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RESEARCH ARTICLE

Evaluation of ecological capability and land use planning for different uses of land with a new model of EMOLUP in Jahrom County, Iran

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Abstract Land use planning is one of the basic principles of sustainable development in a region and in a country. The main objective of this paper is to test a new model of land use planning in order to evaluate ecological suitability and prioritize different land uses in Jahrom County placed in Fars Province, Iran. Hence two main steps were prepared for the new model of Eco-Socio-economic Model of Land Use Planning (EMOLUP). Step 1 includes ecological capability evaluation of different land uses including forest, rangeland, agriculture, conservation, and development. This step is composed of the geometric mean method instead of the Boolean method; and step 2 includes land use planning and prioritizing for the various uses mentioned above. This step is composed of intersecting ecological capability maps and land use planning, based on two scenarios (economic and social). It was compared with qualitative and current quantitative methods. Also, current land use is employed for calibrating and modifying the models. The results of ecological suitability evaluation showed that the EMOLUP model has more accuracy in the process of comparison than other current methods. Accordingly, revised method using the geometric mean (with overall accuracy > 72 and kappa index > 0.55 for all land uses and rangeland with overall accuracy = 32 and kappa index = 0.02) is better than Boolean models, and the method of the calibrated geometric mean (with overall accuracy > 87 and kappa index > 0.73 for all land uses) is the best among different used models. It should be noted that the arithmetic mean has the lowest accuracy (with overall accuracy < 45 and kappa index < 0.24 for all land uses). Also, the results of prioritizing and land use planning showed that the quantitative method with two socio-economic scenarios (result based on average of EPM erosion model = 0.3 that means 30% of modification in whole study area land uses) is the best method for land use planning in the study area.

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1 Introduction

Land (land use) is an essential natural resource performing a number of key environmental, economic, social, and cultural functions, which are vital for life (Alavi Panah et al., 2001; Benthem, 2013; Feng et al., 2014; Asadifard et al., 2019). Land use planning tries to formulate proposed activities, administer potential changes, and protect incompatible changes. Such administrative and management strategies, through land use planning, work to ensure the sustainability of a region (Pourkhabbaz et al., 2014; Masoudi and Jokar, 2015). Hence, before the beginning of development, it is better to select a suitable developing site in terms of ecological capability and land use planning in order to prevent the reduction of natural resources, which may happen due to illogical usage (Nouri and Sharifipour, 2004; Masoudi et al., 2020).

Additionally, since land is a complex system resulting from the interaction of physical, biological, and anthropological phenomena operating over different scales of time and space, choosing a proper method of evaluation for planning is also very important (O'Neill, 1989; Abu Hammad and Tumeizi, 2012; Ayalew, 2015; Masoudi et al., 2017; Masoudi and Zare, 2019; Jokar et al., 2021). A significant amount of literature and research has been dedicated to intelligent systems for land use and management. Since McHarg (1969), land suitability assessment has become a standard practice in land use planning. Land uses include both natural and man-made uses. The Food and Agriculture Organization of the United Nations (FAO) (1976) defined land evaluation as the process of assessment of land performance when used for specified purposes. In this way, land evaluation can be useful for predicting the potential use of land based on its attributes (Rossiter, 1996). In such classic methods like the FAO, Storie (1987) made the classification quite strict based on maximum limitation. This is because, according to Boolean logic, only one low index is enough to reduce the suitability of land from a highly suitable class to a not suitable class. Also, computer-assisted overlay techniques such as the Geographic Information System (GIS) were developed as a response to the manual method's limitations in mapping and combining large data sets (Steinitz et al., 1976; Pan and Pan, 2012; Froja, 2013; Liao and Wu, 2013; Najafinezhad et al., 2013; Ghorbani et al., 2014; Masel Ullah, 2014; Jahantigh et al., 2019; Mokarram and Zarei, 2021). Methods like Multi-Criteria Decision Making (MCDM) and genetic algorithms have considerably advanced the conventional map overlay approaches to land use suitability analysis (Oyinloye and Kufoniyi, 2013). Generally, land use suitability analysis methods have one problem. They do not assure a spatial pattern with contiguity or compactness in land allocations for different types of land use. Also, these methods are complex to use.

Among leading models in the field of economic planning (prioritizing), the French and the Anglo-Saxon models can be mentioned (Kindleberger, 1967). Also, there is a model designed by Nakos (1984) in Greece related to land use planning. Fallahshamsi (2004) investigated the economic evaluation of different land uses in the kalibar-chai forest-covered watershed in Iran, using linear programming and the GIS, and based on the cost-benefit method. Najafinezhad et al. (2013) compared the efficiency of systematic and multi-objective land allocation (MOLA) methods for land use planning using the GIS. They found that the map obtained from MOLA was better in terms of land use allocation, and also, for reducing erosion and sediment production as compared to that of the systematic method. Masoudi and Jokar (2015) have conducted land use planning using a quantitative model and the GIS in the Shiraz County of Iran. The results indicated that the maximum area of proposed use was 39.30%, related to range and dry farming; and the minimum area of proposed use was 3.3%, related to irrigation agriculture with range. Yohannes and Soromessa (2018) evaluated land suitability analysis for major crops by using geographical information system-based multi-criteria approach in Andit Tid watershed, Ethiopia. Results revealed that, though, there are slight variation in suitable classes for each crop, most part of the watershed was moderately suitable for both wheat and barley crops. Pan et al. (2021) conducted practical efficient regional land-use planning using constrained multi-objective genetic algorithm optimization for Dapeng, China. Results showed that the comprehensive model gave superior fitness compared to the contrast experiments. Iterations progressed rapidly to near-optimality, but final convergence involved much slower parent–offspring mutations. Tradeoffs between conversion cost and compactness were the strongest, and conflict degree improved in part as an emergent property of the spatial social connectedness built into our algorithm.

