JOURNAL OF THE FACULTY OF FORESTRY ISTANBUL UNIVERSITY
İSTANBUL ÜNİVERSİTESİ ORMAN FAKÜLTESİ DERGİSİ
ISSN: 0535-8418 e-ISSN: 1309-6257
Online available at / Çevrimiçi erişim
http://dergipark.ulakbim.gov.tr/jffiu - http://dx.doi.org/10.17099/jffiu.16433
Research Article / Araştırma Makalesi

# Prioritization of watersheds in order to perform administrative measures using fuzzy analytic hierarchy process

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**Received (Geliş):** 28.01.2016 - **Revised (Düzeltme):** 17.02.2016 - **Accepted (Kabul):** 24.02.2016

**Abstract:** Prioritization of watersheds in order to perform administrative measures is necessary and inevitable. Determining areas of top priority for flood control projects is a managerial decision that should be approved by studies of physical, social and economic status of the region of interesrt and by assessing the outcomes of the past operations. Therefore, the aim of this research was to study morphological and physiographic characteristics, and to use geographic information systems (GIS) and multi-criteria decision-making methods (MCDM), to identify the critical sub-basins which have the tendency to be destructed, in Galikesh watershed, Golestan province. This watershed is important, yet critical, in terms of land use change, erosion and flooding in the Golestan Province, Iran. In total, nine morphological parameters were used to prioritize sub-watersheds using fuzzy analytic hierarchy process (FAHP). The morphological parameters were by some means linked to watershed drainage system. Based on FAHP approach, sub-basins, as vulnerable zones, have been evaluated and cetegorized in five priority levels (very low, low, medium, high and very high levels). The results showed that 44.44% and 22.22% of sub-basins were categorized respectively under average, and high to very high levels, suggesting that the conservation and management measures are essential in order to maintain stability in the region. Thus, the FAHP technique is a practical and convenient method to show potential zones in order to implement effective management strategies, especially in areas where data availability is low and soil diversity is high. Finally, it can be said that without having to encounter high costs and a waste of time, sub-basins could be categorized by means of morphometric parameters in order to implement conservational measures to simutaneously conserve soil and the environment.

**Keywords:** Watersheds priority, FAHP, GIS, multi-criteria decision making, Galikesh watershed

# Su havzalarında idari tedbirlerin bulanık analitik hiyerarşi yöntemi kullanılarak önceliklendirilmesi

**Özet:** İdari tedbirleri gerçekleştirmek için havza önceliklendirilmesi gerekli ve kaçınılmazdır. Taşkın kontrolü projeleri için öncelikli alanları belirleme yönetimsel bir karardır ve bu karar; söz konusu bölgenin fiziksel, sosyal ve ekonomik statüsü ile geçmişteki işlemlerinin sonuçlarını değerlendirerek alınmalıdır. Bu nedenle, çalışmanın amacı coğrafi bilgi sistemleri (CBS) ve çoklu kriterleri karar verme yöntemleri (MCDM) kullanarak Gülistan eyaleti- Galikesh havzasında tahrip edilme riski taşıyan havzaların morfolojik ve fizyografik özelliklerini incelemektir. İran'ın Gülistan Eyaleti içerisinde bulunan bu havza kritik bir şekilde erozyon ve taşkın riski taşımaktadır. Toplamda, dokuz morfolojik parametre bulanık analitik hiyerarşi süreci (FAHP) için kullanıldı ve bu morfolojik parametreler havza drenaj sistemiyle doğrudan ilişkiliydi. Bu yöntemde alt havzalar; hassas bölgeler olarak, değerlendirilmiş ve beş öncelik düzeyi (çok düşük, düşük, orta, yüksek ve çok yüksek seviyelere) şeklinde kategorize edilmiştir. Sonuçlar; koruma ve alınacak yönetim tedbirlerinin bölgede istikrarın sağlanması için gerekli olduğunu göstermiş; alt havzaların sırasıyla % 44.44

**To cite this article (Atıf):** Arami, S.A., Alvandi, E., Frootandanesh, M., Tahmasebipour, N., Sangchini, E.K., 2017. Prioritization of watersheds in order to perform administrative measures using fuzzy analytic hierarchy process. *Journal of the Faculty of Forestry Istanbul University* 67(1): 13-21. DOI: 10.17099/jffiu.16433

oranında ortalama altında ve % 22.22 oranında çok yüksek düzeyde korunması gerektiğini vurgulamıştır. Bulanık analitik hiyerarşi yöntemi, özellikle teknik veri kullanılabilirliği düşük ve toprak çeşitliliği yüksek olan bölgelerde, etkin yönetim stratejilerinin uygulanması için potansiyel bölgeleri gösterme açısından pratik ve kullanışlı bir yöntemdir. Son olarak, yüksek maliyetler ve zaman kaybı ile karşılaşmaya gerek kalmadan, alt havzalar morfometrik parametreler kullanılarak toprak ve çevre koruması açısından kategorize edilebilmesini sağlamaktadır.

