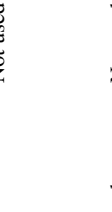
Criteria		Land-use (Fuzzy Membership)						
Factors	Arable land	Horticulture	Rangeland	Aquaculture	Industrial development	Tourism	Ecotourism	
10	Proximity to natural and cultural sites	Not used	Not used	Not used	Not used			
11	Slope							
12	Elevation						Not used	Not used
13	Land unite	User defined	User defined	Not used	Not used	User defined	Not used	
14	Temperature	1–14 = Increasing 14–20 = constant 20 and more = decreasing	Not used	Not used	1–14 = Increasing 14–20 = constant 20 and more = decreasing	1–14 = Increasing 14–20 = constant 20 and more = decreasing	Not used	
15	Microclimate	Extra dry and hot = 0, desert and dry = 0 Desert and dry and temperature = 0.3 Very wet = 1	Extra dry and hot = 0, desert and dry = 0.19 Desert and dry and temperature = 0.5 Very wet = 1	Extra dry and hot = 0, desert and dry = 0.19 Desert and dry and temperature = 0.5 Very wet = 1	Not used	Extra dry and hot = 0, desert and dry = 0, Desert and dry and temperature = 0.3 Very wet = 1	Not used	
16	Precipitation	0–120 mm = 0 120 mm and more = Increasing	0–120 mm = 0 120 mm and more = Increasing	Not used	0–120 mm = 0 120 m and more = Increasing	0–120 mm = 0 120 mm and more = Increasing	Not used	



Table 4 (continued)

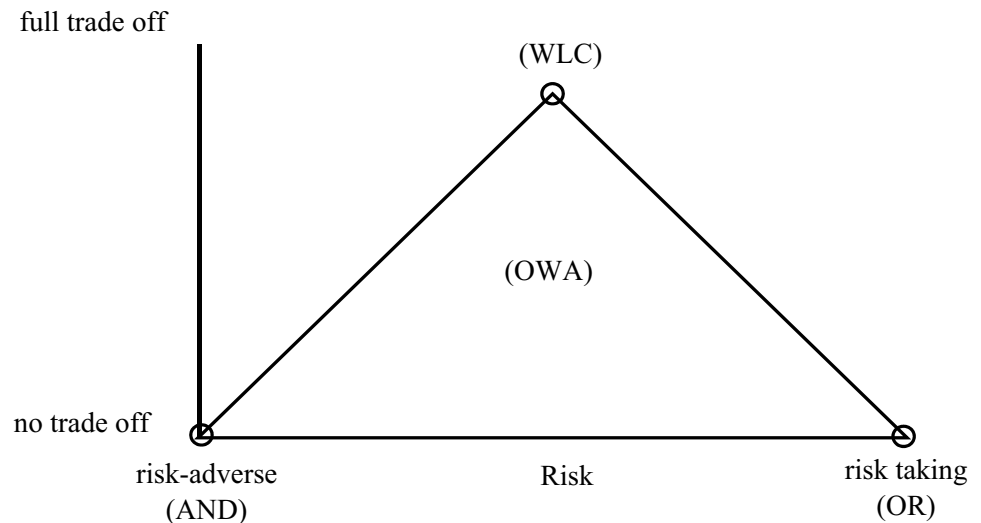
Land-use (Fuzzy Membership)						
Factors						
Criteria						
Factors						
Arable land	Horticulture	Rangeland	Aquaculture	Industrial development	Tourism	Ecotourism
Constraints	Water body, slope > 12%, elevation > 3000 m, wetland boundary Build-up areas (urban, industries, roads, etc.), Salty and rocky land	Water body, slope > 30%, wetland boundary Build-up areas (urban, industries, roads, etc.), Salty and rocky land	slope > 15%, elevation > 3000 m, Marz protected area, wetland boundary Build-up areas (urban, industries, roads, etc.), Salty and rocky land	Water body, slope > 20%, elevation > 3000 m, Marz protected area and wetland boundary Build-up areas (urban, roads), Salty and rocky land	Water body, slope > 15%, Marz protected area (urban, roads) Eroded lands Faults	Slope > 60%
	Precipitation < 120 mm Eroded lands Faults	Eroded lands Faults	Faults	Salty and rocky land Eroded lands Faults Cover > 60%		

Finally, the suitability maps are classified into three classes, including high suitability, average suitability, and low suitability, equal interval was used to divide the range of pixel values into equal-sized subranges.

### MOLA for Land-Use Planning and the Optimal Spatial Distribution

The final part of the analysis process was to demarcate, or zone, the priority areas for each land-use type. The MOLA algorithm has been incorporated into IDRISI GIS software as a decision support module for facilitating multiple and conflicting land-use decision making (Dai and Ratick 2014). This procedure allocates multiple conflicting objectives based on the iterative reassessment of the score in the conflict zone until the defined area requirements are met. It leads to a compromise solution that is achieved by optimizing the land-use suitability of the specified area (Sitko and Scheer 2019). Hence, MOLA’s fundamental underlying procedure is a reclassification of ranked suitability maps with subsequent resolution of conflicting cells. This can also be understood by a decision space defined by using the scale of suitability for each objective as a separate axis in a multi-dimensional space. In this space, each cell in the region can be located based on its suitability to each objective. The best approach for conflict solving would be to split the conflicting cells appropriately between the objectives. A simple solution to do so would be to draw a diagonal through the conflict zone and thereby assign cells to the objective for which it is significantly better suited (Eastman et al. 1993). The suitability map for each land use, which is defined through the MCE method was standardized (by ranking) and imported into the MOLA process. MOLA also requires two additional factors 1—weight for each objective (land use), 2—area for each objective (land use), this two factor gives preference to land use, which means that decision-makers can be interested in a land use by setting more weight or area according to their preferences. To mitigate the influence of the subjective judgment, we use the weight only according to the judgment of the decision maker and it is determined by AHP. For the determination of the area, the area of high suitability class of each land-use type (which is determined via WLC-OWA) was used. Therefore, for this parameter, we only refer to environmental potential. After determining the zoning map, post-processing functions (filters, zone size, and distance) were used to include more integrated zones. We also eliminated the spots with an area of less than 1 hectare, which can provide minimum benefit according to the socioeconomic dimension (Makhdoum 2001).