Masoudi (2018) denominated a new framework for ecological capability evaluation and land use planning of different land uses with a proposed model of "Eco-Socioeconomic Model of Land Use Planning" (EMOLUP), not only useful in Iran but also in other countries. The main objective of this paper is the implementation of simple integration quantitative models and to test the EMOLUP model in order to evaluate ecological suitability and prioritize different land uses in Jahrom County placed in Fars Province, Iran.

2 Materials and methods

2.1 Study area

Jahrom County is located in the Fars Province of southern Iran (Fig. 1). This County has an area of 5436 km^2. It is placed at latitude 28°19′N to 29°10′N and longitude 52°45′E to 54°04′E. The average height is about 1050 m. The climate is warm and generally moderate in the mountainous areas. The average rainfall is about 285 mm per year and the average temperature in this city is about 20°C. The regional crops cultivated in this area are mostly horticultural.

2.2 Modeling process for ecological capability evaluation

The present paper aims to find a suitable model for land capability evaluation, for different land uses in the study area, using software like ArcGis9.3, ENVI4.7, and Excel.

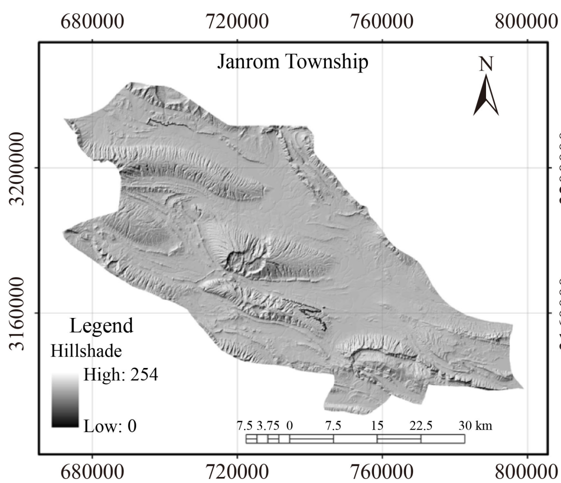

Fig. 1 Location of the study area in Iran.

Two types of data were obtained: numerical data and thematic maps, mainly in the map format. All such relevant data were obtained from the local and main offices and institutes of the Ministries of Agriculture and Energy in Iran. All data were thoroughly processed using the GIS technique.

2.2.1 Classification of models

The Iranian Ecological Model (Makhdoum, 2006; Masoudi, 2018) is a land evaluation model for different land uses. For example, forestry (including 7 Classes); agriculture and rangeland management (including 7 Classes); development (including 3 Classes); and ecotourism (including 3 Classes). It should be noted that the ecological potential in every use reduces by increasing the capability number of the class. In the revised method, classes mentioned were reclassified (in order to make a standard classification). Accordingly, the uses of agriculture and natural resources (forest and rangeland) were reclassified into 4 Classes (Table 1a) including: highly suitable (I_{an}), moderately suitable (II_{an}), poor (III_{an}), and not suitable (IV_{an}). Man-made uses (development and ecotourism) were reclassified into 3 Classes including: highly suitable (I_{mu}), moderately suitable (II_{mu}), poor and not suitable (III_{mu}) (Table 1b). Also, environmental conservation uses or protected land was classified in 2 Classes including: suitable (I_{ecp}), not suitable (III_{ecp}) (Table 1c).

2.2.2 Formulating model

A. **Boolean Algebra**

Boolean logic has three basic operators: Intersection (logical term AND), Union (logical term OR), and Inverse (logical term NOT).

B. **Geometric Mean**

In the geometric mean method such as the MEDALUS model (Kosmas et al., 1999) and according to criteria, in the uses with four classes, every indicator was given the weight between 0 and 3 (Table 1). In this, 0 indicates the non-suitability of the ecological condition (Class 4) and 3 represents the most suitable ecological condition (Class 1) for a utilization like irrigation. Scores of 1 and 2 are given to the third and second classes, respectively. In uses like development with three classes, every indicator was given the weigh between 0 and 2 (Table 1). In this, 0 stands for poor and non-suitable ecological condition (Class 3) and 2 stands for the most suitable ecological condition (Class 1).

Then every criterion (like topography) was calculated based on the geometric mean of indicators (Eq. (1)):

$$\text{Criterion\_}X = [(\text{Layer}-1)\times(\text{Layer}-2)\cdots\times(\text{Layer}-n)]^{\frac{1}{n}}, \tag{1}$$

where Criterion_ X is the defined criterion; Layer is the indicator map of criterion; and n is the number of used indicators. Then the criteria were multiplied through the geometric mean (Eq. (2)):

$$\text{Final Criterion} = [(\text{Layer}-1)\times(\text{Layer}-2)\cdots\times(\text{Layer}-n)]^{\frac{1}{n}}, \tag{2}$$

where Final Criterion is the final layer of ecological capability; n is the number of used criteria. Then classes of qualitative and suitable ecological capability were defined, for uses of three and four classes, in the study area in a GIS (Table 2).

Note: The capability of conservation use was calculated based on the Boolean (OR) method.

C. **Arithmetic Mean (Sum)**

In the arithmetic mean method, scores given to indicators were averaged (Table 2 for classification).

2.2.3 Validation and calibration

A. Validation

To validate models, samples of ground reality (current land use map) were gathered by "Create Fishnet" algorithm (a systematic random sampling) in ArcGIS 9.3 environment (Congalton, 1991; Makhdoum et al., 2009). Number of samples was based on importance of ground reality in every use. So, the regions with more suitable condition for every use were sampled more than other regions (Fallahshamsi, 1997).