**Anahtar Kelimeler:** Su havzaları önceliği, FAHP, CBS, çok kriterli karar verme, Galikesh havzası

## 1.INTRODUCTION

Watershed is a suitable management unit, demanding multi-purpose approach in the management of resources to ensure continued benefits. Watersheds are the primary units for land management which require an interdisciplinary approach for their utilization and ensuring continued use. Therefore, the key issues of natural resources such as water scarcity, land degradation, drought, floods, etc., are resolved through the management of developed areas or sub-units, (Syrvastava et al., 2010). Analysis of Drainage network characteristics such as morphometric features, hydrogeology, etc. playes a pivotal role in the allocation, design and implementation of protective measures in small-scale hydrological units. Having knowledge of physiographic features of a catchment area with an awareness of climatic conditions can provide a fairly accurate picture of the qualitative and quantitative functioning of the hydrological system (Aher et al., 2013). Physiographic characteristics of the basin, in addition to the direct impact on the hydrological regime, flood intensity, soil erosion, and sedimentation, indirectly affects climate, ecology and vegetation (Fazelniya et al, 2012). In most watersheds, floods and its consequences are likely to increase in the upcoming years, and thus determining flood inducing areas of the basin and the prioritization of sub-basins are necessary for flood control projects and integrated watersheds management (Bakhtiarifar et al, 2011). GIS Techniques, remote sensing (RS), and Multiple Criteria Decision Making (MCDM) tools are useful for morphometric indexing and prioritization of sub-basins (Singh, 1994; Grohmann, 2004; Sreedevi et al, 2009; Aher et al, 2010; Rao and colleagues, 2011).

Prioritization of the watersheds has been of interest to many researchers in various fields. Aher and colleagues (2013) prioritized the Pim Palagon watershed in India through 9 morphometric parameters based on the FAHP. The results showed that 60.85% of the area fell into the middle to very high class showing the need for the protective measures. Mishra and colleagues (2007) through morphometric parameters via the Soil and Water Assessment Tool (SWAT) prioritized sub-basins of a semi-humid tropical ecosystems in India through morphometric indices. Vivien et al. (2011), applied the fuzzy MCDM method for selecting the best watershed environmental initiatives. Kaya and Kahraman (2011) by adopting VIKOR and fuzzy AHP approaches, developed a decision-making framework for forest management.

In other pieces of research, socio-economic aspects (Patil, (2007), Gosain and Rao (2004), Newbold and Siikamäki (2009), Kanth and Hassan (2010)) and land degradation and land use change, have been evaluated as the leading parameters of scoring landscape zones (Adinarayana, 2003; Deb and Talukda, 2010; Kanth and Hassan, 2010; Javed and colleagues, 2011; Sarma and Saikia, 2011).

The Galikesh watershed is an important, yet critical, basin in terms of land use change, erosion and flooding in the Golestan province. One of the principles of carrying out any project, whether theoretic or executive in various fields, is to prioritize. In order to apply watershed management practices, sub-basins prioritization would be a considerable effort due to limitations of time and resources. In this study, we tried to prioritize sub-basins through natural drainage network (the drainage system parameters), which is an innovative approach. Therefore, in this study to line up the morphological parameters, fuzzy analytic hierarchy process (FAHP) was used, to finally be able to identify and rank order sub-basins, evaluate the consequences and achieve the best accuracy.

## 2. MATERIAL AND METHOD

### 2.1 Study Area

Galikesh, as a sub-basin of the Gorganroud River, is located in Golestan province. This basin has an area of 404.8 square kilometers and an environment of 88.6 km. Figure 1 illustrates the location of the Galikesh basin in Golestan province. The maximum elevation reaches up to as much as 2461 meters, and its minimum height drops down to 378 m with an average height of 1295 meters above sea level. It has an average slope of 23.3 percent. The Oghan river lies in this basin, eventually joining the Gorganroud River and draining into the Golestan Dam. The main tributary of the river is 26.2 km long with 3.5 percent net slope. Concentration and lag time, using the Kirpich method, have been calculateded 3.9 and 2.3, respectively.