**Fig. 3** Decision strategy triangle defined by risk and trade-off dimension (Zabihi et al. 2019)



## Results

In this study, the optimal spatial distribution of certain land-use zones in Qaleh Ganj County was determined. Suitability maps were produced based on a combination of WLC and OWA aggregation approaches and then an optimal land-use suitability map was produced by combining 7 suitability maps via MOLA.

### Land-Use-Type Suitability Evaluation

Results of combined WLC and OWA approach are shown in Table 5. Also suitability maps produced with these approaches are present in Fig. 4. The results show that ecotourism, with 36.78%, has the greatest potential which followed by rangeland (25.32%), horticulture (13.74%), industrial development (12.15%), arable land (6.53%), also tourism (0.28%), and aquaculture (0.15%) that have the lowest potential in this county.

According to Table 5, although ecotourism has the highest percentage of suitability areas in the entire area, the majority of these areas are in the average suitability class and only 0.11 percent of the total suitability area is in the high suitability class. Meanwhile, industrial development shows the largest suitability area in the high suitability class (11.5%).

The results of suitability class if all factors (cost-relevant and environmental-relevant factors) are allowed to fully trade-off and have average risk that also presented in Table 6, for comparison. The value range (minimum and maximum suitability value) for these two approaches is summarized in Table 7.

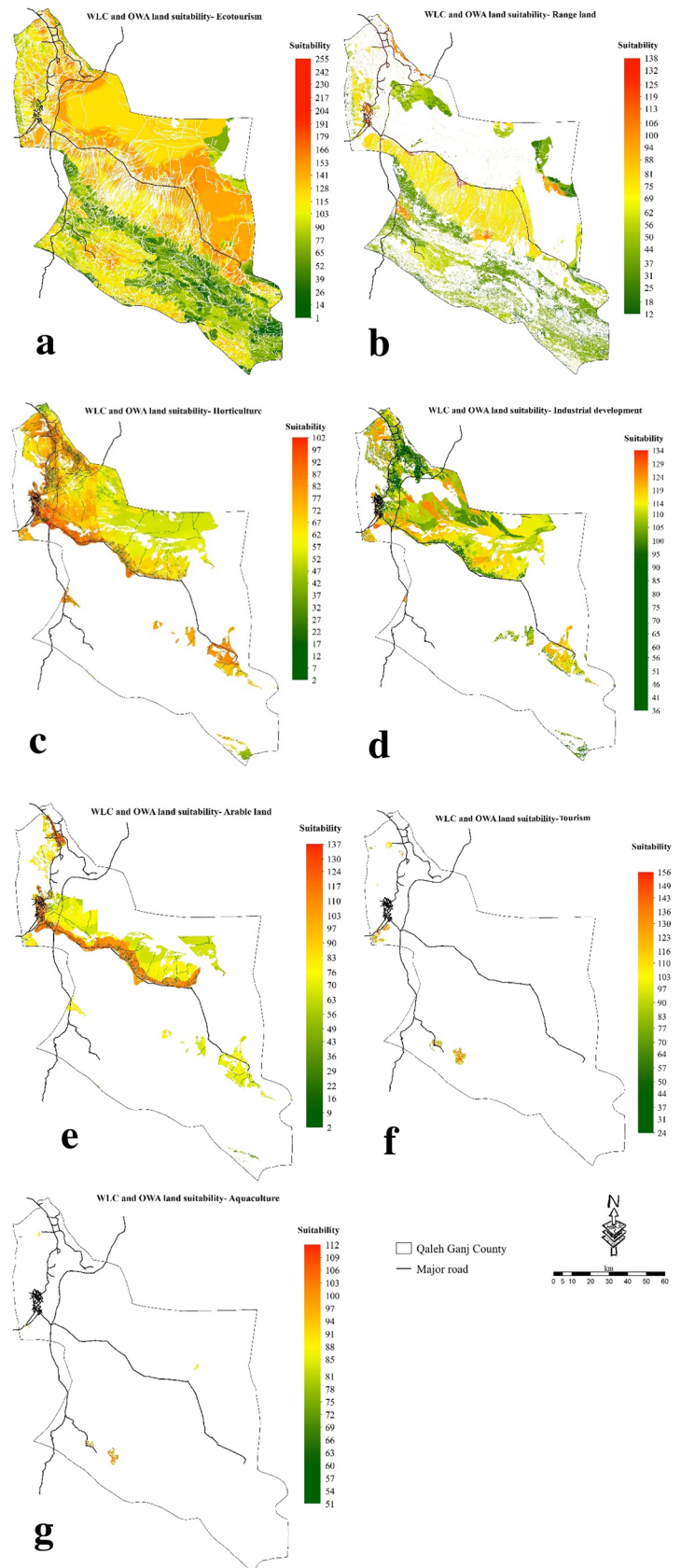
If a full trade-off with the average risk for all factors is made by using WLC, a higher range of suitability value and the area is recognized for seven land uses, whereas control compromise (no trade-off, low risk) by using OWA, the range of suitability value for all land uses tends to decrease (Table 7). However, according to the suitability classification, as it is clear, the larger area is dedicated to the high suitability class, where users control over trade-off and risk

**Table 5** Area of suitability classes for each zone in Qaleh Ganj County (based on WLC and OWA models: no trade-off and low risk for environmental factors, full trade-off, and average risk for cost-relevant factors)

Land uses	High suitability (ha)	Average suitability (ha)	Low Suitability (ha)	Total suitable area	Percent of suitability
Aquaculture	2827	371	–	3199.32	0.15
horticulture	118,807	151,338.2	17,752.5	287,897.7	13.74
Arable land	32,265	95,878.71	8777.97	136,921.68	6.53
Rangeland	<b>60,549.93</b>	353,720.6	116,078.4	<b>530,348.93</b>	<b>25.32</b>
Industrial Development	<b>242,295.93</b>	6923.970	121.59	249,341.49	11.9
Tourism	4026.87	1856.52	174.33	6057.72	0.28
Ecotourism	2399.49	573,829.38	194,293.53	<b>770,522.4</b>	<b>36.78</b>