Then these points were overlaid to land capability maps. The obtained result is observed in a table named "Error Matrix" and by quantitative indices like "Overall Accuracy, Kappa and Inclass Coefficients" (Fallahshamsi, 1997).

B. **Calibration**

To ensure the agreement of capability maps to current conditions (regarding omission and commission in errors and maps of parameters in the geometric mean method), quantitative ranges of suitability classes (Table 2) were slightly changed. For example, the range of Class 0.5–1.5 was changed to 0.5–1.75. This kind of calibration was done in other classifications like the MEDALUS method.

2.3 Prioritizing different land uses

2.3.1 Modeling process

The present paper aims to find a land use planning model for prioritizing different land uses of the study area using ArcGIS. Every use with the best accuracy was intersected in a vector format in the ArcGIS software environment. Current land use was also applied.

It should be noted that the land use planning process is based on selection of the best use in every polygon (unit). Hence, different methods were applied in order to select the best use.

The methods are described as follows.

Table 1 The indicators used in the model of land evaluation of EMOLUP (Masoudi, 2018) for agriculture and natural resources or four classes' models (a) and for development and ecotourism or three classes' models (b) and conservation Use (c)

(a)

Criteria	Parameter	Irrigated farming	Rainfed farming	Forest	Rangeland	Class
Topography	Slope/%	0–8 [1)]	0–5	0–35	0–15	1
		8–15	5–15	35–55	15–25	2
		15–30	15–25	55–65	25–40	3
		> 30	> 25	> 65	> 40 (in mountains)	4
	Elevation/m or Land type	Plain	Plain	0–1000	–	1
		–	–	1000–1800		2
		Hill	Hill	1800–2600		3
		Mountain	Mountain	> 2600		4
Climate	Drought	Slight	Slight	–	Slight	1
		Moderate	Moderate		Moderate	2
		Severe & very severe	Severe & very severe		Severe & very severe	3
		–	–		–	4
	Rain/mm	–	> 400	> 800	> 400	1
			200–400	500–800	200–400	2
			50–200	200–500	50–200	3
			< 50	< 200	< 50	4
	Temperature/°C	–	–	18 – 21	–	1
				< 18, 21.1–30		2
				> 30		3
				–		4
	Current state of climate	Semi-arid to Humid	–	–	–	1
		Arid				2
		Very arid				3
		–				4
Soil	Texture	Heavy, moderate, light	Heavy, moderate, light	Heavy, moderate, light	Heavy, moderate, light	1
		Coarse	Coarse	Coarse, very coarse	Coarse	2
		Very coarse	Very coarse	–	Very coarse	3
		–	–	–	–	4
	Depth/cm	Deep (> 80)	Deep (> 80)	Deep (> 80)	Semi deep to deep (> 50)	1
		Semi deep (50–80)	Semi deep (50–80)	Semi deep (50–80)	Shallow (25–50)	2
		Shallow (25–50)	Shallow (25–50)	Shallow to very shallow (< 50)	Very shallow(< 25)	3
		Very shallow to no soil (0–25)	Very shallow to no soil (0–25)	No soil (0)	No soil (0)	4
	pH	6.1–8.5	⩽ 8.5	4.2–7	⩽ 9	1
		4.2–6, 8.5–9	8.5–9	7.1–8.5	–	2
		9–9.5	9–9.5	8.6–10	> 9	3
		> 9.5	> 9.5	> 10	–	4
	Gravel percent	0–35	0–35	⩾ 15	0–35	1
		35–75	35–75	16–50	35–75	2
		> 75	–	> 51	> 75	3
		–	> 75	–	–	4

(a) (*Continued*)

Criteria	Parameter	Irrigated farming	Rainfed farming	Forest	Rangeland	Class
Soil	Drainage/(cm·hr^{-1})	Good to moderate (0.1−25)	Good to moderate (0.1−25)	Good to moderate (0.1−25)	Good to moderate (0.1−25)	1
		Poor (< 0.1, > 25)	Poor (< 0.1, > 25)	Poor (< 0.1, > 25)	Poor (< 0.1, > 25)	2
		−	−	−	−	3
		−	−	−	−	4
	Erosion	None, slight	None, slight	None, slight	None, slight	1
		Moderate	Moderate	Moderate	Moderate	2
		Severe	Severe	Severe, very severe	Severe, very severe	3
		Very severe	Very severe	−	−	4
	Granulating	Fine to Moderate	Fine to Moderate	Fine	Fine to Moderate	1
		Coarse	Coarse	Moderate	Coarse	2
		−	−	Coarse	−	3
		−	−	−	−	4
	Evolution (Structure)	Perfect (granular)	−	Perfect (granular)	−	1
		Moderate		Moderate		2
		Low		Low		3
		None (no structure)		None (no structure)		4
	Salinity (EC in ds/m)	< 8	< 8	−	< 8	1
		8−16	8−16		8−18	2
		16−32	16−32		18 <	3
		> 32	> 32		−	4
	ESP	< 15	< 15	−	< 15	1
		15−30	15−30		15−30	2
		30−50	30−50		> 30	3
		> 50	> 50		−	4
	Fertility (organic matter %)	Good (> 1.5)	Good to Moderate (> 1)	Good (> 1.5)	Good to Moderate (> 1)	1
		Moderate (1−1.5)	Low (1)	Moderate (1−1.5)	Low (1)	2
		Low to Very low (< 1)	Very low (< 1)	Low (1)	Very low (< 1)	3
		−	−	Very low (< 1)	−	4
Geology	Geology	−	−	Limestone and dolomite, Intermediate pyroclastic rocks of Eocene, shale, clay stone, conglomerate and marl type 1, ophiolite of melange color, floodplain	−	1
				Granite, sandstone, loess, schist and gneiss and amphibolite		2
				Marl Type 2, alluvial fans, alluvial terraces, sand dunes, continental shelf sediments		3
				Salt domes, gypsum dome, calcite and dolomite marble, quartzite		4