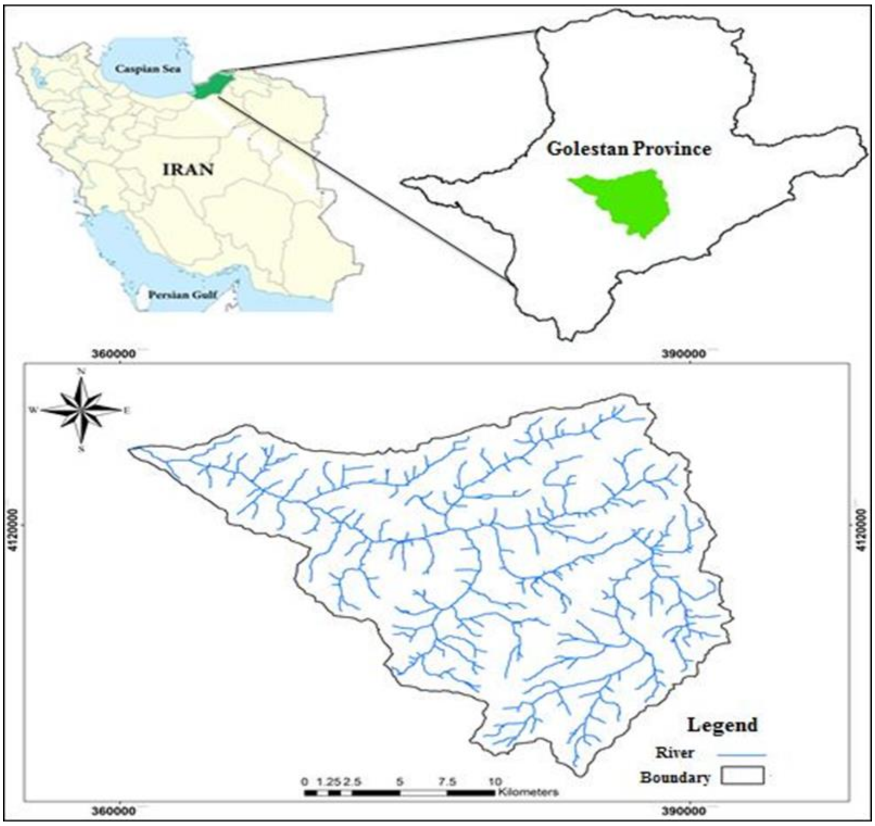


Figure 1. Location and drainage basin of the Galikesh watershed
Şekil 1. Galikesh havzasının konumu ve drenaj haritası

### 2.2 Research Methodology

In this study, prioritization of sub-basins was carried out using morphometric parameters and fuzzy analytical hierarchy process. First morphometric parameters were calculated in each sub-basin. Afterwards, by comparing the results of these indicators, sub-basins were placed in order based on watershed management practices by using the fuzzy analytic hierarchy process. A total of 9 morphometric parameters were used for sub-basins prioritization.

These parameters comprise the compression factor, form factor, elongation factor, streams frequency, drainage density, Bifurcation Ratio, drainage texture, concentration time and basin shape, all of which corresponding to the drainage network of the basin. Thus, this method is also called the Analysis of the natural drainage system. Morphometric parameters, used in the study; are provided in Table 1. In this study, in order to carry out the calculations and estimations of parameters, ARCGIS, Arc Hydro, XTools, Expert Choice and Excel softwares were used.

Table 1. Results and formulae adopted for computation of morphometric parameters
Tablo 1. Morfometrik parametrelerin hesaplanması için kabul edilen sonuçlar ve formüller