Bold indicates area of land uses and their percentage

**Fig. 4** Transitional suitability maps for different land-use types using the WLC and OWA modules of the MCE in Qaleh Ganj County, Iran



**Table 6** Area of suitability classes for each zone in Qaleh Ganj County, Iran (based on WLC method: full trade-off and average risk for all factors)

Land uses	High suitability (ha)	Average suitability (ha)	Low suitability (ha)	Total suitable area	Not suitable (ha)
Aquaculture	594.72	2240.82	363.42	3198.96	2,091,363.75
horticulture	57,044	217,835.64	15,902.55	290,782.19	1,803,780
Arable land	19,246.77	35,774.46	84,100.95	139,122.18	1,955,440
Rangeland	38,103.66	309,343.59	182,901.69	530,348.94	1,564,214.13
Industrial Development	33,600.15	142,257.87	38,906.64	214,764.66	1,879,797.6
Tourism	2643.48	3042.63	371.34	6057.45	2,088,505
Ecotourism	<b>104,234.580</b>	804,052.89	2587.950	<b>910,875.42</b>	1,183,687.65

**Table 7** Range values of suitability for each zone in Qaleh Ganj County, Iran (based on 2 approaches of factor combination: 1-WLC 2-WLC and OWA)

Land use	WLC		WLC and OWA	
	Min value	Max value	Min value	Max value
Aquaculture	98	214	51	112
horticulture	58	167	2	102
Arable land	47	186	2	137
Rangeland	39	206	12	138
Industrial Development	56	207	36	134
Tourism	73	179	24	156
Ecotourism	1	255	1	255

among distinct factors (WLC and OWA), while the full trade-off and average risk between all factors are applied by WLC combination, the majority of the area is dedicated to the average suitability class.

### Land-Use Planning for the Optimal Spatial Distribution

The results of suitability maps (WLC- OWA combination) are used for the zoning process by MOLA module in GIS. The MOLA resulted in a zonation map that shows the optimal spatial distribution for the 7 land uses in Qaleh Ganj County. The calculated percentage of each zone after zonation and post-process modification is rangeland zone, 30.80%; eco-tourism zone, 22.9%; horticulture zone, 12.8%; arable land zone, 8.4%; industrial development, 2.1%; aquaculture zone, 0.26%, and tourism zone, 0.24% of the study area (Table 8). About 22.37% of the entire region is without the potential for any land use, due to the restrictions established during the MCE process, most of which include vulnerable areas such as fault lines or protected areas. Table 9 shows the area of existing land uses in the study area. Results from this study indicated

**Table 8** Final land-use area obtained after zoning by MOLA in Qaleh Ganj County, Iran

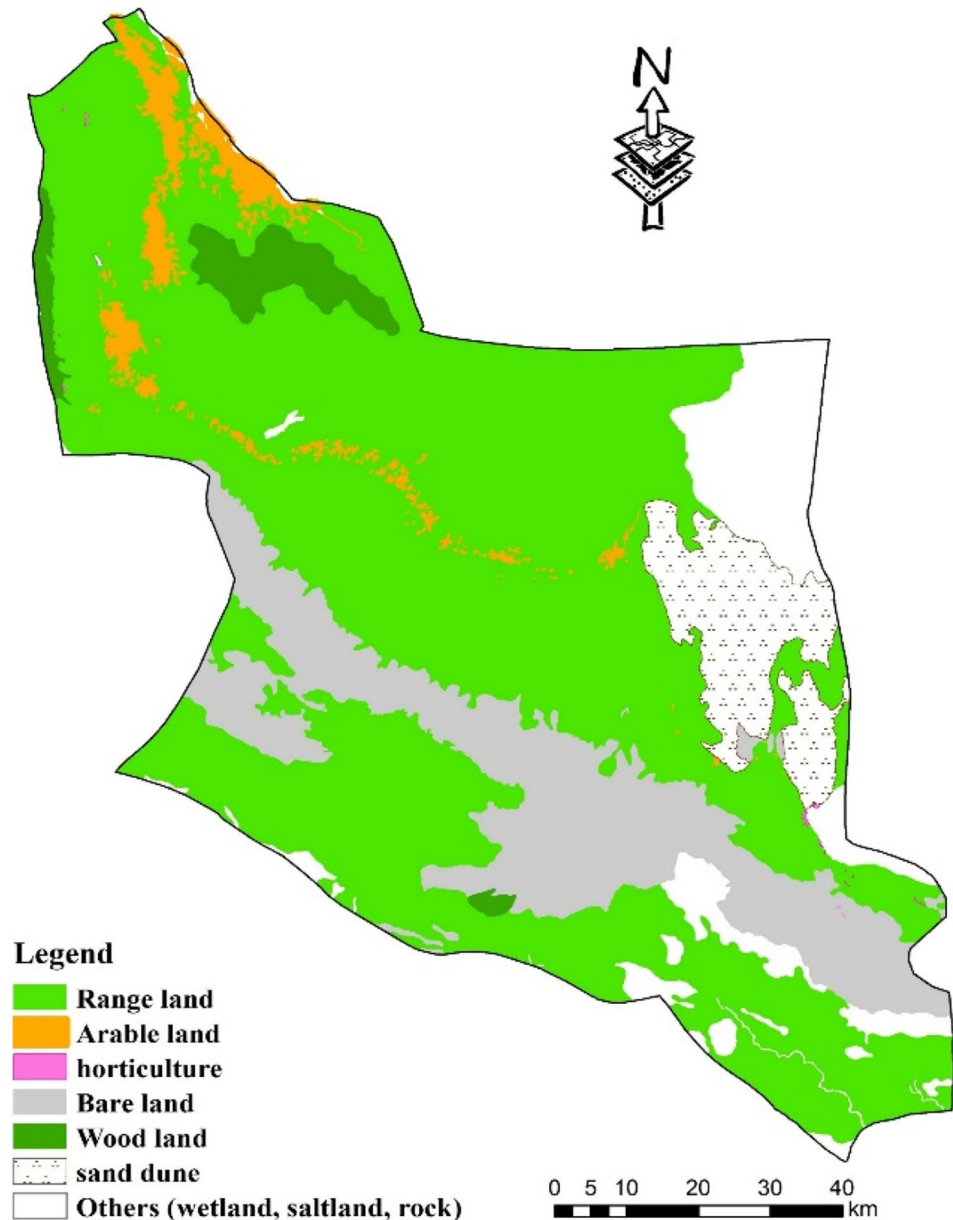
Land uses	Area (ha)	Percent
Aquaculture	2776.506	0.26
Horticulture	134,350.73	12.87
Arable land	87,856.03	8.41
Rangeland	321,547.28	30.8
Industrial development	22,022.91	2.10
Tourism	2534.96	0.24
Ecotourism	239,113.08	22.90