(a) (*Continued*)

Criteria	Parameter	Irrigated farming	Rainfed farming	Forest	Rangeland	Class
Vegetation	Canopy cover/%	–	–	75–100	⩾ 50	1
				25–74	25–50	2
				< 25	5–25	3
				–	< 5	4
	Wood value[2)]	–	–	Wood with grade1	–	1
				Wood with grade 2		2
				Wood with grade 3		3
				None commercial		4
	Vegetation type	–	–	Forest lands	–	1
				–		2
				Rangelands		3
				Poor rangelands (canopy cover <25%), Desert		4
	Annual growth /m^3 [3)]	–	–	> 5	–	1
				2.1–5		2
				< 2		3
				–		4
	Dry forage/($kg \cdot ha^{-1}$)	–	–	–	> 500	1
					350–500	2
					< 350	3
					–	4
Water	Quantity of water /($m^3 \cdot year^{-1}$)	> 3000[4)]	–	–	–	1
		1500–3000				2
		< 1500				3
		Without water resources				4
	Lowering of water table/($cm \cdot y^{-1}$)	0–20	–	–	–	1
		20–30				2
		> 30				3
		–				4
	EC/($\mu mhos \cdot cm^{-1}$)	0–750	–	–	–	1
		750–2250				2
		> 2250				3
		–				4
	SAR	0–18	–	–	–	1
		18–26				2
		> 26				3
		–				4

Note: 1) This slope classification is assigned for horticulture and Class 1: 0–5, Class 2: 5–8, Class 3: 8–15 and Class 4: >15 is assigned for Irrigated cultivation. 2) It is evaluated for only Commercial Forestry suitability. 3) It is evaluated for only Commercial Forestry suitability. 4) This classification is assigned for horticulture and Class 1: >4000, Class 2: 1500–4000, Class 3: <1500 and class 4: Without water resources is assigned for Irrigated cultivation.

(b)

Criteria	Parameter	Development	Ecotourism	Class[1)]
Topography	Slope/%	0−15	0−15	1
		15−30	15−30	2
		> 30	> 30	3
	Land type	Plains except of flood plains	−	1
		Plateau & upper terraces, alluvial-colluvial fans		2
		Mountains, hills, flood Plains		3
Climate	Rain/mm	501−800	−	1
		51−500, > 800		2
		< 50		3
	Temperature[2)]/°C	18.1−24	21−24	1
		24.1−30, < 18	18−21, 24−30	2
		> 30	> 30, < 18	3
	Number of sunny days (in spring and summer months)	−	> 15	1
			7−15	2
			< 7	3
	Relative humid/%	40.1−70	−	1
		< 40, 70−80		2
		> 80		3
	Wind speed/(km·h^{-1})	1−35	−	1
		36−60		2
		> 60		3
Soil	Texture	Moderate (often)	Usually moderate	1
		Light (often)	Coarse, light, heavy	2
		Heavy (often), Regosols, lithosols	Very heavy	3
	Depth	Deep	Deep	1
		Semi deep	Semi deep	2
		Shallow to very shallow	Shallow to very shallow	3
	Gravel percent	0−25	−	1
		26−50		2
		> 50		3
	Drainage/(cm·hr^{-1})	Good (2−6)	Good (2−6)	1
		Moderate (0.1−2, 6−25)	moderate to poor (0.1−2, 6−25)	2
		Poor (< 0.1, > 25)	Incomplete (< 0.1, > 25)	3
	Erosion	None, slight	−	1
		Moderate		2
		Severe, very severe		3
	Granulating	Moderate	−	1
		Fine, coarse		2
		Very fine		3
	Evolution (structure)	Perfect (granular)	Perfect (granular)	1
		Moderate	Moderate	2
		Low	Low	3

(b) (*Continued*)

Criteria	Parameter	Development	Ecotourism	Class[1)]
Soil	Fertility (organic matter %)	–	Good, moderate (> 1)	1
			Low (1)	2
			Very low (< 1)	3
Geology	Lithology	Sandstone, ophiolite of melange color, sediments of continental shelf	Pyroclastic rocks, granite ophiolite of melange color, sand dunes, continental shelf sediments	1
		Limestone and dolomite, intermediate pyroclastic rocks of Eocene, granite, alluvial fans, shale, clay stone, conglomerate, loess, alluvial terraces	Limestone and dolomite, sandstone, loess, schist and gneiss and amphibolite, quartzite, alluvial fans, flood plain	2
		Marl, schist and gneiss and amphibolite, sand dunes, salt domes, gypsum dome, calcite and dolomite marble, quartzite, floodplain, Buffer[3)](Fault, River)	Marl, shale, clay Stone, conglomerate, salt domes, gypsum dome, calcite and dolomite marble	3
Vegetation	Canopy cover/%	0–25	Forest lands with canopy cover of 50–80%	1
		26–50	Forest lands with canopy cover of 5–50%	2
		> 50	Poor rangelands, forest lands with canopy cover > 80%, Desert	3
Water	Quantity of water for everyone /(Lit·day^{-1})	> 225	> 40	1
		150–225	12–39.9	2
		< 150	< 12	3
Conservation	Protected area	–	Forest park of natural and planted, nature park, national park, protected area, biosphere Reserve, World Heritage, historical artifacts and national and pilgrimage	1
			–	2
			Reserve forest, wildlife Sanctuary, national natural monuments	3

Note: 1) Poor & not suitable situation for third class. 2) For ecotourism in spring & summer seasons. 3) Major fault= 1 km, Minor fault =300 m; River= 1 km (Gharakhlou et al., 2009; based on guidelines of Department of Energy and Department of Housing and Urban Development in Iran).

