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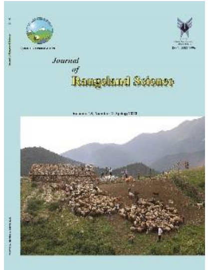

**Research and Full Length Article:**

# Ecological Potential Modeling for Agricultural and Rangeland Development Using GIS-based FAHP Approach: A Case Study of Razin Watershed

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**Abstract.** Determining the environmental capability of optimally using land and preventing the degradation of natural resources arr important steps towards a sustainable development strategy. The present study was conducted in 2014-2017 aiming to assess the ecological capability for agriculture and rangeland of the Razin watershed in Kermanshah province, west of Iran, in seven classes using the Fuzzy Analytic Hierarchy Process (FAHP) and the application of Geographic Information System (GIS). The information layers were initially selected by the research group and those layers that were important were selected according to the research literature, then the final screening of the information layers was performed by fuzzy Delphi method. These layers were including land form units (slope, elevation, aspect), soil information (texture, depth, hydrological groups, erosion, granulating, gravel percentage, evolution, organic carbon content, exchangeable cations, available phosphorus), climate, water, land use, vegetation density, and lithology. FAHP technique was used to calculate the importance coefficients of the criteria and sub-criteria entered into the evaluation model. Weighted layer modeling was performed by ArcMap 9.3 software using the weighted linear composition method in overlay tool. The results showed that water, climate, slope, and soil texture criteria with 0.23, 0.132, 0.118, and 0.88, respectively, were the most important in modeling Razin ecological capability. 1776 environmental units with unique ecological characteristics were identified. This area has ecological potential for agricultural and rangeland use in seven classes. In terms of effective carrying capacity (ECC), all classes except class 2 and 5 were sustainable. Due to the very high accuracy of the FAHP-GIS integrated model in the use of agricultural land suitability, it is recommended to use this model instead of other conventional methods.

**Key words:** Ecological capability, Land use, Fuzzy Analytic Hierarchy Process (FAHP), Effective carrying capacity (ECC), Razin watershed

## Introduction

Population growth and consumption have created new demands on agriculture and natural resources. Today, nearly one billion people on the planet are malnourished while our agricultural systems are simultaneously and globally degraded by soil, water, biodiversity and climate. Sustainable food security for the future requires food production to grow steadily while at the same time the environmental footprint of agriculture must be significantly reduced (Foley *et al*., 2011).

Agriculture is now an imbalance behind many environmental threats including climate change, biodiversity loss, and land and freshwater degradation (Power, 2010). In fact, agriculture is the main driver of environmental degradation across the planet (Lambin *et al*., 2009).

In recent years, natural areas are often subject to severe exploitation and ecological overcapacity for economic aims. Also, lack of proper understanding of the land ability and unreasonable human use of the land have led to the depletion of natural resources (Kopacz *et al*., 2017; Mahdavi *et al*., 2013). In this respect, determining suitable land uses to optimize land use and prevent population degradation can be an effective step in a sustainable development strategy (Prato, 2007). Determining ecological potential and allocating appropriate uses is a way that can create a logical relationship and a sustainable adaptation between the natural potential of the environment, the needs of communities, and human activities in space.

Given the importance of assessing the potential of the environment and the great complexity of this process, which is the result of the interaction of various physical and biological variables, it seems important to adopt approaches through which the variables entered in the model can be weighted. In this regard, Fuzzy Analytic Hierarchy Process (FAHP) technique is able to help us in the form of a systematic, compensatory, and multi-characteristic approach to configure and analyze non-structural issues in different decision-making situations (Socaciu *et al*., 2016) while taking into account the inherent ambiguities and uncertainties in the preferences and limitations of decision-making issues (Mahmoudi *et al*., 2019).

In reviewing the research literature, ecological capability assessment for agriculture and rangeland has been the subject of many studies. Mosaffaie *et al.* (2018) conducted a study with the aim of determining the ecological potential of Akujan watershed in Qazvin, Iran for agricultural and rangeland uses. Using the information layers of precipitation, elevation, slope, vegetation, soil depth and texture, and erosion intensity, they extracted a map of homogeneous environmental units in the Geogeraphical Information System (GIS) environment and then fitted each unit to that use by the Makhdoom ecological model. The results of their study showed that 44% of the watershed is used by unauthorized uses such as livestock and rangeland, irrigated and dry farming, which has diverted the use of this area from the principles of sustainable development.

Alikhah and Rezvani (2018) evaluated the potential of lands for agriculture and rangeland using AHP method in a case study of Gazdraz-Lavor coastal watershed of Bushehr province Ran. The main criteria used by them included topographic maps, lithology, soil, climate, vegetation, and land use. Using the opinion of experts, they determined the importance of criteria and sub-criteria and by adding the coefficient of importance to the information layers, they obtained the final map of ecological potential for agricultural and rangeland use. The final map extracted by them lacked agricultural classes 1 and 2 due to erosion and salinity constraints. Of the total area studied by them, 18.93% was suitable for Class 3 agriculture, 49.56% for Class 3 rangeland, and 30.56% for Class 4 rangeland.

Dehghan *et al.* (2018) designed the ecological model of agriculture and rangeland for Eshtehard, Iran using FAHP approach. Criteria used in their study included vegetation type and density, elevation, slope, climate, and soil texture, drainage and erosion. The results of their research showed that the study area has seven classes of agricultural and rangeland use of Makhdoom ecological model, and Class 1 (1.5%) and Class 4 (25.36%) lands had the lowest and highest areas of the study area for agricultural and rangeland use, respectively.

Rahmanabadi *et al.* (2021) used the Makhdoom ecological model with the aim of determining the ecological potential for agricultural and rangeland use in the study of Kangavar, Iran. By combining maps in the ArcGIS software environment and weighing the criteria, they identified 58 environmental units in seven classes for agricultural and rangeland use. The results showed that out of the total of 883.9 $Km^2$ of the studied area, 356.79 $Km^2$ have suitable capacity for agricultural activities and 72.23 $Km^2$ have suitable capacity for dry farming and rangeland use. 126.47 $Km^2$ of the studied area is exploited by agricultural use if it does not have the necessary competence for this use and such an action has occurred with the change of rangeland use to agriculture.

Razin watershed, placed in central area of Zagros, is one of the sites of The Middle East and North Africa Regional Program for Integrated Sustainable Development (MENARID) project. This study was carried out to evaluate the ecological potential of Razin watershed for the establishment of agricultural and rangeland use based on the region's natural ability to prevent erosion, protect environment, conserve water and soil resources, reduce production costs in the region, and supply food security.