**Table 9** Existing land-use area in Qaleh Ganj County, Iran

Land uses	Area (ha)	Percent
Horticulture	403.5158	0.04
Arable land	31,372.256	3.123
Rangeland	675,032.634	67.203
Bare land	196,528.64961	19.565
Others (sand dune, lake and rocky lands)	101,122.671798	10.067

that the differences between existing and potential land use are apparent. In the potential land-use zoning, some land uses, such as industrial development or horticulture and ecotourism, have shown strong potential in the region but are ignored in the study area’s current land use (Fig. 5). However, we can see some selected areas already served the same uses in the region. For example, the roadside located in the middle of the county is mostly used for arable land (based on the existing land-use map, Fig. 5). For example, the roadside in the middle of the city is mostly used for usable land (based on the existing land-use map, Fig. 5). Likewise; this study shows a high potential for arable land in this area of the county. Results of the modification to land-use zones after the post-processing operation are shown in Fig. 6.

**Fig. 5** Existing land-use map of Qaleh Ganj County, Iran

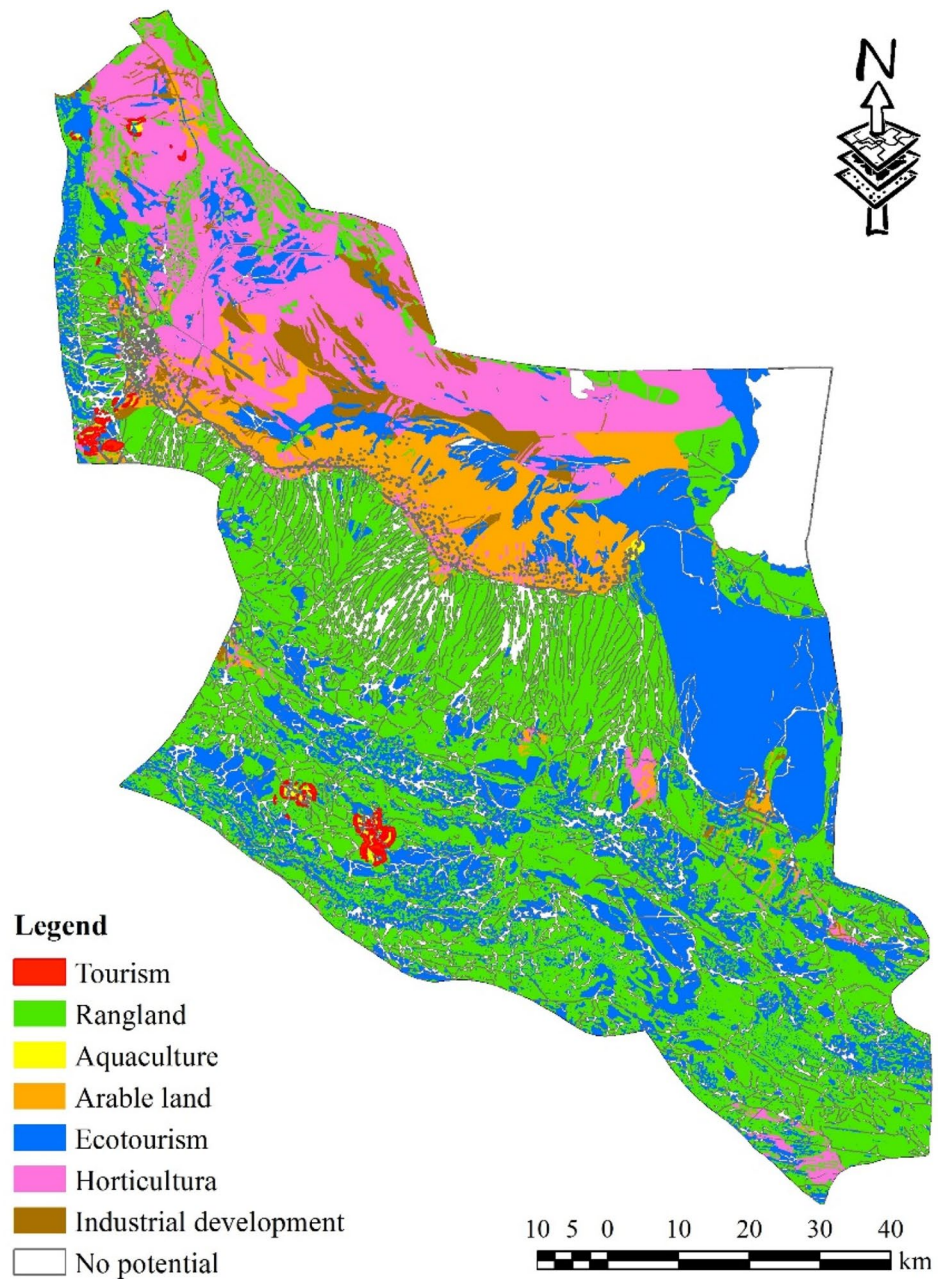


## Discussion

In recent years, spatial planning has increasingly focused on environmental protection issues (Tortora et al. 2015; Romano et al. 2015; Memarbashi et al. 2017). GIS-based MCE provides spatial planners with a support tool for effective land-use planning and management (Shuaibu and Kara 2019). In this research, land suitability has been derived using weighted map overlay techniques (WLC -OWA) based on MCDM using GIS tools, a procedure concluded in seven maps detailing land-use suitability. The results indicate the potential suitability and optimal spatial distribution for each land-use type, varying from high to low, in the Qaleh Ganj County.