(c)

Parameter	Description	Class
Value of species (Mammals)	Cheetah, zebra, fallow deer, ibex, chamois, panther, gazelle, chinkara, wild goat, ovis, wolf, sable, wild cats, bear	Suitable
	Fox, badger, hyena, weasel, pig, porcupine, squirrel, jackal, pika, hedgehog, bat, rabbit, rodents	None suitable
Species biodiversity	⩾ 5	Suitable
	< 5	None suitable
Sensitive habitats	Mangroves, estuaries, ponds	Suitable
	Other	None suitable
Protected area	Reserve forest, forest park of natural and planted, national park, nature park, protected area, biosphere reserve, wildlife refuges, national natural monuments	Suitable
	Other	None suitable

Quantitative Method: initially, the quantitative method developed by Nakos (1984) was used. Then it was revised (based on conditions in Iran) by Makhdoum (2006). Based on regional information, four scenarios were developed for different land uses: current land use area, ecological scenario, economic scenario, and social scenario. Table 3a shows one example describing the four scenarios in a study area (as a planning unit).

The first scenario was ranked by evaluating the current land use. But for other scenarios, questionnaires was prepared. Experts of the study area were asked to rank different land uses for these other scenarios based on their knowledge and experience. Then all land uses were

Table 2 Suitability classes in capability maps and models for 4 classes' uses (a) and models for 3 classes' uses (b) regarding the scores ranges of polygons in the model of EMOLUP (Masoudi, 2018)

(a)

	Suitability classes			
Their score	Good (1)	Moderate (2)	Poor (3)	Not suitable (4)
	2.5−3	1.5−2.5	0.5−1.5	< 0.5

(b)

	Suitability classes		
Their score	Good (1)	Moderate (2)	Poor and Not suitable (3)
	1.5−2	0.5−1.5	< 0.5

Table 3 Example of scenarios designed for the study area (a) and Relative values (0−10) assigned to different land uses according to capability classes of the land with taking into consideration of different scenarios (b)

(a)

Scenario1	**Rangeland >**	**Forest >**	**Agriculture >**	**Conservation >**	**Development**
Scenario2	**Conservation >**	**Rangeland >**	**Forest >**	**Agriculture >**	**Development**
Scenario3	**Development >**	**Agriculture >**	**Rangeland >**	**Conservation >**	**Forest**
Scenario4	**Development >**	**Agriculture >**	**Conservation >**	**Rangeland >**	**Forest**
Weighted values	10	9	8	7	6

(b)

Capability class	**Rangeland**	**Forest**	**Agriculture**	**Conservation**	**Development**
	1	3	2	1	2
Scenario					
1	10	7	7	7	5
2	9	6	6	10	5
3	8	4	8	7	9
4	7	4	8	8	9
Sum	34	21	29	32	30
Priority	1	5	4	2	3

ranked for each scenario and given scores of 10 and below based on their ranks (Table 3a) and classes of ecological capability (Table 3b). For example, if in one scenario in a land unit, the rank of forest is in the third place and its ecological capability is in Class 2, then the score in its first step is 8, and one point is lowered for its capability reduction (Class 2), making the forest score 7. If ecological capability is in Class 3, the reduction in each scenario would be of two points.

To achieve a systematic analytical model, all layers of ecological capability maps were used by a vector format in the ArcGIS software environment. These maps were operated using ArcGIS, and the appropriate utilization of each land unit (polygon) was determined and prioritized. Appropriate utilizations are those that have a higher sum of scores among the used scenarios (Table 3b). Many of the units were seen to be fit for two appropriate uses by the quantitative model – first to determine and subsequently to select the best utilization for the area, considering the socio-economic status of the area, consistency of land uses, and current land use.

Modified Quantitative Method (four scenarios): modifications were made in the process of work for assessing land use planning with a quantitative model. These modifications are described as follows.

a. Each use was prioritized based on the highest score derived after summing up the scores of the scenarios. Of course, it is necessary to have appropriate capability (suitable or Classes 1 and 2) for the utilization with highest score.

b. The compatibility of uses was considered. If uses are compatible together (for example, forest and conservation), they will be considered together. If uses are not compatible together (for example, development and forest), they will be considered based on economic needs (especially current land use).

c. Current land use map was applied for assessment because of socio-economic compulsions of the population, especially in rural areas. The main modifications in this step are to hold the following land utilizations.

1) Agricultural lands with suitable capability (classes 1 and 2).

2) Settlement lands (urban, rural, and industrial areas).

3) Forest lands with a canopy cover of more than 25% (F_1 and F_2) and those with conservational roles based on compatibility of uses.

4) Forest lands with a canopy cover of less than 25% (F_3) that were prioritized as rangeland. They are prioritized as Forest – Rangeland based on compatibility of uses.

5) Rangelands with a canopy cover of more than 25% (R_1 and R_2), F_3, and ecotourism with suitable capability (Class 1) with taking into consideration of compatibility of uses.

6) Current protected lands with taking into consideration of compatibility of current land use (for example, natural resources) and holding man-made current land use in current protected lands (except core zones).

7) Lakes and river beds.

8) Lands not prioritized in earlier steps (with suitability Classes 3 and 4); their utilizations are retained.

Note: Proposed land use: F (Forest); R (Rangeland); IF (Irrigated Farming); DF (Dry Farming); D (Settlement and Development); E (Ecotourism); C_1 (Current Conservation); C_2 (Future Conservation); W (Water Body).