| Morphometric Parameters | Formula | Reference |
|---|---|---|
| Compression Ratio | $C_C = 0.28 \times \left(\frac{P}{\sqrt{A}}\right)$<br>Where, P is the basin's circumference in km<br>A= Area of the Basin($km^2$)<br>CC = Gravelius Compression Ratio | Strahler (1964) |
| Form Factor | $Rg=A/Lb^2$<br>Where, Rf=Form Factor<br>A=Area of the Basin($km^2$)<br>$Lb^2$=Square of Basin length | Horton (1932) |
| Drainage Texture (Rt) | Rt=Nu/P<br>Where, Rt = Drainage Texture<br>Nu=Total no. of streams of all orders<br>P=Perimeter (km) | Horton(1945) |
| Drainage Density(D) | D=Lu/A<br>Where, D=Drainage Density<br>Lu=Total stream langth of all orders<br>A=Area of the Basin($km^2$) | Horton(1932) |
| Stream Frequency(Fs) | Fs=Mu/A<br>Where, Fs= Stream Frequency<br>Mu= Total on. Of streams of all orders<br>A= Area of the Basin($km^2$) | Horton(1932) |
| Elongation Ratio | Re=2v (A/Pi/Lb)<br>Where, Re=Elongation Ratio<br>A=Area of the Basin (km 2)<br>Pi='Pi ' value i.e. 3.14<br>Lb=Basin length | Schumn (1956) |
| Bifurcation Ratio (Rb) | Rb= Nu/Nu+ 1<br>Where, Rb = Bifurcation Ratio<br>Nu = Total no. of stream segments of order 'u'<br>Nu + 1 = Number of segments of the next higher order | Schumn (1956) |
| Concentration Time | $t_c = 0.0078 \times L^{0.77} \times S_0^{-0.385}$<br>Where, $S_0$ = The main channel slope (m/m )<br>L= The main channel length(m) | Kirpich (1940) |
| Basin Shape | $L_1=(L*L_{ca})^{0.3}$<br>Where, L = Basin length<br>$L_{ca}$= Centroid Basin | Birkowski(1989) |

### 2.3 Prioritization of sub-basins

Once the morphometric parameters estimated, the Fuzzy Analytic Hierarchy Process (FAHP) was used in order to prioritize sub-basins.

AHP, as one of the most popular multi-criteria decision-making techniques, was developed in the 1980s by Thomas Saaty. AHP method relies on pairwise comparisons. The decision-maker initiates the analysis by providing a decision tree hierarchy. This tree illustrates the indicators and options of the decision. In an attempt to measure the Fuzzy concepts in a numerical manner, at least it has been tried to define numbers that compatibly describe the possible fuzzy concepts. Therefore, in this study, after drawing hierarchical tree (Figure 2), in order to make pairwise comparisons, triangular fuzzy numbers in the form of (li, mi, ui) were used. Then, pairwise comparison matrix was produced. For each row of the matrix of pairwise comparison, the value of Si, which is a triangular fuzzy number, was calculated using the following formula:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \times \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad \text{.....(1)}$$

$$\sum_{j=1}^{m} M_{gi}^{j} = (\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j) \quad \text{.....(2)}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = (\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i) \quad \text{.....(3)}$$

$$\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = (\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}) \quad \text{.....(4)}$$

Where "g" represents row number; "i" and " j" denote indicators and options. After calculating "Si", their comparative magnitude was calculated so that if M1 and M2 are two triangular fuzzy numbers, M1 to M2 magnitude ratio was defined as follows:

$$V(M_2 > M_1) = hgr(M_1 \cap M_2) = \mu_{M2}(d) = \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \dfrac{(l_1 - u_2)}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad \text{.....(5)}$$

To calculate the index weight in pairwise comparison matrix, following formula holds:

$W^{'}\{(x_i)=\min\{V(S_i>S_k)\}$ k=1,2,…,n, k=I……………………………………………………..(6)

Thus, the weight vector of the indices was calculated by the following equation, which is the non-normal vector of coefficients in fuzzy AHP.

$W^{'}=(W'(x_1), W'(x_2),…, W'(x_n))^t$ …………………………………………………………………...(7)

After normalizing eq. (7), the number of non-fuzzy (W) was determined by the following equation:

$W=(W(x_1), W(x_2),…, W(x_n))^t$ ……………………………………………………………………………(8)

In consequence, priority of all of sub-basins in the Galikesh watershed was estimated following the Fuzzy Analytic Hierarchy Process (FAHP).

## 3. RESULTS

Morphometric parameters calculated for each sub-basins are provided in Table 2. These values were obtained via formulas and softwares described in the Materials and Methods section. These values were used to form a pairwise comparison matrix in AHP.