According to the results, the largest suitable area, 36.78%, belongs to ecotourism, followed by rangeland with 25.32% of the total area (Table 5). This is mainly because these land uses require fewer maintenance specifications and coordinated action compared to other land uses (Makhdoum, 2001). However, the highest suitable area (high suitability class) belongs to industrial development and rangeland. Industrial development shows strong or high suitability, indicating that there is good infrastructure for this use, concentrated in some parts of Qaleh Ganj (mainly north and northeast). Also aquaculture and tourism have the lowest potential, which, based on the selected variables and the large current constraints, is normal in this region (Table 3).

**Fig. 6** Final land-use zoning map in Qaleh Ganj County, Iran



All suitability maps were combined using the MOLA function. The calculated percentage of each land-use type after zoning shows that the rangeland zone with 30.80% and the ecotourism zone with 22.9% have the highest potential in the county, which it means that the rangeland zone has higher suitability values compared to ecotourism, while ecotourism covers more area of the county, but the values are not in the upper range. However, these automatic zoning mechanisms also have limits, including the inability to guarantee optimal solutions globally (Dai and Ratick 2014), and the salt and pepper noise in the results (Eastman 2003), so they need to be modified to remove noise and create more

integrated zones (Eastman 2010). Incidentally, in this study, MOLA produced a very consistent and integrated zoning plan that required a minimum of post-processing (filters and area), which meant that the impact of the decision-makers' judgment was minimized at this stage.

There are a few reasons why some land uses have more suitability and, consequently, are more appropriate for a certain area, for example, (1)—its proximity to existing land use with a high probability of finding existing infrastructure, (2)—its proximity to water resources essential for most land-uses' functioning, like arable land, aquaculture, horticulture, and industrial development, (3)—its proximity

to main roads, enabling access to transportation routes, and (4)—its geographical location which presents environmental constraints, such as climate, elevation, natural features. In this case study, mainly the northern part of the county, as well as the central part, contains a more suitable area for most land uses, as it contains water resources, infrastructure, accessibility, and here we see the highest opportunity for most land uses. When comparing the relevant classes of the created potential land use with the current pattern of land use, we can find that: the differences between these two patterns of land use reflect the limitation of approach and management. As some land uses such as industrial development or horticulture and ecotourism are ignored in the existing land use, while in the evaluation land use has shown strong potential in this region.

The ability to assign different relative weights to any of the factors through aggregation is one of the WLC method's advantages which used in this study. These weights indicate the importance of a factor relative to all other factors and regulate how factors will trade-off. So where factors fully trade-off, factors with high suitability can be compensated for other factors with low suitability in a given location, which can be a drawback in some cases. For instance, where environmental factors and economic factors are considered at the same time and have different levels of trade-off. OWA approach allows us to control the level of trade-off and risk with the order weighting. So in this study, we considered our factors as two distinct sets because of the different levels of trade-off and risk. By separating factors into two groups, cost-relevant factors and environmental relevant factors, we prevent environmental factors from being compromised by cost-related factors, which is vital for the vision of environmental protection. With this strategy, we bring a robust environmental perspective to determine suitability for each land use, which is the strength of this study.

We also examined whether the full trade-off for all factors applied differences of some kind, so the WLC approach was employed to compute and aggregate all factors, weights, and constraint maps. Due to the complete trade-off of the WLC method, the results show a larger proportion of area and a higher suitability value range for different land uses compared to the result of the OWA approach. This difference was also indicated by Drobne and Liseč (2009) and Sanaee et al. (2010). Since our purpose, in this case, is land-use planning with a goal of environmental protection, we have chosen the result of the WLC-OWA combined approach for the following step (MOLA). It should be noted that the application of the approach (WLC-OWA) we have used in this study can be adapted in a single operation by the use of OWA alone as a significant advantage of using this method. In this case, reordered weights should be defined for all cost relevance and environmental factors to control the trade-off and risk between all factors. It seems to be more complicated than

the approach we used in this study, but the result will be the same.

Another strength of this study is using the fuzzy set theory for the standardization of variables, enabling more flexible MCE operations in the construction of criteria layers and taking into account the validity and complexity of the relationship between the criteria and the decision set (Hajehforooshnia et al. 2011; Barzeshkar et al. 2019). Also, by applying the AHP methodology, which plays an important role in qualitative and quantitative classification (Aguarón et al. 2019), we enabled decision-makers to be involved in the selection of suitable sites and land-use planning, as the criteria (for land suitability assessment by WLC and OWA) and objectives (for land-use planning by MOLA) were prioritized by experts and decision-makers. However, AHP allows the assessment of the consistency of the decision-makers when the judgments are introduced into the pairwise comparison matrices which can minimize subjectivity in decision making.

The advantages of the multi-criteria analysis, GIS-based decision support system, including WLC or OWA in spatial and terrestrial planning, were discussed in several studies (Aydi et al. 2016; Corona et al. 2008; Jamil et al. 2018; Kumar and Kumar 2014; Masoodi et al. 2016b; Raza et al. 2018; Romano et al. 2015; Shuaibu and Kara 2019; Zolekar et al. 2015; Zabihi et al. 2019).

This study recognized GIS-based MCE techniques as an efficient tool that involves the use of geographic data, weights, and a Multi-Criteria Decision Analysis (MCDA) aggregation function that incorporates spatial data and weights of criteria to evaluate sites for suitability assessment (Karimi et al. 2020). Also, it shows combined WLC and OWA as a generic methodology that can be applied in a variety of situations and for different types of data. GIS spatial analysis and modeling was also well implemented in this study which automatically completed all zoning processes.

## Conclusion

This study highlights the effectiveness of the GIS-based MCE techniques as a decision support system for land-use planning. The single-objective multi-criteria evaluations are resolved by defining criteria, standardizing criteria, determining factor weights, and implementing a multi-criteria assessment. And the problem of multi-objective allocation is resolved by standardizing single-objective suitability maps and assigning the best-ranked cells to each objective.

