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RESEARCH PAPER

An ecological agricultural model using fuzzy AHP and PROMETHEE II approach

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Abstract
Over-capacity reduction is one of the major challenges facing humanity in the last century. To achieve sustainable development, there must be a tendency towards rational planning and utilization of resources based on their potential. Since agriculture has many environmental impacts on urban areas, evaluation of agricultural lands is necessary. The aim of this present study was to evaluate the ecological agriculture potential of Eshtehard city, Iran. Therefore, the ecological potential of the area was evaluated using ecological criteria and PROMETHEE II and Fuzzy AHP methods. To rank the criteria, to standardize the layers, and to assign the weights to each criterion, PROMETHEE II, Fuzzy and Fuzzy AHP methods were used respectively. The results showed that the lands with the first and four classes of ecological capability with 1.50% and 25.36% are included the smallest and highest percentage of the whole study areas, respectively. The results of our study showed the high efficiency of the combination of PROMETHEE II and Fuzzy-AHP in assessing the ecological potential of the area. In this study, the PROMETHEE II method is proposed independently of the number of land uses and criteria and it can be used with the changes for other areas.

Keywords: Environmental Impact, Land use, Potential Class, GIS.

Introduction

Currently, conventional sources are not enough for energy demand. (Çolak and Kaya, 2017). Excessive depletion of natural resources along with other factors such as increasing population growth, increasing pollution, industrial growth and unbalanced resource distribution are among the biggest challenges facing mankind in the last century (Mirmohamadi, 2007). Evaluating the ecological potential of a land in an area is to evaluate the potential of that land in the form of expected land uses. Evaluation of the ecological potential of each land as one of the important tools for sustainable development, seeks to evaluate the existing power in the land based on pre-defined criteria.

Ecological assessment was formerly called "eco-friendly development" and then "environmental development" and is now known as sustainable development. In the context of sustainable development, various aspects of the relationship between development and the environment are revealed. The most important of these are the need to internalize the development process, to recognize the role of people in the development process, and to pay attention to the ecological potential of the environment. (Alliott, 1999).

Different ways of evaluating the ecological potential of the land are evaluated by making rules in the form of ecological models for each type of use. In the sense that ecological models are first designed for any use, depending on regional or national conditions. Then, the

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ecological characteristics summarized in each land unit are compared with ecological models and land potentials are evaluated for each type of land use. (Makhdoum, 2014).

Environmental and ecological capabilities are environmental datasets that are effective in the economic exploitation of the environment by humans, in line with human economic activities in the user environment (Nuri, 2000). In many cases, humans have not adopted the proper way in the face of the natural environment that his survival inevitably depends on it. Instead of holistic planning and proper utilization of the environment and its constrained resources, the man has consumption and exploited unsustainable profits with two mismanagement methods related to land use and inappropriate land use (Nasiri *et al*., 2012).

Since agriculture has many environmental effects on urban areas, it is necessary to evaluate agricultural lands (Dehghan *et al*., 2018). Various studies have been conducted in the past about the preparation of land in the world. Qiao (2008) provided a model for tourism development in suburban areas in Fengquan region of xinxiang, in china. The purpose of this research was to develop and promote tourism in the region using four criteria including ecological, economic importance, social and landscape importance. He concluded that the region with the scale of 89% is appropriate for tourism development. Reshmidevi *et al*. (2009) evaluated the agricultural potential in west Bengal watershed using fuzzy inference system in an integrated approach with GIS. Two weighted linear and Yager combination methods were used to evaluate the agricultural capability. The results showed that Yager combination method was more suitable than weighted linear method and integration of fuzzy inference system with GIS imply the ability of this method to study the large amounts of data as well as its efficiency in assessing the ecological agricultural capability. Ghasemi and Danesh (2012) determined the optimal groundwater treatment option in Torbat-e-Heydariyeh using fuzzy hierarchical analysis, and concluded that fuzzy hierarchy analysis is a suitable and effective tool in systematicizing large-scale decisions in water resources management. Nasiri *et al*. (2012) provided an ecological agricultural model considering the 8 criteria in Marvdasht, Iran. Fuzzy AHP method was used to determine the weights of each factor in assessing the ecological agriculture. The results showed that the studied area has seven agricultural and rangeland categories based on Makhdoum model. The results of the sensitivity analysis also showed the acceptable efficiency of the combined PROMETHEE II and Fuzzy-AHP methods in evaluating ecological capability. Ahmadi *et al*. (2012) evaluated the land suitability for agricultural and rural development of Geshlag Dam watershed in the Kurdistan province using fuzzy multi-criteria decision making method. They concluded that ecological decision-making criteria and land zoning can be done more easily and accurately using fuzzy logic in land evaluation. Graymore *et al*. (2009) developed a framework for sustainability assessment of watershed management using multi-criteria in GIS environment to assess the sustainability of sub-basins. Tseng *et al.* (2018) assessed the sustainability of tourism development in Vietnam based on a hierarchical structure approach and fuzzy theory. Tian *et al*. (2020) assessed tourism environmental impact in China based on improved AHP and picture fuzzy PROMETHEE II methods.