Modified Quantitative Method (two scenarios): due to problems in evaluation of the quantitative methods (4 scenarios) [a) the larger area of one utilization (for example, rangeland) as compared to the smaller area of another utilization, giving higher weight to the former; b) the existing ecological scenario in land ecological capability evaluation where experts may mistakenly prioritize the ecological scenario], the revised quantitative method was used based on two scenarios (economic and social) with mentioned modifications.

Qualitative and Its Modified Method: qualitative method (Makhdoum, 2006; Khosravi et al., 2012; Masoudi, 2018) keeps current utilizations with suitable capability (Classes 1 and 2) after intersecting ecological capability maps with the land use map. Other lands are prioritized based on utilizations that have better land capability. In modified qualitative method, some positive changes (mentioned in the modified quantitative method) were added.

2.3.2 Validation of models

To validate the models, the Erosion Potential Method (EPM) model was used (Gavrilovic, 1998). Based on the EPM model assigned with land uses, maps of the new models were compared with the current land use map. The model close to good land uses assigned to the EPM model is considered to be the better model. The ranked land uses (agriculture and natural resources) were assigned to the EPM model (with a little modification (were sorted based on their impact on soil protection (Table 4a). This ranking helps to compare land use planning maps to current land use. Based on Table 4a, if the optimized uses have better situations than current land use (A), positive (+1) score is given; if the optimized uses have worse situations than current land use (B), negative (−1) score is given; and if the optimized uses are the same as current land use (C), zero (0) score is given.

Point 1: If the current land use is kept and its ecological capability is in Class 1 (except protected lands), a positive (+1) score is given (D) due to its socio-economic importance.

Point 2: Converting a river bed to other uses is equivalent to a negative (−1) score.

It should be noted that the use of residential and industrial development has not been mentioned in the EPM model. Hence, a separate table (Table 4b) was made to compare the current and optimized land uses with regard to destructive out-site and in-site effects, and socio-economic special features for this use.

Table 4 Validation of the models by EPM model to compare with current land use (a) and validation of the models by comparing with current land use and development (b)

(a)

Order	Land use	Description
1	F_1, F_2	Current dense and semi dense forest (capability classes of 1 and 2 in optimized use)
2	IF, DF with suitable capability(classes of 1, 2)	Irrigated and dry farming with suitable capability (classes of 1 and 2)
3	F_3, R_1	Current sparse forest (capability class of 3 in optimized use), current dense range (capability class of 1 in optimized use)
4	R_2	Current semi dense range (capability class of 2 in optimized use)
5	IF, DF with none suitablecapability (3, 4) and R_3	Irrigated and dry farming with weak to none suitable capability (classes of 3 and 4) and current sparse range (capability class of 3 in optimized use)
6	DESERT (BL, SL)	Barren and saline lands
Examples		Examples code
R_2 (current) to F_2 (optimized)		A
F_2 (current) to R_1 (optimized)		B
F (current) to F (optimized)		C
IF (current) to IF (capability 1)		D

(b)

Current land use	Optimized use	Score	Reason and description
Development	Every use (e.g., range)	−1	Socio-economic conditions
Development	Development	0	No change
Every use	Development	−1 to + 1	Based on capability degree of both uses

Also, for future (not current) environmental conservation, the score was considered to be positive due to land improvement and its protective role. Additionally, to convert areas of natural resources and agriculture to ecotourism, the rating −1 to +1 was used based on the capability degree of agriculture and ecotourism areas, and due to environmental and socio-economic special features for these uses.

Based on the above points, the new models were compared together. For this purpose, a certain number of points (1002) was scattered with the Create Fishnet algorithm in ArcGIS9.3 environment and was based on the study area (a systematic-random sampling). In the next step, the new models were compared based on average ratings. So, the final number is between ±1. If the positive number obtained is larger, it represents the suitability of the prioritization process.

3 Results and discussion

3.1 Ecological capability evaluation

The final results of validation for different uses are observed in Table 5. Results (Table 5) generally show that the revised method using the geometric mean (with overall accuracy > 72 and kappa index > 0.55 for all land uses and rangeland with overall accuracy = 32 and kappa index = 0.02) is better than Boolean models, and the method of the calibrated geometric mean (with overall accuracy > 87 and kappa index > 0.73 for all land uses) is the best among the different used models. It should be noted that the arithmetic mean has the lowest accuracy (with overall accuracy < 45 and kappa index < 0.24 for all land uses). The Boolean method (with a revised model) is suitable in forest (with overall accuracy = 74 and kappa index = 0.58) and rangeland (with overall accuracy = 73 and kappa index = 0.13) uses. This is because it takes into consideration that native species have adapted with the total ecological conditions of the area. These results coincide with Sanaee et al. (2010). Although the geometric mean with its calibration (for forest, with overall accuracy = 94 and kappa index = 0.9; for rangeland, with overall accuracy = 87 and kappa index = 0.73) was estimated to be the favorable ground reality. Also, inclass coefficient was found to be the best to estimate suitable classes. In relation to man-made uses, especially irrigated agriculture and development, it was found that the geometric mean with its calibration (for irrigated agriculture, with overall accuracy = 87 and kappa index =