The results have shown various spatial distribution potentials for each land-use, where suitability varies from high potential areas to poor potential. According to the maps, areas with high suitability for different land-uses are concentrated in the north and middle of the county. In particular,

the region has great potential for ecotourism and strong potential for rangeland and industry. It also has a very low potential for aquaculture and tourism, as these two land uses require more infrastructure.

Separating the factors into two different groups when assessing land suitability (cost-related and environmental factors) and using WLC along the OWA helped to avoid trade-offs between the defined factors, which was one of the objectives of our study. This is important from the environmental perspective and led to sustainable land-use planning and mitigates environmental impact.

Furthermore, the MOLA function helped to produce a land-use zoning map of the study area. The automatic zoning model, MOLA, which is based on a computerized decision-making matrix, provided an opportunity to solve conflict and overlap between zones based on the optimal suitability of each pixel.

The implementation of AHP for the weighting of criteria (through MCE) and priorities of objectives (through MOLA) offers experts and decision-makers an opportunity to participate in land-use planning. However, since a large part of the process is focused on computer modeling and automated GIS zoning, we have avoided subjectivity in the term of zones. We also found that by defining the proper area and weight in the MOLA function, the result is consistent and has sufficient integrity, resulting in a minimum of modification and minimizing the need for decision-maker intervention.

This study illustrates the advantages of using automatic MCE and MOLA methods for spatial planning in Iran with emphasis on environmental preservation vision. We offered an integrated land-use management strategy, in particular, an overlay analysis based on GIS to determine the optimal site for different land uses that fulfill all desired characteristics for each one. The offered approach (a combination of WLC and OWA) for suitability land evaluation would help to protect the natural environment of the urban environment while allowing for continued economic development. This study also shows that MOLA represents a potential solution to the conflict between zoning types of land use and contributes to the optimization of site selection. Also because MOLA is an automatic zoning procedure, it helps to minimize subjectivity in land-use planning.

The approach used in this study can help developing country like Iran and the sensitive areas which have significant natural resources but facing environmental challenges due to rapid development.

In the end, regardless of some limitations, like funding issues to run this planning or national development plans, combining the results of this study with the area management plan, could lead to sustainable development, improving the living standards of the residents, and protecting the natural environment.

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## Compliance with Ethical Standards

**Conflict of Interest** The author declares no conflict of interests.

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## References

- Aguarón J, Escobar MT, Moreno-Jiménez JM, Turón A (2019) AHP-group decision making based on consistency. *Mathematics* 7(3):242. <https://doi.org/10.3390/math7030242>
- Akbari M, Neamatollahi E, Neamatollahi P (2019) Evaluating land suitability for spatial planning in arid regions of eastern Iran using fuzzy logic and multi-criteria analysis. *Ecol Indic* 98:587–598. <https://doi.org/10.1016/j.ecolind.2018.11.035>
- Aydi A, Abichou T, Nasr IH, Louati M, Zairi M (2016) Assessment of land suitability for olive mill wastewater disposal site selection by integrating fuzzy logic, AHP, and WLC in a GIS. *Environ Monit Assess* 188(1):59–72. <https://doi.org/10.1007/s10661-015-5076-3>
- Barzehkar M, Dinan NM, Mazaheri S, Tayebi RM, Brodie GI (2019) Landfill site selection using GIS-based multi-criteria evaluation (case study: SaharKhiz Region located in Gilan Province in Iran). *SN Appl Sci* 1(9):1082–1093. <https://doi.org/10.1007/s42452-019-1109-9>
- Bocco G, Mendoza M, Velázquez A (2001) Remote sensing and GIS-based regional geomorphological mapping—a tool for land-use planning in developing countries. *Geomorphology (Amst)* 39(3–4):211–219. [https://doi.org/10.1016/S0169-555X\(01\)00027-7](https://doi.org/10.1016/S0169-555X(01)00027-7)
- Briassoulis H (2019) Combating land degradation and desertification: the land-use planning quandary. *Land* 8(2):27. <https://doi.org/10.3390/land8020027>
- Bunruamkaew K, Murayama Y (2012) Land-use and natural resources planning for sustainable ecotourism using GIS in Surat Thani, Thailand. *Sustainability* 4(3):412–429. <https://doi.org/10.3390/su4030412>
- Chen J (2014) GIS-based multi-criteria analysis for land-use suitability assessment in the City of Regina. *Environ Syst Res* 3(1):13–23. <https://doi.org/10.1186/2193-2697-3-20>
- Chivasa W, Mutanga O, Birada C (2019) Mapping land suitability for maize (*Zea mays* L.) production using GIS and AHP technique