Systematic exploitation of natural resources in each country and land use planning based on the ecological capability of the region plays an important role in managing the environment and preventing its degradation for sustainable development. Evaluation of ecological capability as a core of environmental studies by warning and preventing potential crises provides a suitable context for environmental planning. Agriculture as one of the most important economic sectors of society by applying scientific principles and methods can play an influential role in achieving sustainable. In addition, since agriculture has major environmental impacts on the marginal areas of the cities, evaluation of agricultural lands seems necessary. Therefore, to better organize the lands, the ecological potential of Eshtehard city was investigated and the suitability of these lands for agricultural activities was determined. This has helped planners to achieve sustainable development.

Materials and Methods

The study area

The study area covers an area of 39637 hectares in the central part of Alborz province with coordinates of "32 '12 ° 50 to" 38 '27 ° 50 'east longitude and "50 '37 ° 50 to" 50 '49 ° 50' north latitude (Fig. 1). The climate of study area is hot dry to cold dry. In many parts of the study area, environmental constraints, especially edaphic and climatic are severe and cause poor vegetation cover. The annual rainfall occurs most in winter and autumn. Most of the region is covered by plains and flat lands (Izadi and Zakeri Nayeri, 2017).

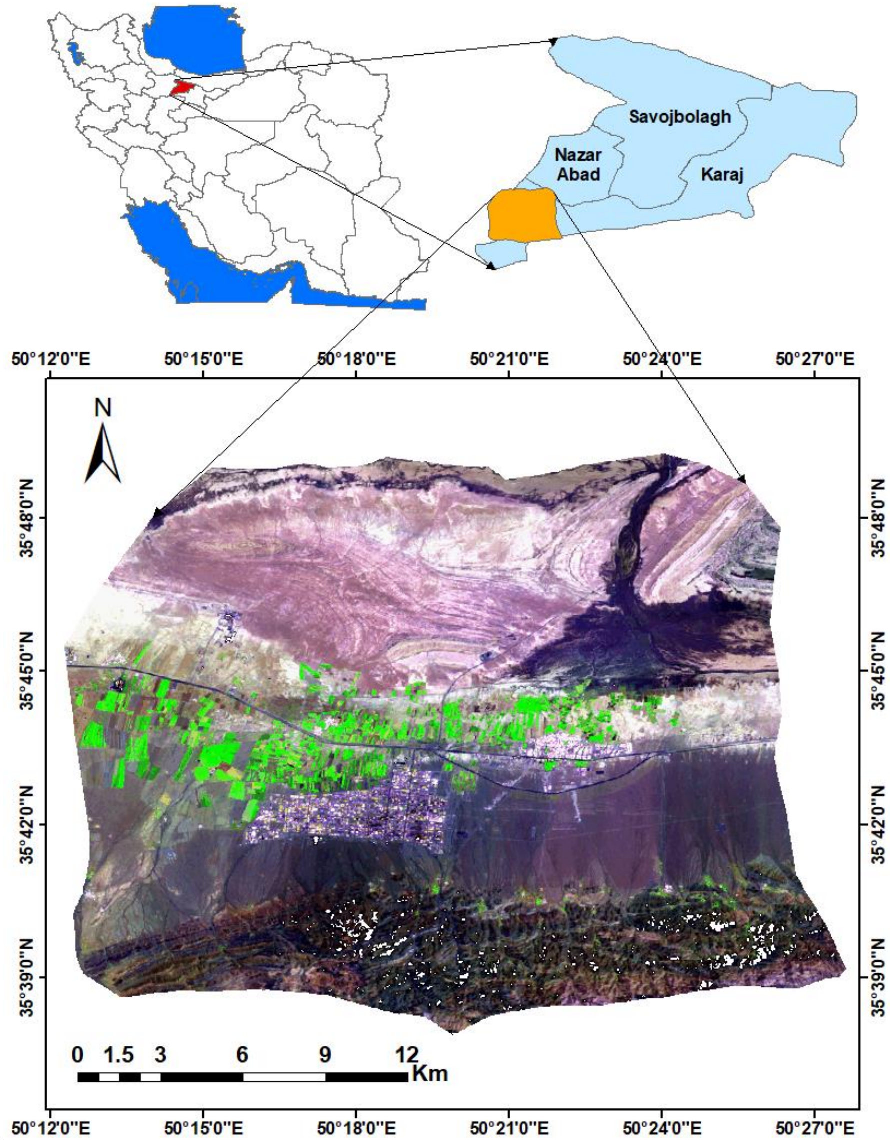


Figure 1. Location of the study area

Methodology