## Materials and Methods

### Site Description

The present study was carried out during 2014 to 2017 in the Razin watershed located in the north of Kermanshah Province, Iran, with a geographical range of 34°34′34″ to 34°42′27″N latitude and 47°01′47″ to 47°43′43″E longitude (Fig. 1). The total area of the basin was 14,685 ha which now comprises: 4,196.2 ha drylands, 1,886.9 ha irrigated fields, 391.9 ha orchards, 3,061.6 ha forest, 3,346.5 ha pasture, and 1,802.1 ha rock mass.

The northern part of the basin consists of irregular slope hills with appropriate soil depth. The southern part of the basin consists of rocky hills that are restricted to agricultural operations. The southeastern part of the basin consists of a mountainous unit of irregular slope that is currently exploited as rangeland or scattered forest. Down slope direction tillage has led to soil instability in the northeast slope.

The basin altitude ranges from 1,407 to 2,867m above sea level. The slope of the studied region ranges from zero to 90%. The average annual rainfall is 460 mm, with 45% of the annual rainfall occurring in winter and 40% in spring, and the region has a humid/cold climate based on the Domartan system. The average annual temperature has recorded 11.4°C, and the average annual minimum and maximum temperature are 3.5°C and 19.3°C, respectively. The average number of frost days in the basin is 87 days per year with the maximum number of frost days in February (26 days), and the frost season is from November to April. The average annual sunshine of the region is 2,982.6 hours.

### Data collection

This study was designed to determine suitable sites with ecological potential for agricultural and rangeland use in seven classes in the Razin watershed. First, by reviewing the available documents in the Forests, Range and Watershed Management Organization and consulting with the experts of the General Department of Natural Resources of Kermanshah province, basic maps and preliminary watershed management data were provided. The information layers were initially selected by the research group and those layers that were important were selected according to the research literature, then the final screening of the information layers was performed by fuzzy Delphi method (Kaufmann and Gupta, 1988), (Table 1).

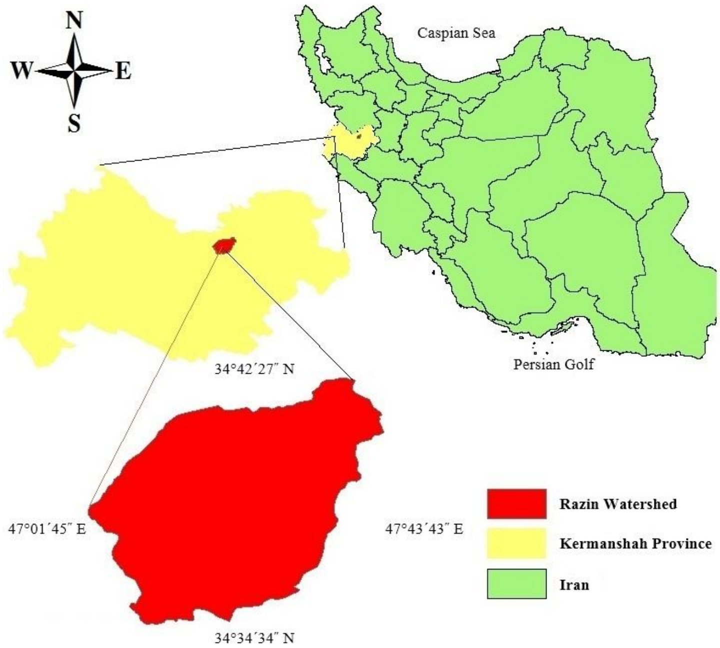


**Fig. 1.** Location of Razin watershed in Kermanshah province, Iran

The Digital Elevation Model (DEM) in a GIS environment using the Raster Surface tool in 3D Analyst was used to prepare the map of layers of landform (elevation, slope, and aspect). Then based on the region conditions, elevation, slope, and aspect maps were arranged in 5, 9 and 5 classes, respectively.

Entered sub-criteria of soil into the model were classified into two categories including soil physics and soil chemistry. Soil physics information layers included texture, depth, erosion, structure (soil aggregation, pebble percentage, and evolution), and hydrological groups. Classification of soil chemistry information layers also included pH, organic carbon content, CEC [1] (meq/100g), and phosphorus content. Lithological information was also classified according to the lithological features of the study area for entering into the model.

1 Cation exchange capacity

**Table 1.** Criteria selected by fuzzy Delphi technique to enter the ecological potential assessment model to locate suitable agricultural and rangeland areas in the Kermanshah Razin watershed (Tolerance threshold= 0.7)

| Criteria | Weight | Result | Criteria | Weight | Result |
|---|---|---|---|---|---|
| Slope percentage | 0.933 | Accept | organic carbon% | 0.742 | Accept |
| Above sea level | 0.921 | Accept | CEC | 0.769 | Accept |
| Slop direction | 0.814 | Accept | Soil phosphorus (Ava.) | 0.703 | Accept |
| Soil texture | 0.941 | Accept | Climate | 0.816 | Accept |
| Depth of soil | 0.712 | Accept | The amount of water available | 0.945 | Accept |
| Hydrological soil groups | 0.702 | Accept | Land use | 0.730 | Accept |
| Soil erosion | 0.807 | Accept | Vegetation density% | 0.712 | Accept |
| Soil granulomere | 0.722 | Accept | The amount of dry forage obtainable | 0.566 | Reject |
| Soil pebbles% | 0.716 | Accept | Range trend | 0.650 | Reject |
| Soil evolution | 0.717 | Accept | Range Carrying Capacity | 0.509 | Reject |
| Soil EC | 0.690 | Reject | Lithology | 0.722 | Accept |
| Soil pH | 0.650 | Reject | The resistance factor of rocks to erosion | 0.502 | Reject |

Rangeland and forest vegetation were classified into three and two types, respectively. Information on the percentage of vegetation density and amount of dry forage harvested from natural vegetation was also determined for each hydrological unit. To accurately identify and evaluate the watersheds and facilitate the identification of the potentials and limitations of each watershed, each watershed was subdivided into smaller units called hydrological units. Accordingly, the Razin basin was divided into 23 hydrological and 6 non-hydrological units.

Precipitation was classified as a category for all regions (500 to 800 mm). Surface and subsurface water calculations must be performed to determine the basin water regime. In this study, the Uttar Pradesh Irrigation Research Institute (UP2) method (Major and Schwarz, 2013) was used to calculate surface water volume in hydrological units of the basin.