- in Zimbabwe. *SAJG* 8(2):265–281. <https://doi.org/10.4314/sajg.v8i2.11>
- Comber A, Carver S, Fritz S, McMorran R, Washtell J, Fisher P (2010) Different methods, different wilds: evaluating alternative mappings of wildness using fuzzy MCE and Dempster-Shafer MCE. *Comput Environ Urban Syst* 34(2):142–152. <https://doi.org/10.1016/j.compenurbysys.2009.10.006>
- Corona P, Salvati R, Barbati A, Chirici G (2008) Land suitability for short-rotation coppices assessed through fuzzy membership functions. *Patterns and processes in forest landscapes*. Springer, Dordrecht, pp 191–211
- Dai W, Ratick SJ (2014) Integrating a raster geographical information system with multi-objective land allocation optimization for conservation reserve design. *Trans GIS* 18(6):936–949. <https://doi.org/10.1111/tgis.12085>
- Drobne S, Lisec A (2009) Multi-attribute decision analysis in GIS: weighted linear combination and ordered weighted averaging. *Informatica*. 33(4):459–474 (**Corpus ID: 463816**)
- Eastman JR (2003) *IDRISI Kilimanjaro: a guide to GIS and image processing*
- Eastman JR (2010) *Applied remote sensing and GIS with Idrisi*. Translated and compiled by Salmanmahiny, A, Kamyab, H. Mehr Mahdis Publication, Tehran, p 582
- Eastman JR (2012) *IDRISI Selva tutorial*. Idrisi Production, Clark Labs-Clark University, 45, 51–63
- Eastman JR, Toledano J, Jin W, Kyem PA (1993) Participatory multi-objective decision-making in GIS. In *Autocarto-conference* (1993 October). ASPRS American Society for Photogrammetry. Available at: <https://cartogis.org/docs/proceedings/archive/auto-carto-11/pdf/participatory-multi-objectivedecision-making-in-gis.pdf>
- Fataei E, Mohammadian A (2015) Industrial state site selection using MCDM method and GIS in Germe Ardabil Iran. *JIII* 3(4):324–329. <https://doi.org/10.12720/jiii.3.4.324-329>
- Feizizadeh B, Blaschke T (2013) Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS. *J Environ* 56(1):1–23. <https://doi.org/10.1080/09640568.2011.646964>
- Gorsevski PV, Jankowski P, Gessler PE (2006) A heuristic approach for mapping landslide hazard by integrating fuzzy logic with analytic hierarchy process. *Control Cybern* 35:121–146 (**Corpus ID: 122664170**)
- Hajehforooshnia S, Soffianian A, Salmanmahiny AS, Fakheran S (2011) Multi-objective land allocation (MOLA) for zoning Ghamishloo Wildlife Sanctuary in Iran. *J Nat Conserv* 19(4):254–262. <https://doi.org/10.1016/j.jnc.2011.03.001>
- Hajizadeh F, Poshidehro M, Yousefi E (2020) Scenario-based capability evaluation of ecotourism development—an integrated approach based on WLC and FUZZY-OWA methods. *Asia Pac J Tour Res* 25(6):627–640. <https://doi.org/10.1080/10941665.2020.1752752>
- Hanssen F, May R, Van Dijk J, Stokke BG, De Stefano M (2018) Spatial multi-criteria decision analysis (SMCDA) toolbox for consensus-based Siting of Power lines and wind-power plants (ConSite). NINA Report 1455. Norwegian Institute for Nature Research.
- Hoseini Y (2019) Use fuzzy interface systems to optimize land suitability evaluation for surface and trickle irrigation. *Inf Process Agric* 6(1):11–19. <https://doi.org/10.1016/j.inpa.2018.09.003>
- Ichwani SN, Wulandari R, Ramachandra A (2018) Carbon stock projection in North Sumatera using multi-objective land allocation approach. *E&ES* 149(1):012042. <https://doi.org/10.1088/1755-1315/149/1/012042>
- Jafarian Z, Kavian A (2013) Effects of land-use change on soil organic carbon and nitrogen. *Commun Soil Sci Plant Anal* 44(1–4):339–346. <https://doi.org/10.1080/00103624.2013.741949>
- Jamil M, Ahmed R, Sajjad H (2018) Land suitability assessment for sugarcane cultivation in Bijnor district, India using geographic information system and fuzzy analytical hierarchy process. *GeoJournal* 83(3):595–611. <https://doi.org/10.1007/s10708-017-9788-5>
- Jiang H, Eastman JR (2000) Application of fuzzy measures in multi-criteria evaluation in GIS. *IJGIS* 14(2):173–184. <https://doi.org/10.1080/136588100240903>
- Karimi H, Herki BM, Gharibi S, Hamiditehrani S, Kakhani A (2020) Identifying public parking sites using integrating GIS and ordered weighted averaging approach in Sanandaj city, Iran. *J Crit Rev* 7(4):506–513. <https://doi.org/10.31838/JCR.07.04.95>
- Kumar S, Kumar R (2014) Site suitability analysis for urban development of a Hill Town using GIS-based multicriteria evaluation technique: a case study of Nahal Town Himachal Pradesh India. *IJARSG* 3(1):516–524 (**Corpus ID: 44032411**)
- Mahini AS, Gholamalifard M (2006) Siting MSW landfills with a weighted linear combination methodology in a GIS environment. *Int J Environ Sci Technol* 3(4):435–445. <https://doi.org/10.1007/BF03325953>
- Mahmoodzadeh H, Panahi S, Herischian M (2019) Application of multi-objective land allocation technique for land-use planning approach case study: Hamadan County. *J Appl Res Geogr Sci* 19(52):211–234. <https://doi.org/10.2952/jgs.19.52.211>
- Makhdoum MF (2001) *Fundamental of land-use planning*. Tehran University Publications, Tehran, p 285
- Malczewski J (2006) Integrating multi-criteria analysis and geographic information systems: the ordered weighted averaging (OWA) approach. *Int J Environ Sci Technol* 6(1–2):7–19. <https://doi.org/10.1504/IJETM.2006.008251>
- Malczewski J, Rinner C (2015) *Multicriteria decision analysis in geographic information science*. Springer, New York, pp 220–228
- Masoodi M, Salmanmahiny A, Mohammadzadeh M, Mirkarimi SH (2016a) Optimization of recreational site selection using multi-criteria evaluation and functional relationship diagram (Case study: Miankaleh wildlife sanctuary). *Pollution* 2(2):163–181. <https://doi.org/10.7508/PJ.2016.02.006>
- Masoodi M, Salmanmahiny A, Mohammadzadeh M, Mirkarimi SH (2016b) Application of multi-criteria evaluation and GIS to ecotourism planning in protected areas (case study: MianKaleh wildlife refuge). *J Nat Environ* 69(1):211–229
- Mehri A, Salmanmahiny A, Tabrizi ARM, Mirkarimi SH, Sadoddin A (2018) Investigation of likely effects of land-use planning on the reduction of soil erosion rate in river basins: a case study of the Gharesoo River Basin. *CATENA* 167:116–129. <https://doi.org/10.1016/j.catena.2018.04.026>
- Memarbashi E, Azadi H, Barati AA, Mohajeri F, Passel SV, Witlox F (2017) Land-use suitability in Northeast Iran: application of AHP-GIS hybrid model. *ISPRS Int J Geoinf* 6(12):396. <https://doi.org/10.3390/ijgi6120396>
- Mendoza GA (2000) GIS-based multicriteria approaches to land-use suitability assessment and allocation. United States Department of Agriculture Forest Service General Technical Report NC 89–94
- Mensour ON, El Ghazzani B, Hlimi B, Ihlal A (2019) A geographical information system-based multi-criteria method for the evaluation of solar farms locations: a case study in Souss-Massa area, southern Morocco. *Energy* 182:900–919. <https://doi.org/10.1016/j.energy.2019.06.063>
- Mosadeghi R, Warnken J, Tomlinson R, Mirfenderesk H (2015) Comparison of Fuzzy-AHP and AHP in a spatial multi-criteria decision-making model for urban land-use planning. *Comput Environ Urban Syst* 49:54–65. <https://doi.org/10.1016/j.compenurbysys.2014.10.001>
- Motlagh ZK, Sayadi MH (2015) Siting MSW landfills using MCE methodology in GIS environment (case study: Birjand plain, Iran).