In this study, eight criteria data sets including Vegetation Type, Vegetation Cover, Height, Slope, Climate, Soil Texture, Soil Drainage, and Soil Permeability were used to evaluate the ecological potential of Eshtehard city. The slope and height maps were prepared using digital elevation model. The vegetation density map of the study area was obtained by classifying and interpreting Landsat 8 satellite images with the TM multispectral power of 2015. The climate layer of the study area was prepared based on De Martonne aridity index. Soil information data layer was extracted from 1: 25000 topographic map of Iran National Cartographic Center (2013) and vegetation type from 1: 50,000 map of Iran Soil and Water Research Institute (2013). The criteria layers were digitalized in ArcGIS10.3. To implement the proposed PROMETHEE II method, all criteria layers were converted to raster format with pixels of 30 m in 30 m. Qualitative maps such as soil drainage, soil erodibility, soil texture, vegetation type, and climate were converted to a raster format with quantitative structure. Eight layers were used as input data layers in the PROMETHEE II model (Figure 2).

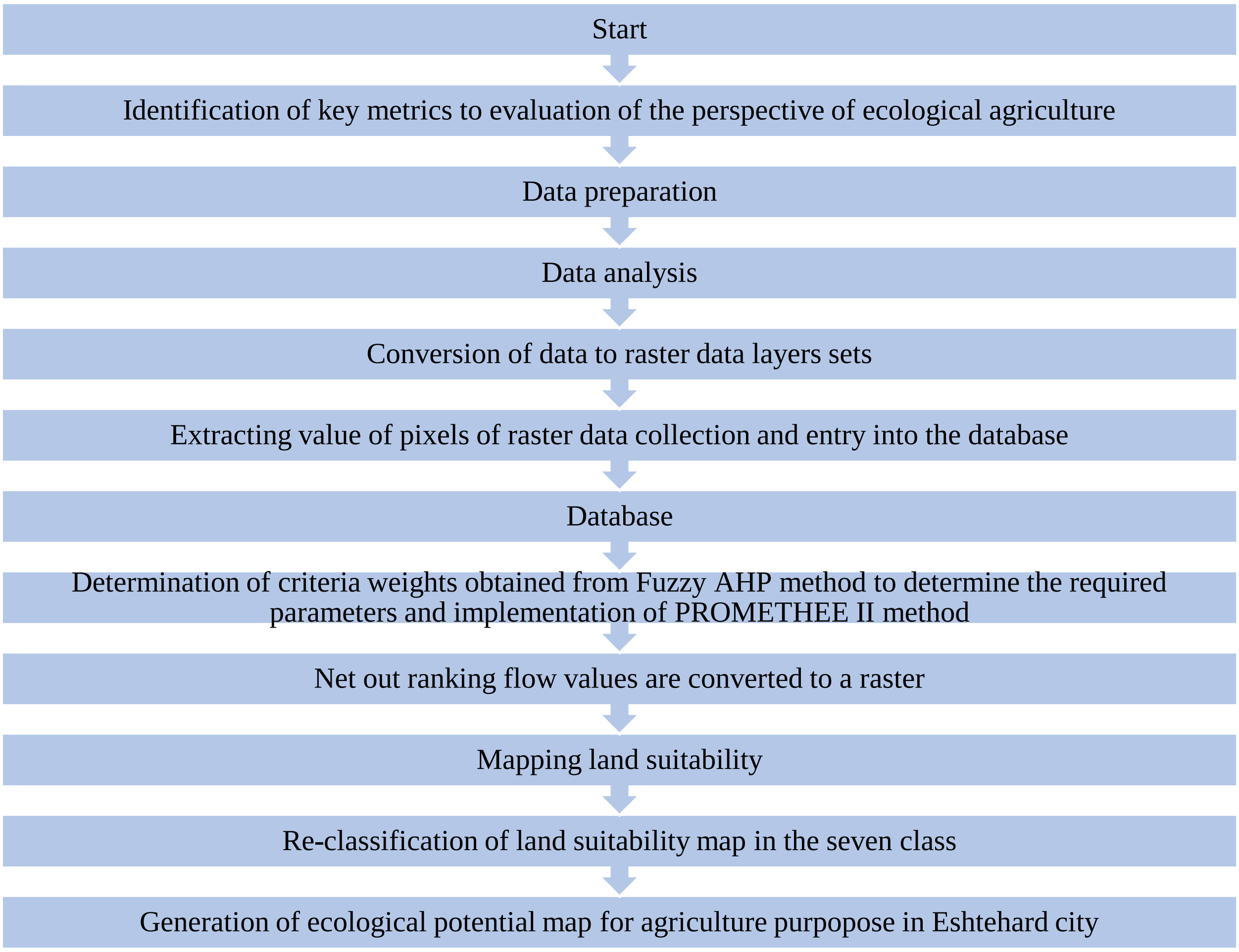


Figure 2. Flowchart to implement the proposed model for assessing the ecological potential of agriculture

After preparing and providing eight information layers including vegetation type, vegetation density, height, slope, climate, soil texture, soil drainage and soil erodibility based on the trend line, to implement the PROMETHEE II, at first, these information layers were inserted into the GIS environment raster format, then the initial spatial analysis was performed on them. The values of the raster data pixels associated with the evaluation criteria of ecological agricultural capability were extracted and were stored in eight separate categories in the database. The Expert Choice 10 software was used to implement the PROMETHEE II method.