Table 5 Overall Accuracy, Inclass and Kappa coefficients in the used models

Land uses	Index	Model				
		Boolean		Average		
		Ecological	Max limit	Arithmetic	Geometric	Calibrated
Irrigated farming	Overall accuracy	70	68	38	73	87
	Kappa coefficient	0.56	0.52	0	0.55	0.79
	Inclass coefficient	0.85	0.43	0.61	1.43	3.8
Rainfed farming	Overall accuracy	91	88	45	85	88
	Kappa coefficient	0.81	0.75	0	0.71	0.76
	Inclass coefficient	3.88	2.73	0.83	2.59	3.04
Rangeland	Overall accuracy	70	73	30	32	87
	Kappa coefficient	0	0.13	0	0.02	0.73
	Inclass coefficient	0	0.1	0.42	0.44	2.29
Forest	Overall accuracy	54	74	22	72	94
	Kappa coefficient	0.06	0.58	0	0.55	0.9
	Inclass coefficient	0	0	0.32	0.82	11.31
Development (urban and industry)	Overall accuracy	54	54	42	86	87
	Kappa coefficient	0.32	0.32	0.24	0.75	0.77
	Inclass coefficient	0	0	3.93	4.36	4.56

0.79; for development, with overall accuracy = 87 and kappa index = 0.77) has the best accuracy as compared to the Boolean method. These results coincide with Fallahshamsi (2004). In rain-fed agriculture evaluation, it was found that the Boolean method (with little difference compared to the geo-mean) is the best method (with overall accuracy = 91 and kappa index = 0.81). In fact, due to less suitable economic and ecological (drought) conditions, the study area does not have enough potential for rain-fed agriculture. Hence, the Boolean method is suitable based on strict evaluation.

The final maps of ecological capability, with the best accuracy and suitability classes for different methods (based on Table 5), are observed in Fig. 2(a). The maps include methods of Iranian ecological model and maximum limit by Boolean algebra, arithmetic and geometric mean, and calibration of geometric mean. Additionally, Fig. 2(b) shows that the study area by the arithmetic mean tends to fall under good classes; Boolean methods tend to fall under not suitable classes; and the geometric mean and its calibration tends to be placed between the other methods (for all land uses). This indicates that the geometric mean and its calibration can be a useful and flexible model for finding the potential of

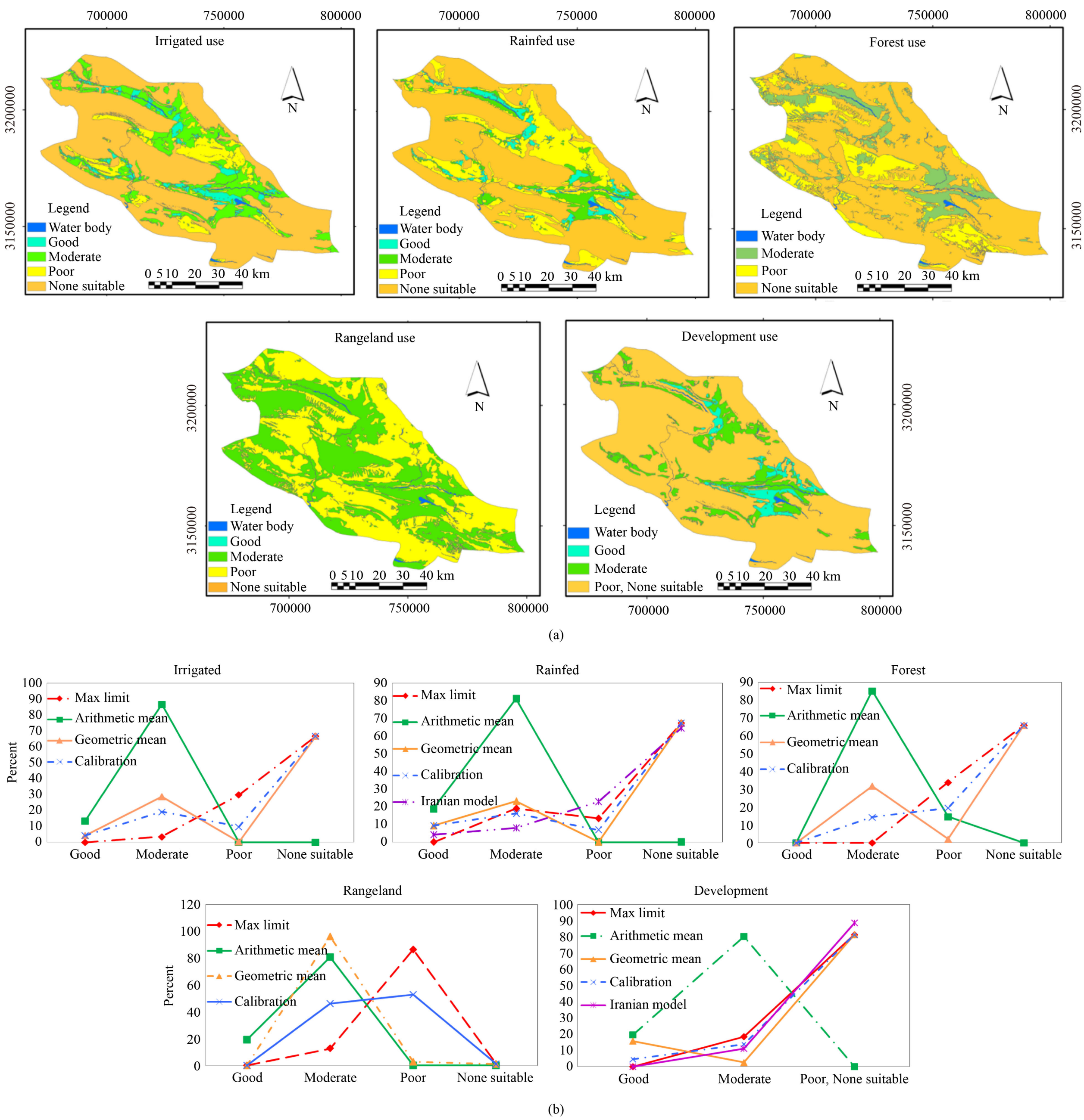

Fig. 2 Ecological capability maps prepared with best accuracy (a) and percent of land under different capability classes for different methods of every use (b).

use. These results coincide with Elaalem et al. (2010) and Najafinezhad et al. (2013), and are based on the same methods.