Equation 1 was used to estimate runoff height. Based on this equation, surface water discharge was estimated for each hydrological unit and the entire basin and the amount of surface water volume per hectare was calculated for the whole year. To calculate the subsurface water, the springs, aqueducts and wells in the basin were calculated at the level of each hydrological unit. Overall, data on 109 springs, 16 aqueducts and 60 wells in the Razin watershed were investigated and used in subsurface water availability calculations.

$$R = P - 1.17P^{0.86} \qquad (1)$$

Where, P and R are average annual rainfall and runoff height (both in cm), respectively.

The landform units were obtained by integration and overlap the slope, elevation and aspect layers (Fig. 2, A). The map of basic environmental units was obtained by integrating the above layer with the soil information layer (Fig. 2, B). The final environmental unit map was obtained by integrating the basic environmental unit map with the vegetation information layer (Fig. 2, C). For this purpose, all the soil information was implemented on the land unit map. All information on vegetation, water and climate of the region was also included in the hydrological unit's map. Finally, the final weights of the criteria and sub-criteria were applied to all layers of information in the GIS environment and a fuzzy map was extracted based on the importance of all criteria and sub-criteria for use in agricultural and rangeland. The felowchart in Fig.3 shows the steps of this study step by step.

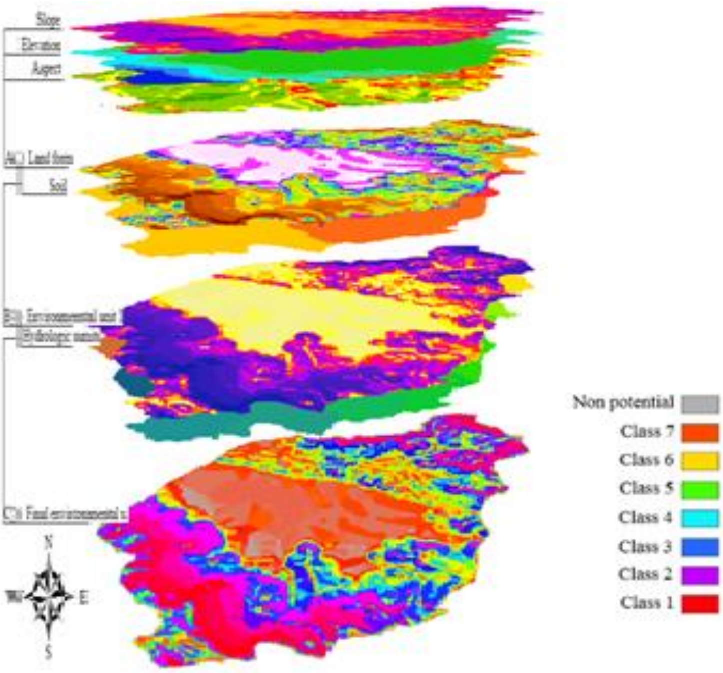


**Fig. 2.** Map of landform units (A), basic environmental units (B), and final environmental units (C) of Razin watershed

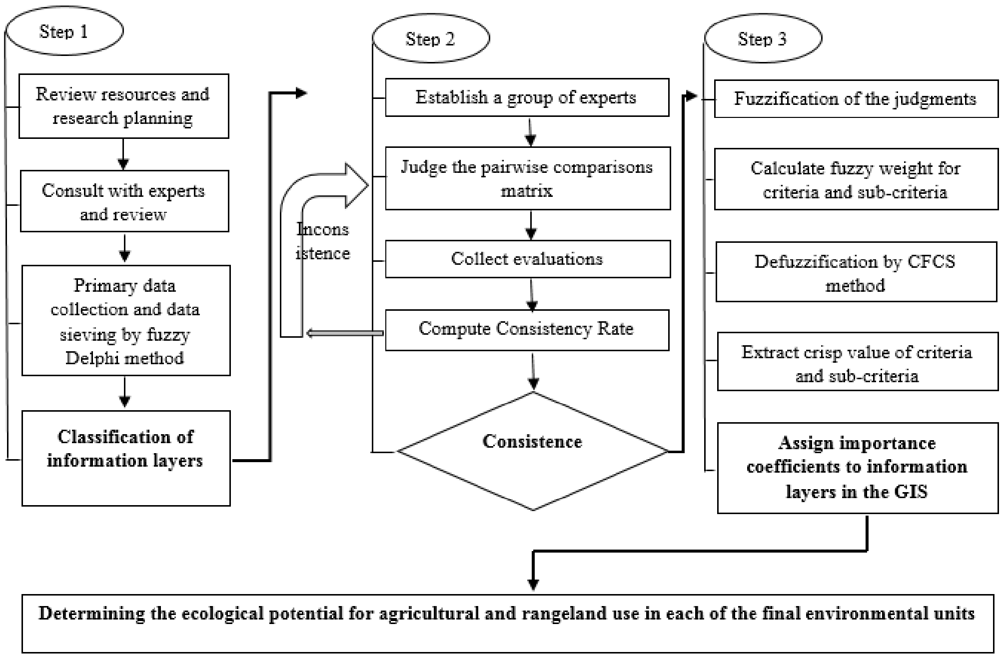


**Fig. 3.** Flowchart study of resin watershed

## FAHP technique

The AHP was introduced by Saaty to solve simple and complex problems in different fields (Saaty, 1977). The AHP decomposes complex decision-making problems into a hierarchical structure with the goals (objectives) found on the top of the hierarchy, the criteria and sub-criteria located at the mid-level of the hierarchy, and the decision alternatives found at the bottom of the hierarchy (Dagdeviren *et al.*, 2009). Traditional AHP is not able to fully reflect the ambiguities in human thinking style. The use of fuzzy numbers (FNs) is more compatible with lingual and sometimes ambiguous human expressions. Chang

(1992) has used the concept of degree of possibility to generalize the AHP technique to fuzzy space. The degree of possibility refers to the probability that one FN is larger than the other FN. In this research work, we used an improved FAHP algorithm that follows the basic principles of the AHP technique. After establishing an expert team, the elements of a particular level were compared pairwise with respect to a specific element in the immediate upper level. According to the goal of the evaluation, experts used nine linguistic scales to judge, then turned these scales into corresponding TFNs by the researcher (Table 2). The TFN $\tilde{a}_{ij}$ is displayed as follows (Equation 2):

$$\tilde{\mathbf{a}}_{\mathbf{ij}} = (\mathbf{l}_{\mathbf{ij}}, \mathbf{m}_{\mathbf{ij}}, \mathbf{u}_{\mathbf{ij}}) \qquad (2)$$