• *PROMETHEE Method*

PROMETHEE method is a non-ranked method of multi-criteria decision-making system that is used to rank the finite set of strategies among conflicting criteria (Behzadian and Pirdashty, 2009, Sadeghravesh *et al*., 2016). This method was first presented by Brans in 1982 at a conference at the Laval University in Quebec Canada (Halony, 2009), then it was developed by Vincke and Brans (1985), Brans *et al*. (1986) and Brans and Marshescal (2005). By developing this method various versions what are referred to as the Prometheus family were including Prometheus I, II, III, V, VI, IV. Since the purpose of this study was to select the plant, climatic, soil and physiographic parameters based on the set of effective criteria, Prometheus II having the ability to rank the discrete strategies was used. This approach is effective where numerous strategies must be evaluated on the basis of multiple quantitative and qualitative and often inconsistent criteria. (Badawi *et al*., 2007).

• *Weighting the criteria*

Weighting the criteria through PROMETHEE II method consists of the following three steps:

Step 1: Modeling

Solve the multi-criteria problems by constructing the decision matrix has been presented in Table 1, where in A={A_i for i=1,2,3,…,m} represents a set of indices, C={C_j for j=1,2,3,…,n} shows the selected criteria, and X_{ij} indicates the performance of A_i option when evaluated by C_j criterion.

Table 1. Decision Matrix

Index / Criterion	C_1	C_2	…	C_n
A_1	X_{11}	X_{12}	…	X_{1n}
A_2	X_{21}	X_{22}	…	X_{2n}
.	.	.		.
.	.	.	…	.
.	.	.		.
A_m	X_{m1}	X_{m2}	…	X_{mn}

The performance values of the qualitative criteria were obtained by expert opinion using the Five Point Likert Scale (Table 2).

Table 2. Five point Likert scale

1	2	3	4	5
Very Low	Low	Medium	High	Very High

In this way, the decision maker was asked to make his/her decision on the indicators according to the above qualitative criteria.

Step 2: Calculating the priority value of the criteria

1. Formulation of normal decision matrix: Selected criteria have different units of measurement. Therefore, it is necessary to normalize the performance values of the indices according to the criteria (Table 3). For each of the decision matrix columns, if the criterion was incremental, relation (1) and if it is subtractive, relation (2) was used.

$$Nij = \frac{X_{ij}}{X_{j,max}}; \forall_{ij} \quad \text{where} \quad X_{j,max} = \max_j \{X_{ij}\}; \forall_{i,j} \qquad (1)$$

$Nij = \frac{Xj,minx}{X_{i,j}}$; $\forall_{i,j}$ where $X_{j,min} = \min_j \{X_{ij}\}; \forall_{i,j}$ (2)

Table 3. Normalized decision matrix

Criterion \ Indictor	C_1	C_2	…	C_n
A_1	N_{11}	N_{12}	…	N_{1n}
A_2	N_{21}	N_{22}	…	N_{2n}
.	.	.		.
.	.	.	…	.
.	.	.		.
A_m	N_{m1}	N_{m2}	…	N_{mn}

2. Calculate the average normalized data: Using the normalized values, the mean of each criterion was obtained using relation (3):

$$\bar{N}_j = \frac{1}{m}\sum_{i=1}^{m} N_{ij} \text{ , } \forall_{i,j} \quad (3)$$

3. Calculate the priority value of change: The priority value of the change between the values of each criterion is calculated using the following equation:

$$\pi_j = \sum_{i=1}^{m}[N_{ij} - \bar{N}_j]^2 \quad (4)$$

4. Determining deviation in priority value: the deviation in priority value was obtained for all the selected criteria using the following equation:

$$\varphi_j = |1- \pi_j| \quad (5)$$

5. Calculating the total priority value: The value of total priority or in other words the final weight of the criteria was calculated by the following equation:

$$W_j = \frac{\varphi_j}{\sum_{i=1}^{m}\varphi_j} \quad (6)$$

Step 3: Final ranking

The final ranking was performed through the following steps:

1. Creating an evaluation table: The evaluation table is the starting point of the PROMETHEE method. In this table, the options are evaluated based on the different criteria. This table presents the criteria and related options.

2. Calculating the preference function: When comparing two criteria, A1 and A2 ∈ A, the results of these comparisons are expressed on a preference basis. In the PROMETHEE method, the preference function of each criterion is often determined by the nature of each criterion and the decision maker's perspective.