3.2 Prioritizing different land uses

Land use planning methods were applied in every polygon after intersecting ecological capability maps of different land uses with the current land use. Final results of validation for land use planning methods are observed in Table 6. The basic methods are based on primary methods of Nakos (1984) and Makhdoum (2006).

Results generally showed that modified methods (with EPM index for modified qualitative = 0.17, for modified quantitative with 4 scenarios = 0.23 and for modified quantitative with 2 scenarios = 0.3) are better than basic models (with EPM index for basic qualitative = 0.1 and for basic quantitative with 4 scenarios = 0.04) due to reforms; and revised quantitative methods are better than qualitative models due to quantitative calculations, existing scenarios, and modifications. Also, the modified quantitative method with two scenarios (EPM index = 0.3) is the best among the different used models. Actually, the quantitative method with two scenarios is even better than the quantitative method with four scenarios. It shows that the area and ecological scenarios are not suitable for land use planning. These results agree well with Babaee and Ownegh (2006). Additionally, the study area has regions that should be protected like the Gorm Mountain (Fig. 3) in the center of the map, as well as parts of the west and north-west. The importance of biodiversity was investigated by Zareian (2009) and land degradation by Najafifar (2012) in the mentioned regions. It was found that the quantitative method with two scenarios (Fig. 3) has more land for future conservation (in accordance to the mentioned regions) than the quantitative method with four scenarios. In other words, the existing scenarios of area and ecology led to the use of conservation being seen as less than range or forest. The areas defined in Fig. 3 represent future conservation. On the whole, Fig. 3 and Table 6 show that 30% of the study area will be improved by the two scenarios method, using socio-economic and ecological information.

The total results obtained in Table 7 are as follows.

1. To keep most forest lands and rangelands (especially R1, R2, and most of R3) in the optimized land use map.

Table 6 Validation of land use planning methods

Index	Model				
	Basic			Modified	
	Qualitative			Quantitative	
				4 scenarios	2 scenarios
EPM (Average)	0.1	0.04	0.17	0.23	0.30

2. To keep most irrigated lands in the optimized land use map.

3. To increase conservation lands in optimized land use as compared to current land use.

4. To increase development use due to socio-economic issues and to increase rain-fed lands in poor rangelands, taking into consideration environmental conservation and Environmental impact assessment (EIA).

5. To convert deserts to natural resources in optimized land use.

6. To perform ecotourism in some forest lands.

4 Conclusions

In this paper, different evaluation methods such as the Boolean and average were investigated. Results showed that the suitability of every use and the selection of

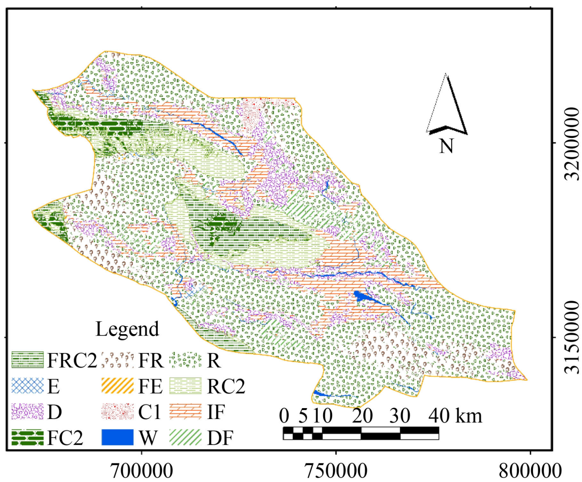

Fig. 3 Final map of land use planning by two scenarios.

Table 7 Percent area of current and optimized land uses

Land use	Current land use/%	Optimized land use
Forest	18.64	2.26 (FC_2)
		6.52 (FRC_2)
		8.32 (FR)
		0.38 (FE)
Rangeland	66.11	45.85 (R)
		9.03 (RC_2)
Irrigated farming	12.95	12.26
Rainfed farming	0.67	2.9
Development	0.57	10.63
Desert	0.14	–
Conservation	0.93	0.93 (C_1)
Water body	0.92	0.92
Sum	100	100

suitable evaluation methods could be estimated by current land use. Since current land use is an important parameter, the socio-economic conditions in a region were stated (Di Gregorio and Jansen, 1998). The modified classification of parameters has helped to increase the accuracy of the new model of EMOLUP. This indicates that in each specific area, a special classification appropriate to the conditions of the area is required. The geometric mean method has also improved the accuracy of the models, which shows this method has higher flexibility and accuracy. Another important advantage of this method is the simplicity of implementation compared to other methods.

Also, the new method of EMOLUP using geometric mean and different criteria reduces the high effect of certain criteria like soil with ten indicators as compared to other important criteria with fewer indicators. Therefore, climate and topography with only two indicators have an equal weight as the soil factor. Also, there is a range of ecological conditions that create restrictions in the land such as very severe salinity. By placing the number zero in an equation and multiplying, these regions were not considered to be suitable.

In this paper, it was found that the quantitative method with two scenarios (social and economic) is the best method for land use planning. It should be noted that this method considers ecological as well as socio-economic issues. Of course, if socio-economic information is not available, we can use the revised qualitative method. In this method, due to the combination of land use planning methods, the accuracy of the model has been increased.

Finally, the results of this land management study based on geo-mean, its calibration and validation methods, and modification methods of land use planning (especially quantitative method with two scenarios) are suggested to managers. Also, we denominate this kind of ecological capability evaluation and land use planning for different land uses with a proposed model of EMOLUP to the scientific societies (Masoudi, 2018).

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