Where, $l_{ij} \leq m_{ij} \leq u_{ij}$, and $l_{ij}, m_{ij}, u_{ij} \in [1/9\,, 1] \cup [1, 9]$

The fuzzy positive reciprocal matrix for ‘‘$n$’’ criteria in the second level, with respect to the final goal, are formed as follows (Equation 3):

$$\tilde{\mathbf{A}} = [\tilde{\mathbf{a}}_{\mathbf{ij}}] = \begin{bmatrix} \mathbf{1} & \cdots & \tilde{\mathbf{a}}_{\mathbf{1n}} \\ \vdots & \ddots & \vdots \\ \mathbf{1}/\tilde{\mathbf{a}}_{\mathbf{1n}} & \cdots & \mathbf{1} \end{bmatrix} \qquad (3)$$

Where, $\tilde{a}_{ij}$ denotes a TFN in the positive reciprocal matrix for the relative importance criterion $C_i$ over criterion $C_j$.

To implement the AHP technique, the key decision-making problem was identified primarily involving identifying suitable locations for the ecological potential for agricultural and rangeland use. Then, the selected criteria and sub-criteria by the fuzzy Delphi model (Table 1) were placed at the middle level of the model. These criteria have also been used in many previous studies (Hou *et al*., 2016; Kharat *et al*., 2016; Malmir *et al*., 2016). Expert questionnaires were prepared based on different levels of the model to refer to the selected specialists. After collecting the questionnaires, the experts' viewpoints were fuzzed using the appropriate spectrum. The linguistic assessments of the experts were converted to FNs (Table 2), and thus, the initial fuzzy matrixes were obtained. Then, the geometric mean was used to aggregate the experts' point of view (Mikhailov, 2003), (Equation 4).

$$\tilde{F}_{AGR} = (\prod_{i=1}^{n}(l_i), \prod_{i=1}^{n}(m_i), \prod_{i=1}^{n}(u_i)) \qquad (4)$$

Where, $\tilde{F}_{AGR}$ is fuzzy experts' point that aggregated, l, m, and u are Low bound, probable value and high bound of the fuzzy points obtained from the viewpoint of different experts, respectively.

For normalized fuzzy calculations, at first, the geometric mean of the elements of each row was calculated in the fuzzy matrix of pairwise comparison obtained from the experts' views assembled, according to Equation 5. Then, the fuzzy sum of the total elements' preference was calculated according to Equation 6. To normalize, the sum of each element's preferences was divided by the total elements' preference (Equation 7). The obtained weights were the final fuzzy weight of the studied elements (Paksoy *et al*., 2012).

**Table 2.** Linguistic scales and corresponding TFNs used for pairwise comparisons in FAHP method (Khashei-Siuki and Sharifan, 2020)

| Linguistic variable | Corresponding TFNs | Inverse of corresponding TFNs |
|---|---|---|
| Equal importance | (1, 1, 1) | (1, 1. 1) |
| Intermediate | (1, 2, 3) | (0.333, 0.5, 1) |
| Moderate importance | (2, 3, 4) | (0.25, 0.333, 0.5) |
| Intermediate | (3, 4, 5) | (0.2, 0.25, 0.333) |
| Strong importance | (4, 5, 6) | (0.166, 0.2, 0.25) |
| Intermediate | (5, 6, 7) | (0.142, 0.16, 0.2) |
| Very strong importance | (6, 7, 8) | (0.125, 0.142, 0.166) |
| Intermediate | (7, 8, 9) | (0.111, 0.125, 0.142) |
| Extreme importance | (9, 9, 9) | (0.111, 0.111, 0.111) |

$$\prod_{j=1}^{n} \tilde{a}_{ij} \quad (5)$$

$$\sum_{i=1}^{n}\prod_{j=1}^{n} \tilde{a}_{ij} \quad (6)$$

$$\tilde{S}_i = \prod_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{i=1}^{n}\prod_{j=1}^{n} \tilde{a}_{ij}\right]^{-1} \quad (7)$$

Where, $\tilde{S_i}$ is the normalized final fuzzy weight of each of elements

Following the method of Mahmoudi *et al*. (2019), Converted fuzzy data into crisp scores (CFCS) technique were used for defuzzification of the final fuzzy weights. First, the final fuzzy weights were normalized for the criteria and sub-criteria. The left and right bounds of normal values were calculated. Finally, the Normalized crisp value and Final crisp value were calculated.

## Environmental carrying capacity assessment

Equation 8 was used to calculate the physical carrying capacity (PCC), (Baud-Bovy and Lawson, 1998). In this regard, limiting factors have not been considered, so by considering the ecological limiting factors of the carrying capacity in Razin watershed, the real carrying capacity (RCC) was calculated (Equation 9) (Busby *et al.*, 1996). Here, the ecological limiting factors of carrying capacity include: water (for all classes), slope (for classes 4, 5, and 6), erosion, soil depth and CEC (for class 6), and vegetation (for all classes except class 1). Obviously, for a more accurate evaluation of the carrying capacity, the role of the management factor is undeniable, therefore, due to the limitations of human, technological, educational and extension resources in the Razin watershed, the effective carrying capacity (ECC) was calculated (Equation 10) (Busby *et al.*, 1996).

$$PCC = A * v/a \quad (8)$$

$$RCC = PCC\ (1 - Cf_1)(1 - Cf_2) \ldots (1 - Cf_n) \quad (9)$$

$$ECC = RCC(1 - FM) \quad (10)$$

Where:

PCC is the physical carrying capacity,

A and v/a are area and space required per person (0.3 ha), respectively;
RCC is real carrying capacity,
*Cf* is correction factor for limiting factors including slope = 0.15, erosion = 0.07, CEC = 0.1, soil depth = 0.02, water = 0.18, vegetation = 0.04, which have been estimated according to different classes of ecological potential;
ECC is effective carrying capacity,
*FM* is management adjustment coefficient, which is here 0.2.

### The software used in this research

ArcGIS 9.3 software was used to extract the information layers from the basic maps, correction and normalization of the information as well as integration of the layers. expert choice 11 software was used to perform the AHP calculations. To perform fuzzy and defuzzification operated by MATLAB 10 software, Databases were also created in Excel 2013 software environment.