The preference function converts the difference between the two options (A1 and A2) to a degree of preference function which varies from 0 to 1.

$P_j(A_1,A_2) = F_j \; [d_j(A_1,A_2)] \quad \forall \; A_1, \; A_2 \in A$ (7)

Where, $d_j\,(A_1,A_2) = f_j\,(A_1) - f_j\,(A_2)$ and $1 \leq 0 \leq P_j(A_1,A_2)$

There are six pre-defined functions for Fj [dj (A1, A2)] function that cover most of the applications including: Regular normal criterion, Gaussian criterion, linear criterion (V-shaped), level criterion, criterion with linear preference and indifference area. Figure 3 shows the six preference functions of the criterion.

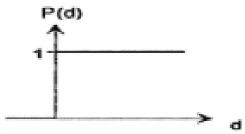
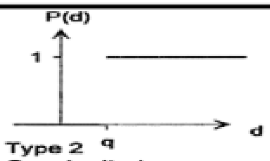
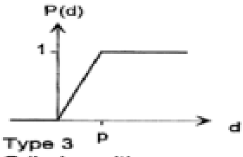
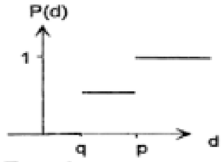
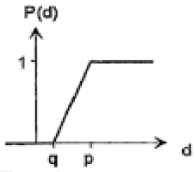
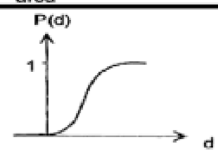
Generalized criterion	Definition	Parameters to fix
 Type 1 Usual criterion	$P(d)=\begin{cases}0, & d\leq 0\\ 1, & d>0\end{cases}$	–
 Type 2 Quasi-criterion	$P(d)=\begin{cases}0, & d\leq q\\ 1, & d>q\end{cases}$	q
 Type 3 Criterion with linear preference	$P(d)=\begin{cases}0, & d\leq 0\\ \dfrac{d}{p}, & 0<d\leq p\\ 1, & d>p\end{cases}$	p
 Type 4 Level criterion	$P(d)=\begin{cases}0, & d\leq q\\ \dfrac{1}{2}, & q<d\leq p\\ 1, & d>p\end{cases}$	p,q
 Type 5 Criterion with linear preference and indifference area	$P(d)=\begin{cases}0, & d\leq q\\ \dfrac{d-q}{p-q}, & q<d\leq p\\ 1, & d>p\end{cases}$	p,q
 Type 6 Gaussian criterion	$P(d)=\begin{cases}0, & d\leq 0\\ 1-e^{-\frac{d^2}{2\sigma^2}}, & d>0\end{cases}$	σ

Figure 3. The six preference functions of the criterion (Brans and Mareschal, 2005), P threshold indicates the slightest deviation that is considered as a definite preference

3. Calculating the total preference: the total preference index was calculated using the following equation:

$$\pi'(A_1,A_2) = \sum_{j=1}^{n} P_j(A_1,A_2).W_j \quad (8)$$

Where; $\pi'(A_1,A_2)$ is the total weight of $P(A_1,A_2)$ for each criterion and W_j is the related weight of j criterion.

4. Calculating the positive and negative flows: The positive preference flow (output) was calculated by the equation (9) and the negative flow (input) by the equation (10):

$$\Phi^+ (A_1) = \frac{1}{m-1}\Sigma_{x\in A}\pi'(x,A_1) \quad (9)$$

$$\Phi^- (A_1) = = \frac{1}{m-1}\Sigma_{x\in A}\pi'(A_1,x) \quad (10)$$

Calculating the net flow: To calculate the net flow the following equation was used:

$$\Phi (A_1) = \Phi^+ (A_1) - \Phi^- (A_1) \quad (11)$$

• *Weighting the criteria using Fuzzy AHP method*

AHP method reflects the inherent behavior and thoughts of human (Enayat Nia *et al*., 2019). Fuzzy AHP method presented by Buckley is an extended form of the classical AHP method. In this method, fuzzy numbers and geometrical averages are used for pairwise comparison and preferences weights, respectively. This method is easily generalized to fuzzy mode and determines a unique solution for the pairwise comparative matrix. In this method, the decision maker can express the pairwise comparison of the elements of each level in the form of trapezoidal fuzzy numbers. According to the above mentioned, Buckley's algorithm was implemented in the following three steps:

First step: At this stage, the pairwise comparative matrices were determined by the decision maker. The elements of this matrix were trapezoidal Fuzzy numbers. The preference of i to j is shown as the following:

$$\bar{a}_{ij} = (a_{ij}, b_{ij}, b_{ij}, d_{ij}) \quad (12)$$

Then the preference of j to i will be:

$$\bar{a}_{ji} = (\frac{1}{a_{ij}}, \frac{1}{b_{ij}}, \frac{1}{b_{ij}}, \frac{1}{d_{ij}}) \quad (13)$$

Second step: In this stage, the fuzzy weights (W_j) were calculated. To do this, the geometric mean of each row of pairwise comparative matrices was determined using the following equation:

$$\bar{Z} = (\bar{a}_{i1}, \bar{a}_{i2}, \bar{a}_{i3} \dots \bar{a}_{in})^{1/n} \quad (14)$$

Then the fuzzy weight ($\overline{W_j}$) was obtained from the following equation:

$$\overline{W_i} = \bar{Z}_i \times (\overline{Z_1} + \overline{Z_2} + \overline{Z_3} + \ldots + \overline{Z_n})^{-1} \quad (15)$$

The multiplicative and multiplicative operators in the above relationships are fuzzy operators.