- J Waste Manag 46:322–337. <https://doi.org/10.1016/j.wasman.2015.08.013>
- Nguyen TT, Verdoodt A, Van YT, Delbecque N, Tran TC, Van Ranst E (2015) Design of a GIS and multi-criteria based land evaluation procedure for sustainable land-use planning at the regional level. *Agric Ecosyst Environ* 200:1–11. <https://doi.org/10.1016/j.agee.2014.10.015>
- Ostovari Y, Honarbakhsh A, Sangoony H, Zolfaghari F, Maleki K, Ingram B (2019) GIS and multi-criteria decision-making analysis assessment of land suitability for rapeseed farming in calcareous soils of semi-arid regions. *Ecol Indic* 103:479–487. <https://doi.org/10.1016/j.ecolind.2019.04.051>
- Purnamasari RA, Ahamed T, Noguchi R (2019) Land suitability assessment for cassava production in Indonesia using GIS, remote sensing, and multi-criteria analysis. *Asia Pac J Reg Sci* 3(1):1–32. <https://doi.org/10.1007/s41685-018-0079-z>
- Raza SMH, Mahmood SA, Khan AA, Liesenberg V (2018) Delineation of potential sites for rice cultivation through multi-criteria evaluation (MCE) using remote sensing and GIS. *Int J Plant Prod* 12(1):1–11. <https://doi.org/10.1007/s42106-017-0001-z>
- Rinner C, Malczewski J (2002) Web-enabled spatial decision analysis using ordered weighted averaging (OWA). *J Geogr Syst* 4(4):385–403. <https://doi.org/10.1007/s101090300095>
- Romano G, Dal Sasso P, Liuzzi GT, Gentile F (2015) Multi-criteria decision analysis for land suitability mapping in a rural area of Southern Italy. *Land Use Policy* 48:131–143. <https://doi.org/10.1016/j.landusepol.2015.05.013>
- Rossiter DG (1996) A theoretical framework for land evaluation. *Geoderma* 72(3):165–190
- Saaty TL (2000) *Fundamentals of decision making and priority theory with the analytic hierarchy process*, vol 6. RWS Publications, Pittsburgh, p 527
- Salmanmahiny A, Jozie H, Karimi Pour H, Mehri A, Kamyab H, Zare Garizi A, Mansouri M (2014) *Land assessment and planning for integrated management of Hablehroud watershed*. Tehran Pouneh publications, Tehran, p 368
- Sanaee M, Fallah SS, Ferdowsi AH (2010) Multi-criteria land evaluation, using WLC and OWA strategies to select the suitable site of forage plantation (Case study; Zakerd, Fars). *Rangeland* 4(2):216–227
- Shaygan M, Alimohammadi A, Mansourian A, Govara ZS, Kalami SM (2013) Spatial multi-objective optimization approach for land-use allocation using NSGA-II. *IEEE J Stars* 7(3):906–916. <https://doi.org/10.1109/JSTARS.2013.2280697>
- Shuaibu JA, Kara C (2019) Evaluating suitability for sustainable urban growth of Abuja by using MCE and GIS. *IJAAS* 6(7):68–76. <https://doi.org/10.21833/ijaas.2019.07.009>
- Sitko R, Scheer L (2019) Multi-objective land allocation for zoning of ecosystem services in mountain forests. *Cent Eur For J* 65(3–4):233–244. <https://doi.org/10.2478/forj-2019-0019>
- Song M, Chen D (2018) An improved knowledge-informed NSGA-II for multi-objective land allocation (MOLA). *Geo Spat Inf Sci* 21(4):273–287. <https://doi.org/10.1080/10095020.2018.1489576>
- Sumida SS, Valente RA (2019) Multicriterial evaluation in the definition of protected areas at the Piedade municipality SP. *Revista Árvore*. <https://doi.org/10.1590/1806-90882019000300007>
- Tortora A, Statuto D, Picuno P (2015) Rural landscape planning through spatial modeling and image processing of historical maps. *Land Use Policy* 42:71–82. <https://doi.org/10.1016/j.landusepol.2014.06.027>
- Yiannakou A, Salata KD (2017) Adaptation to climate change through spatial planning in compact urban areas: a case study in the city of Thessaloniki. *Sustainability* 9(2):271–289. <https://doi.org/10.3390/su9020271>
- Zabihi H, Alizadeh M, Kibet Langat P, Karami M, Shahabi H, Ahmad A, Nor Said M, Lee S (2019) GIS multi-criteria analysis by ordered weighted averaging (OWA): toward an integrated citrus management strategy. *Sustainability* 11(4):1009. <https://doi.org/10.3390/su11041009>
- Zhang X, Fang C, Wang Z, Ma H (2013) Urban construction land suitability evaluation based on improved multi-criteria evaluation based on GIS (MCE-GIS): case of New Hefei City China. *Chin Geogr Sci* 23(6):740–753. <https://doi.org/10.1007/s11769-013-0609-6>
- Zolekar RB, Bhagat VS (2015) Multi-criteria land suitability analysis for agriculture in the hilly zone: remote sensing and GIS approach. *Comput Electron Agric* 118:300–321. <https://doi.org/10.1016/j.compag.2015.09.016>