## Results and Discussion

### Results of FAHP model and its rationality

The final crisp values for the criteria entered into the model are presented in Fig. 4 and Table3. The results showed that the highest weight were belonged to water, climate, slope and texture with values of 0.230, 0.132, 0.118 and 0.108, respectively. Regarding the slope criterion, the slope class (sub-criterion) $S_1$ and $S_2$ (0-2% and 2-5%) gained more important with 0.327 and 0.253, respectively (Fig. 4, a). Elevation class $El_1$ (1400-1700 m) with 0.50 was the most important for agricultural and rangeland use (Fig. 4b). The flat lands (P) followed by the southern direction (S) with values of 0.365 and 0.239, respectively, were more important in determining the unit with suitable potential for agricultural and rangeland use (Fig. 4c). In terms of lithological criteria, the sub-criterion of alluvial sediments ($L_4$) with value of 0.378 was the most important for the mentioned use (Fig. 4,d). Final crisp values of sub-criteria related to soil texture, erosion, depth, evolution, Pebble percentage, CEC, hydrological groups, organic matter, and phosphorus as well as water, climate, and vegetation cover are presented in Table 3. The results showed that silty clay and clay loam sub-criteria (whit values of 0.315 and 0.224, respectively) were more preferred for agricultural and rangeland use. In the soil hydrological groups, sub-criterion B with value of 0.731 was the most important for this use, and also in the climate criterion, the mediterranean climate sub-criterion with 0.345 was the most important agricultural and rangeland use (Table 3).

Water had a special value and importance in assessing the ecological potential of the land for various human uses to the extent that land and water have an interaction with each other. The importance of water resources in environmental planning is such that macro-policy reforms and planning for water resources have been identified as essential (Fidelis and Roebeling, 2014; Liefferink *et al*., 2011). To produce crops and fruits in Tigray, Ethiopia, Teka and Haftu (2012) introduced suitable soil characteristics as follows: silty clay texture, deep soil, slope less than 4%, gravel less than 2%, low erosion, and CEC 20-40 meq/100g soil.

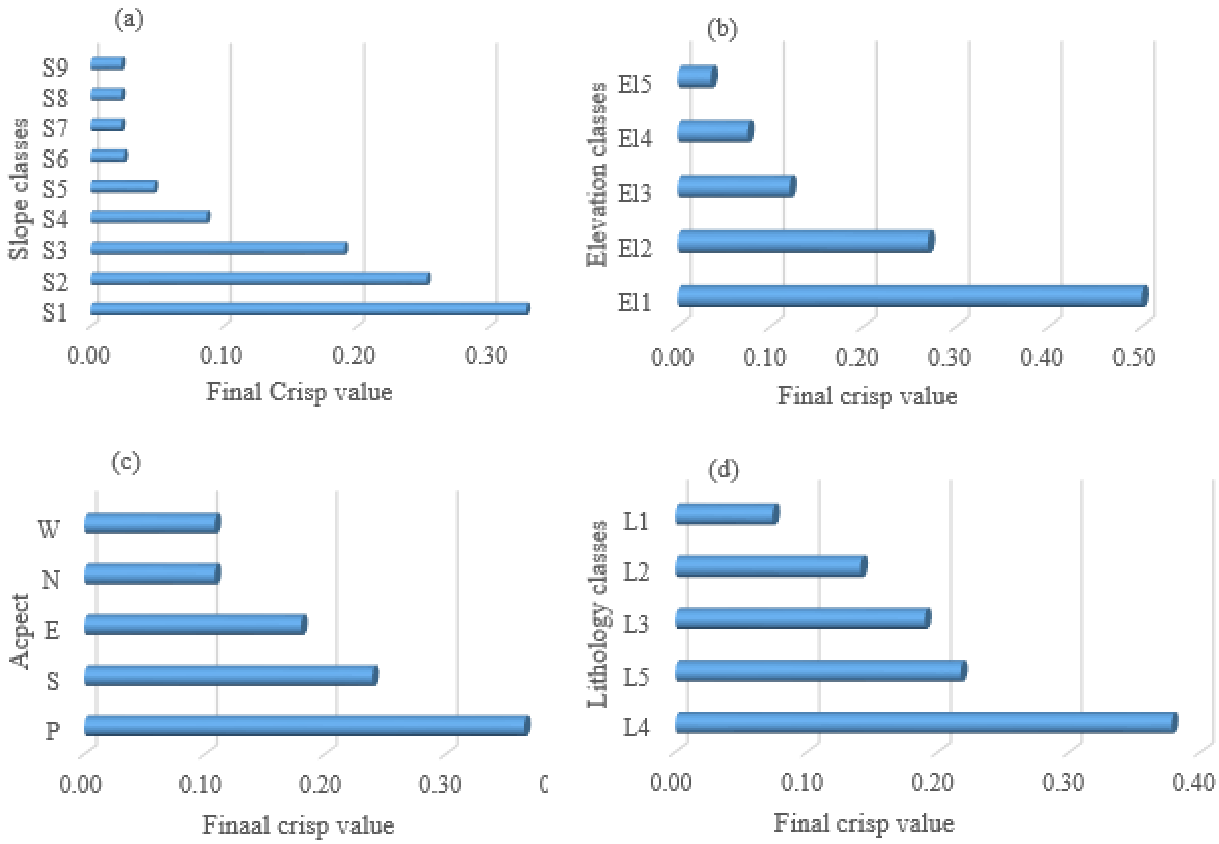


**Fig. 4.** The final crisp values of the sub-criteria related to the criteria of slope (a), Elevation (b), Aspect (c), and lithology (d)
Note. Slope%: 0-2 ($S_1$), 2-5 ($S_2$), 5-8 ($S_3$), 8-12 ($S_4$), 12-15 ($S_5$), 15-20 ($S_6$), 20-30 ($S_7$), 30-65 ($S_8$), > 65 (S9);
Elevation: 1400-1800 ($El_1$), 1800-2100 ($El_2$), 2100-2400 ($El_3$), 2400-2600 ($El_4$), > 2600 ($El_5$);
Aspect: flat (P), Northern (N), Eastern (E), Southern (S), Western (W);
Lithology: Limestone and dolomitic limestone ($L_1$), Sandstone ($L_2$), Shale, Conglomerate, Marne Type 1 ($L_3$), Alluvial sediments ($L_4$), Fillet ($L_5$)