Third step: At this stage, by combining the preferences and weights obtained in the previous step, Ui was calculated using the following equation:

$$U_i = \sum_{j=1}^{n} \overline{W_j}\, \acute{r}_{ij} \quad (16)$$

The Figure 4 shows the input layers for the implementation of the proposed model to evaluate the agricultural ecological potential of Eshtehard city.

Results

PROMETHEE method is designed to solve multiple criteria and the required information on the procedure for analysts and decision-makers is clear and understandable. The decision matrix was obtained using the expertise of experts for prioritization of criteria (Table 4).

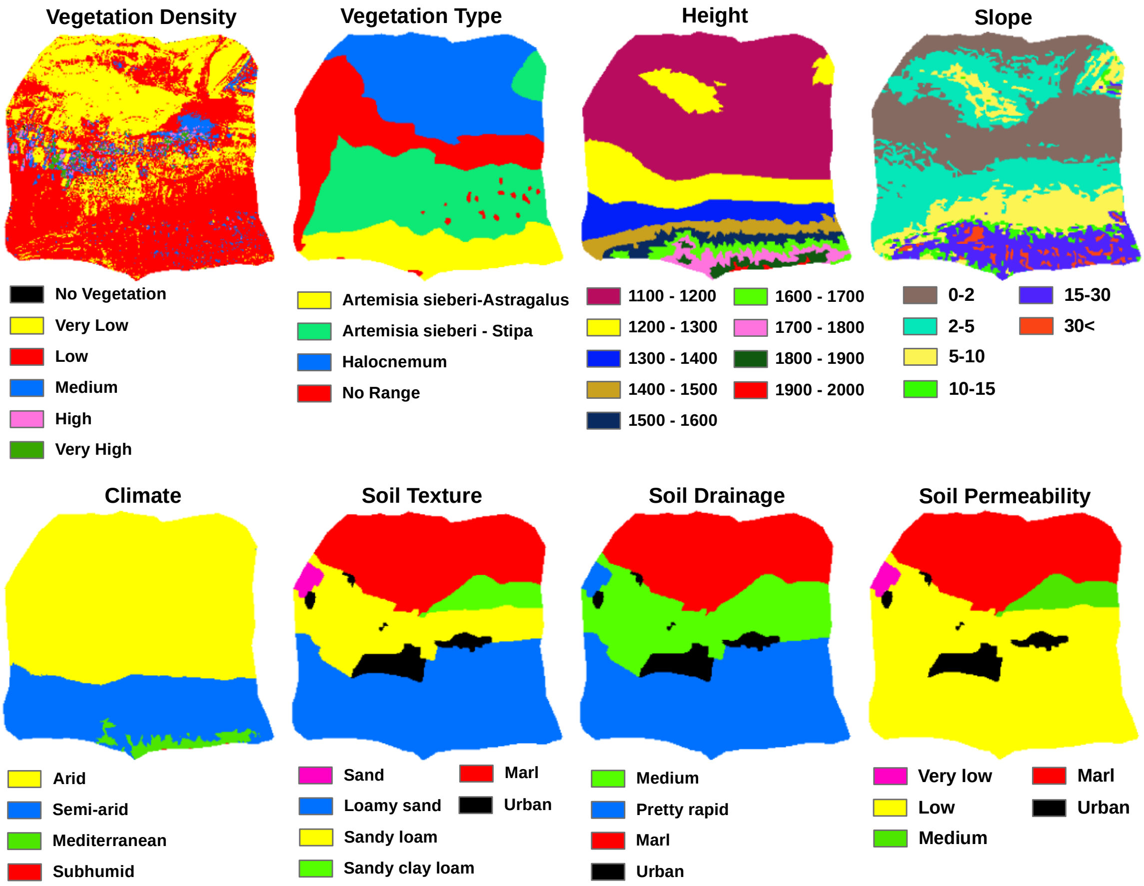


Figure 4. Input layers to the model to evaluate agricultural ecological capability

Table 4. Decision matrix using the expertise of experts

Indicator / Criterion	Ease and Accuracy	Costs and Time	Fitness for Purpose	Sensitive to Minor Changes
Vegetation Type	3.46	3.15	3.85	2.92
Vegetation Cover	3.62	2.85	3.54	3.69
Height	4.54	1.77	3.54	2.85
Slope	3.31	1.77	3.31	2.77
Climate	3.54	3.23	4.15	2.31
Soil Texture	2.54	4.00	3.69	2.69
Soil Drainage	2.46	3.77	3.92	2.54
Soil Permeability	3.46	2.69	4.46	2.85

Decision matrix was normalized after preparing it. Ease and accuracy, sensitivity to minor changes and fitness for purpose are augmenter criteria that the equation (1) was used to normalize it, and cost and time is regressive criteria that equation (2) was used to normalize it. The result of normalized decision matrix is shown in table 5.

Table 5. Normalized decision matrix

Indicator / Criterion	Ease and Accuracy	Costs and Time	Fitness for Purpose	Sensitive to Minor Changes
Vegetation Type	0.76	0.56	0.86	0.79
Vegetation Cover	0.80	0.62	0.79	1.00
Height	1.00	1.00	0.79	0.77
Slope	0.95	1.00	0.74	0.75
Climate	0.78	0.55	0.93	0.63
Soil Texture	0.56	0.44	0.83	0.73
Soil Drainage	0.54	0.47	0.88	0.69
Soil Permeability	0.74	0.66	1.00	0.77

At the next step, the mean of normalized dataset was calculated:
$\bar{N}_1 = 0.77$, $\bar{N}_2 = 0.66$, $\bar{N}_3 = 0.85$, $\bar{N}_4 = 0.77$
Then, the value of the priority change was calculated:
$\pi_1 = 0.20$, $\pi_2 = 0.34$, $\pi_3 = 0.05$, $\pi_4 = 0.09$
After that, the deviation in the value of the priority was calculated:
$Ø_1 = 0.80$, $Ø_2 = 0.66$, $Ø_3 = 0.95$, $Ø_4 = 0.91$
At the end, the weight or priority value of each criterion was calculated:
$W_1 = 0.24$, $W_2 = 0.20$, $W_3 = 0.29$, $W_4 = 0.27$
For ease and accuracy, fitness for purpose and sensitive to minor changes, the normal function and V function was considered to measure the costs and time. The results of Positive and Negative flows were calculated in Visual PROMETHEE (Table 6).

Table 6. Positive and Negative flows in Visual PROMETHEE software

Row	Action	Ø	$Ø^+$	$Ø^-$
1	Soil Permeability	0.4929	0.6639	0.1710
2	Height	0.2424	0.5653	0.3229
3	Vegetation cover	0.1394	0.4846	0.3451
4	Vegetation Type	0.0637	0.4493	0.3856
5	Slope	-0.276	0.4510	0.4786
6	Climate	-0.0626	0.4044	0.4670
7	Soil Drainage	-0.4043	0.2490	0.6533
8	Soil Texture	-0.4440	0.2357	0.6797

According to table 6, the indicators are ranked as: Soil Permeability, Height, Vegetation Cover, Vegetation Type, Slope, Climate, Soil Drainage and Soil Texture. Land Suitability Map was classified numerically to 7 classes with an equal numerical range from 1st class to

7th class. The final map of ecological agriculture capability assessment is shown in Figure (5). Moreover, in table (7) the area of these seven classes is presented in terms of percentage and hectares.

Based on the final zoning map of the whole Eshtehard city, an area of 593 hectares has the first class capability and an area of 4041 hectares has seventh class of capability.

The results show that the areas with agricultural potential in one to three grades mainly exist in the slope of 0 to 5% and soils with a high fertility (sandy loam) and low erosion. In these areas, the soil has huge potential for a regular cultivation of agricultural products (cereals, oilseeds, vegetables, and fodder) without incurring a loss.

The results of sensitivity analysis model used in this study indicate that a large area of land with one, two and three ecological capability degree of final map is in accordance with the completely appropriate classes of any input parameters in the model, and this shows obtaining satisfactory results in ecological capability assessment.

Table 7. Area and percentage of each class of land in the study area

Classes	Area (ha)	Percent
Class 1	593	1.5
Class 2	3793	9.57
Class 3	4969	12.54
Class 4	10057	25.36
Class 5	6398	16.14
Class 6	9786	24.69
Class 7	4041	10.20
Sum	39637	100