## Results of ecological capability assessment

In this study, 192 landform units, 598 basic environmental units, and 1776 final environmental units resulted from the interaction of fixed and variable ecological factors. The final obtained map by modeling the results of the FAHP shows seven ecological capability classes in the studied region for agricultural and rangeland use (Fig. 5). Classes 1, 2 and 3 characterize lands with high ecological capability for major agricultural activity. Lands with class 1 (2870.6 ha) were capable of intensive cultivation of crops and orchards. Although lands with class 2 (1669.5 ha) were capable of producing crops, the ecological restraints frequently discourage cultivation. So, it is necessary to apply agricultural management such as fallow in these lands. Lands with class 3 (1718.9 ha) had low to medium potential for crop production and horticulture, so agricultural activities must be taken with care to protect environmental resources to prevent the destruction of ecological resources such as soil and water. Classes 4 and 5 are suitable for dryland cultivation and agricultural side activities. Lands with class 4 (1888.9 ha) had a high potential for rangeland and dry farming (cultivation, forage, and horticulture), and dry land farming can be done with or without rangeland management. The land had a medium capacity for growing fruit trees with or without irrigation and setting up livestock, poultry and beekeeping. Lands with class 5 (686.8 ha) had a medium potential for rangeland and dry land farming. Lands with class 6 (1582.4 ha) were capable of indirect agricultural activities such as poor beekeeping and pasture, and these lands are not capable of cultivation. Lands with class 7 (2073.5 ha) are not suitable for pasture and farming and are only suitable for protecting and grazing wildlife. From the study area, 2194.6 ha lacked the necessary ecological potential for agricultural and rangeland use in seven potential classes.

**Table 3.** Final crisp value of criteria of the soil texture, erosion, depth, evolution, Pebble percentage, CEC, hydrological groups, organic matter, and phosphorus, as well as water, climate, and vegetation cover, and their sub-criteria

| Sub-criteria | Final crisp value | Sub-criteria | Final crisp value |
|---|---|---|---|
| Soil erosion | 0.061 | Soil texture | 0.108 |
| Very low | 0.450 | Silty clay | 0.315 |
| Low | 0.298 | Clay loam | 0.242 |
| Moderate | 0.165 | Clay | 0.157 |
| Severe | 0.058 | Loam | 0.150 |
| Very severe | 0.029 | Sandy clay loam | 0.126 |
| Soil depth | 0.051 | Soil evolution | 0.030 |
| Very deep (> 120 cm) | 0.399 | Evolved | 0.472 |
| Deep (80-120 cm) | 0.360 | Semi-evolved | 0.256 |
| Moderate (50-80 cm) | 0.159 | Evolving | 0.164 |
| Shallow (25-50 cm) | 0.082 | Unchanged | 0.108 |
| Pebble percentage | 0.046 | CEC (meq/100g soil) | 0.042 |
| < 15% | 0.731 | 30-40 | 0.658 |
| 15-35% | 0.188 | 20-30 | 0.263 |
| 35-50% | 0.082 | 10-20 | 0.079 |
| Vegetation cover | 0.028 | Soil hydrological groups | 0.025 |
| 50-75% | 0.637 | Group B | 0.731 |
| 25-50% | 0.258 | Group C | 0.188 |
| 6-25% | 0.105 | Group D | 0.082 |
| Water ($m^3$. $ha^{-1}$. $Y^{-1}$) | 0.230 | Soil Phosphorus (ppm) | 0.015 |
| 3000-6000 | 0.750 | 10-15 | 0.833 |
| < 3000 | 0.250 | 5-10 | 0.167 |
| Climate | 0.132 | Soil organic carbon | 0.050 |
| Mediterranean | 0.345 | 1-1.5% | 0.833 |
| Semi-humid | 0.263 | 0.5-1% | 0.167 |
| Humid | 0.208 | - | - |
| Very humid | 0.184 | - | - |

## Model accuracy assessment

To determine the accuracy of the model and the efficiency of applying the GIS and FAHP techniques simultaneously, a sensitivity analysis was performed for important indices in sustainable ecological agriculture (Fig. 6). Sensitivity analysis was measured for units with classes 1, 2 and 3 that indicate the main agricultural activity. The most conformity was observed with the slope 0-8% (more than 80%), silty clay and clay textures (over 90%), deep soils with good drainage and low erosion, and Mediterranean climate (more than 80%).

The high degree of conformity of areas with classes 1, 2, and 3 that are suitable for the main agricultural activity with appropriate classes of criteria entered into the model in terms of ecologically sustainable agriculture indicates the high accuracy of FAHP modelling technique in estimating the impact coefficients of criteria and sub-criteria entered into the model. Also, the classification of criteria based on a scientific procedure has ensured the accuracy of this conformity.

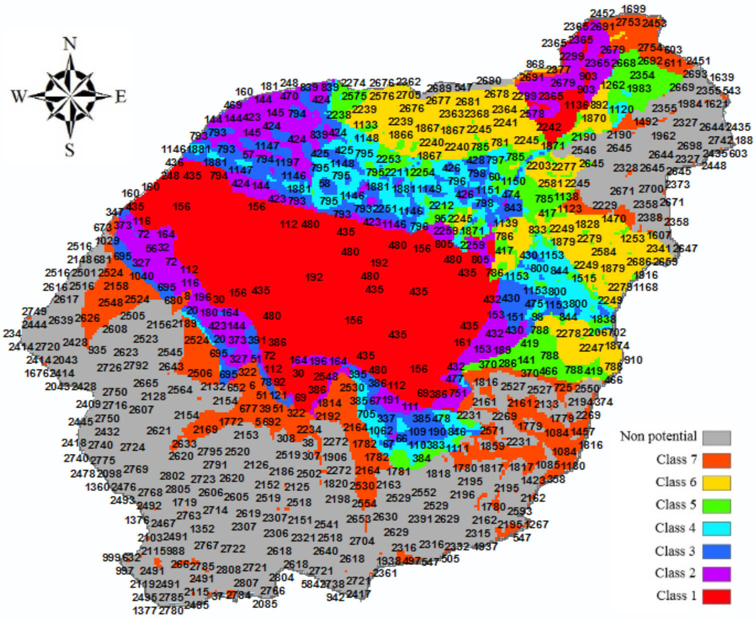


**Fig. 5.** Final ecological capability map of Razin Watershed for agricultural and rangeland activity in seven class based on FAHP modeling technique

Note. For example, environmental unit 192 has Class 1 capability for agriculture and rangeland characterized by the slope of 0-2%, elevation less than 1800 m.a.s.l., western aspect, soil with silty clay texture, very deep, low erosion, good construction, less than 15% pebble, Evolved, with 1.5% organic carbon content has alluvial lithological features, Mediterranean climate and water fewer than 3,000 $m^3$. $ha^{-1}$. $Year^{-1}$. (classes 1, 2 and 3; agriculture, classes 4 and 5; dryland farming; class 6; beekeeping and pasture, and class 7; protecting area for wildlife)

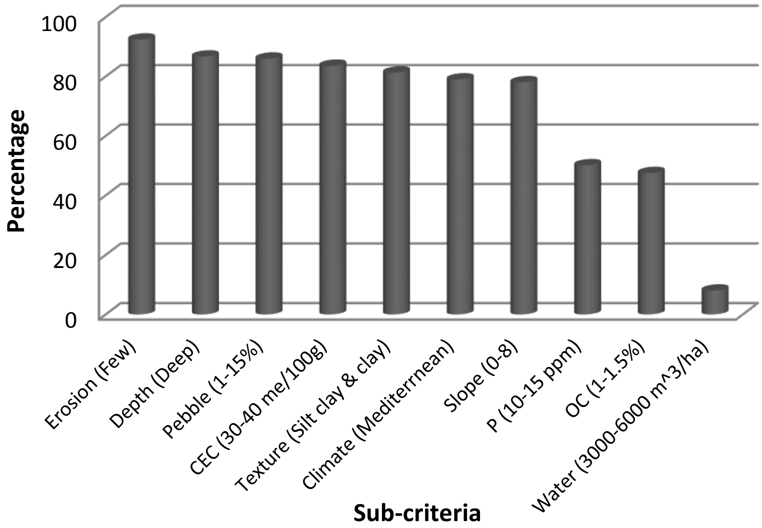


**Fig. 6.** Compliance percentage of the classes 1-3 for agricultural and rangeland use with important indices in sustainable ecological agriculture

Measuring the suitability of land in a large area requires the involvement of various and complex factors, and in this case, it is necessary to use Multiple-criteria decision analysis (MCDM) techniques. MCDM models complex world assumptions and can improve the quality of decision-making through a very clear, sensible, and effective structure (Zavadskas and Turskis, 2010). The hybrid of AHP and Fuzzy techniques makes it possible to have an appropriate structure for measuring the interaction of the studied factors, uncertainties in human judgments and the reflection of experts' mental secrets in a completely scientific and mathematical way. Therefore, the combination of these techniques with the use of GIS software in locating suitable areas for human activity in the land has a high accuracy. The FAHP technique leads to reliable results using a set of fuzzy functions to normalize the scales of different indices based on the characteristics of the selected criterion while maintaining relationships (Li *et al*., 2016; Li *et al*., 2011; Yu *et al*., 2011).

## Comparison of present land use with potential

The compatibility of the current land use map with the modeled map in Razin basin was shown in Fig. 7. It is clear that activities have been carried out without considering the ecological potential in some parts of the basin. Currently, dry land farming, dry land horticulture, and rangeland activities are carried out in the northeast of the study area while the environmental units located in this part do not have the necessary ecological capacity for these activities. In some parts of the east, rangeland activities are carried out while it is possible to carry out dry land farming (Class 4). In the northwest, rangeland activities are carried out, which due to the ecological potential of this sector, there is the possibility of agriculture (classes 2 and 3). In some parts of the study center, dry land farming is underway while there is the possibility of agricultural activities with class 1 for environmental units 69, 112, and 386, with class 2 for environmental units 67, 111, and 191, and also with class 3 for environmental units 62, 66, 109, 190, 386, and 387 in this sector.

As can be seen in Fig. 7, there are numerous springs in the northeastern part of the basin, which have led to agricultural activity in areas with unsuitable characteristics such as unsuitable slope, sandy texture, unsuitable depth, severe erosion, hydrological group D, and altitude above 1800 m. The result of this action is a depletion of water resources in this part and break off the ‘Water Right’ of downstream parts that have led to both soil and water resources destruction. In the northwest, all factors are suitable for agricultural and horticultural activities, but its water resources are limited and it is currently dedicated to Type 2 rangeland activities, which may be due to the country's natural resources and watershed management policies. In the central part of the basin, where irrigated agricultural and horticultural method is performed, drilling of abundant wells and excess exploitation of subsurface water resources is worrying and some operations should be taken to prevent the ecological vulnerability of the region.

## Environmental carrying capacity

The results of environmental carrying capacity assessment for the modeled agricultural and rangeland land use in seven classes with respect to the current population of the Razin watershed were shown in Table 4. Considering the ECC, it can be seen that all classes except class 2 and class 5 have a sustainable condition. Classes 2 and 5 have faced some ecological constraints due to resource degradation and are therefore in a semi-sustainable state. Therefore, appropriate proceedings should be taken in macro and regional planning according to the ecological potential of the region to prevent further degradation and to conserve available resources.