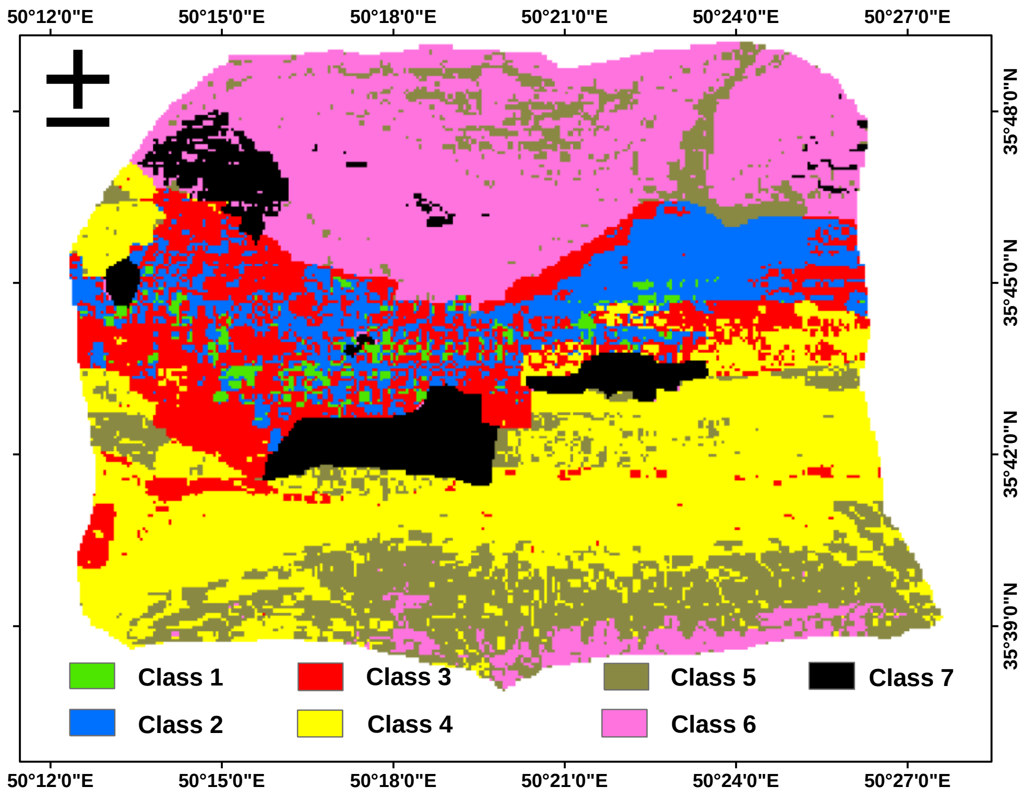


Figure 5. The map of ecological agriculture potential in Eshtehard city

Conclusion

The natural environment of the world has limited ecological capabilities for human use. In some areas, these natural environments are ready for development with the least damage, and in some areas, the slightest development and action will result in the destruction of the environment in those areas. Therefore, in order to develop the environment, its ecological potential should be evaluated in the form of basic planning. Sustainable agriculture is one of the most important global issues today and has a wide variety of components because of its environmental protection, food security and livelihoods. Therefore, in this study the ecological agricultural potential was evaluated by PROMETHEE II and Fuzzy AHP integrative approaches considering the indices of vegetation, vegetation density, height, slope, climate, soil texture, soil drainage and soil erodibility. PROMETHEE II method was used to rank the alternatives, the Fuzzy method to standardize the layers, and Fuzzy AHP method to assign a weight for each index.

The results indicate the appropriate performance of multi-criteria decision-making systems, especially the PROMETHEE II method in determining of land predictability in land evaluation Studies. Amiri *et al*. (2009), Behnia *et al*. (2010), Nasir *et al*. (2012), Motii and Langroodi *et al*. (2012) and Manser (2007) acknowledged that fuzzy logic and multi-criteria decision-making methods in integration with geographic information systems should be used to increase the accuracy in determining the evaluation of ecological potential. The results of Fuzzy AHP method indicate that this method is effective in land preparation studies, especially the studies related to assess the ecological potential, which these results are consistent with the results of Nasiri *et al*. (2012) and Motii and Langroodi *et al*. (2012).

Application of GIS at various stages of this study has also been shown due to the many advantages and disadvantages of the technology, including the ability to store and access descriptive data quickly and efficiently, the ability to use different functions and the ability to modify data. The use of geographic information systems was found to be highly effective in determining land potential. This is consistent with the results of Nasiri *et al* (2012), Motiee Langroudi *et al* (2012), Ahmadi Sani *et al*. (2013) and Pourkhabbaz *et al* (2014).

According to the results of this study, the best areas for agricultural activities in the study area are central and close to urban areas. These areas (class 1 and 2) are mainly located in the 0 to 5% slope, which is suitable for agriculture. Northern lands due to marl hills and southern areas due to steep slope have little ability to do agricultural work. The areas with class 3 potential are suitable to develop rangeland, as well as forage and livestock production. Comparing the results of this study with the current condition in the region shows that the first and second zones are suitable for agriculture and the existing agriculture should be strengthened. The region with a third class capability has favorable conditions for agriculture and gardening as well as forage and livestock production.

Considering the results obtained in this study, due to the proximity of agricultural areas to urban areas, the expansion of urbanization into agricultural lands should be prevented as much as possible and using novel methods such as machine learning approach in ecological potential assessment (land use planning) and other location-related operations can be useful for better design and more appropriate evaluation of the ecological potential of the lands.

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