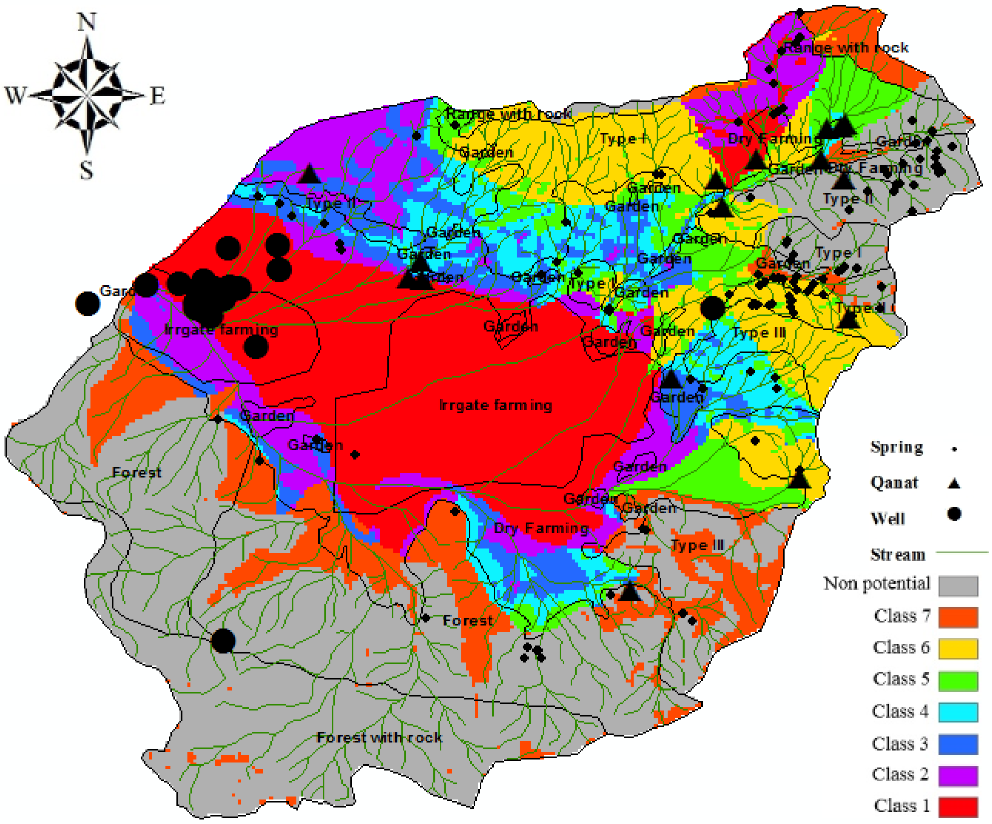


**Fig. 7.** Conformity land use map with ecological potential map for agricultural and rangeland use and water resources map in Razin watershed (classes 1, 2 and 3; agriculture, classes 4 and 5; dryland farming; class 6; beekeeping and pasture, and class 7; protecting area for wildlife)

**Table 4.** Environmental carrying capacity of Razin watershed for sustainable development of agriculture and rangeland based on its ecological potential

| Capability level | Area (ha) | Physical carrying capacity | Real carrying capacity | Effective carrying capacity | Population | Land per capita (ha) | Situation |
|---|---|---|---|---|---|---|---|
| Class 1 | 2870.6 | 861.2 | 706.2 | 564.9 | 1386 | 0.41 | Sustainable |
| Class 2 | 1669.5 | 500.9 | 394.3 | 315.4 | 1601 | 0.2 | Semi-sustainable |
| Class 3 | 1718.9 | 515.7 | 405.9 | 324.7 | 598 | 0.54 | Sustainable |
| Class 4 | 1888.9 | 566.7 | 379.2 | 303.3 | 163 | 1.86 | Sustainable |
| Class 5 | 686.8 | 206 | 137.9 | 110.3 | 497 | 0.22 | Semi-sustainable |
| Class 6 | 1582.4 | 474.7 | 260.6 | 208.4 | 250 | 0.83 | Sustainable |
| Class 7 | 2073.5 | 622.1 | 341.4 | 273.1 | 72 | 3.79 | Sustainable |
| **Sum** | 12490.6 | 3747.2 | 2625.4 | 2100.3 | 45667 | 0.46 | Sustainable |

## Conclusions

Razin watershed has several stable and unstable ecological resources, from the interaction of these resources, 1776 environmental units with unique ecological characteristics were identified. This area has ecological potential for rangeland use in seven classes (classes 1, 2 and 3; agriculture, classes 4 and 5; dryland farming; class 6; beekeeping and pasture, and class 7; protecting area for wildlife). Conformity of the land use map with the modeled map showed that in parts of the northeast, northwest, and center of the basin, the current activities are not commensurate with the capacity of those units and necessary proceedings should be taken to prevent further degradation and greater ecological vulnerability. In terms of ECC, all classes except class 2 and class 5 were sustainable. This modeling method has a very high accuracy and therefore, it is suggested to use the integrated FAHP-GIS model instead of conventional methods in assessing ecological potential.

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# مدلسازی توان اکولوژیک برای کاربری کشاورزی و مرتعداری توسط رویکرد FAHP مبتنی بر GIS (مطالعه موردی حوضه آبخیز رزین استان کرمانشاه)

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**چکیده.** تعیین قابلیت زیست محیطی در استفاده بهینه از زمین و جلوگیری از تخریب منابع طبیعی گامی مهم در جهت استراتژی توسعه پایدار است. مطالعه حاضر با هدف ارزیابی توانایی اکولوژیک حوزه آبخیز رزین در استان کرمانشاه، غرب ایران، برای کشاورزی و مرتعداری در هفت کلاس با استفاده از فرآیند تحلیل سلسله مراتبی فازی (FAHP) و استفاده از اطلاعات جغرافیایی (GIS) در طول سال‌های ۱۳۹۳ تا ۱۳۹۶ انجام شد. ابتدا، لایه‌های اطلاعاتی با توجه به پیشینه تحقیق و اهمیت آن‌ها انتخاب شدند، سپس غربالگری نهایی لایه‌های اطلاعاتی توسط روش دلفی فازی انجام شد. این لایه‌ها شامل واحدهای شکل زمین (شیب، ارتفاع، و جهت)، اطلاعات خاک (بافت، عمق، گروه‌های هیدرولوژیک، فرسایش، دانه‌بندی، درصد سنگ‌ریزه، تحول یافتگی، محتوای کربن آلی، کاتیون‌های قابل تبادل و فسفر در دسترس)، اقلیم، آب، کاربری اراضی، تراکم پوشش گیاهی، و سنگ‌شناسی بود. برای محاسبه ضرایب اهمیت معیارها و زیرمعیارهای وارد شده به مدل ارزیابی از روش FAHP استفاده شد. مدلسازی لایه‌های وزن‌دار توسط نرم افزار ArcMap 9.3 با استفاده از ترکیب خطی وزن‌دار در Overlay tool انجام شد. نتایج نشان داد که معیارهای آب، اقلیم، شیب، و بافت خاک به ترتیب با وزن های ۰/۲۳ ، ۰/۱۳۲ ، ۰/۱۱۸ و ۰/۸۸، بیشترین اهمیت را در مدل‌سازی توان اکولوژیک منطقه رزین داشتند. ۱۷۷۶ یگان زیست محیطی با ویژگی‌های منحصر به فرد اکولوژیک شناسایی شدند. این منطقه دارای توان اکولوژیک برای کاربری کشاورزی و مرتعداری در هفت طبقه می‌باشد. به غیراز طبقات ۲ و ۵، بقیه طبقات دارای ظرفیت برد موثر (ECC) پایدار بودند. با توجه دقت بسیار بالای مدل تلفیقی FAHP-GIS در کاربری شایستگی اراضی کشاورزی پیشنهاد می‌شود از این مدل به جای سایر روش‌های مرسوم استفاده شود.

**کلمات کلیدی:** توان اکولوژیک، کاربری زمین، فرآیند تحلیل سلسله مراتبی فازی، ظرفیت بار مؤثر، حوضه آبخیز رزین