Table 2. Comparison matrix of morphometric components in the Galikesh watershed, Golestan
Tablo 2. Galikesh, Golestan havzasındaki morfometrik bileşenlerin karşılaştırma matrisi

| Sub basin Name | Area ($Km^2$) | compression ratio | roufness coefficient | Form factor | Elongation ratio | Drainage density | Bifurcation ratio | Basin Shape | Drainage texture | Overland flow length | Concentration Time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SW1 | 38.07 | 1.36 | 0.53 | 0.40 | 0.71 | 1.07 | 2.58 | 0.19 | 1.13 | 0.46 | 1.86 |
| SW2 | 23.76 | 1.62 | 0.37 | 0.18 | 0.47 | 0.98 | 4.16 | 0.18 | 0.7 | 0.5 | 1.52 |
| 3A | 48.05 | 1.46 | 0.45 | 0.45 | 0.76 | 1.02 | 2.87 | 0.09 | 0.99 | 0.48 | 2.09 |
| 4A | 44.84 | 1.61 | 0.37 | 0.26 | 0.57 | 0.99 | 5.5 | 0.23 | 0.95 | 0.5 | 3.05 |
| 5A | 48.5 | 1.33 | 0.55 | 0.39 | 0.71 | 0.99 | 3.33 | 0.12 | 1.29 | 0.5 | 2.73 |
| 6A | 37.2 | 1.81 | 0.29 | 0.19 | 0.49 | 1.11 | 5.58 | 0.27 | 0.96 | 0.44 | 4.35 |
| 7A | 60.94 | 1.28 | 0.59 | 0.48 | 0.78 | 1.03 | 3.46 | 0.15 | 1.55 | 0.48 | 2.34 |
| 8A | 25.99 | 1.37 | 0.52 | 0.39 | 0.7 | 1.15 | 4.33 | 0.14 | 0.84 | 0.43 | 1.35 |
| 9A | 72.67 | 1.47 | 0.45 | 0.31 | 0.63 | 1.09 | 3.52 | 0.20 | 1.31 | 0.45 | 3.40 |

For prioritizing sub-watersheds, 9 morphometric evaluation indices were used in the form of a hierarchical tree shown in Figure 2.

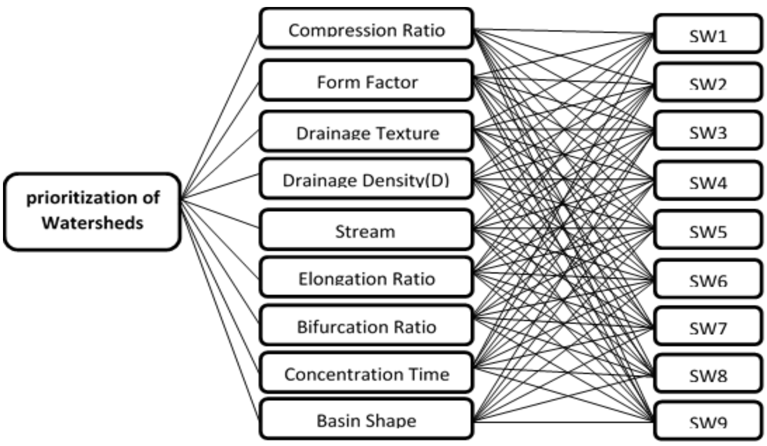


Figure 2. Illustrates the hierarchical tree of the FAHP method for prioritizing sub-categories
Şekil 2. FAHP met hiyererarşik gösterimi

According to the FAHP method, each standard morphometric criterion was evaluated through a pairwise comparison matrix, based on the weight scale obtained by normalized fuzzy calculations (Table 3). In addition, the ratings resulting from the proposed weight and morphometric parameters were introduced into the ARCGIS software environment, to map a comprehensive risk assessment for the implementation of protective measures (Figure 3).

In this study, FAHP analysis values ranged between 0.661 and 0.364 (Table 3). The priority of each index was obtained from the FAHP analysis, with the first priority having the largest value in the given drainage network. Therefore, the SW6 sub-basin received the highest priority by the numerical value of 0.661, and the SW3 received the lowest priority by the value of 0.364. other sub-basins falls somewhere in between.
Based on the multi-criteria decision analysis, priority of the sub-basins as well as comprehensive vulnerability assessment map consisting of 9 sub-basins were caluculated as given in Figure 4. Accordingly,

high-priority areas of SW6 and SW4 (priority 1 and 2) were determined. These areas must be placed under proper management principles due to the extent of degradation of natural resources. In addition, sub-basins were grouped under five classes of very low to very high, based on the total weight and the classification of morphometric parameters using MCDM method FAHP (Table 4). Compared with the classification above, it was found that 44.4% of the region, falls under the average class.

Table 3. Priority ranking of the sub-basins
Tablo 3. Althavzaların öncelik sıralaması

| Sub basin Name | Score based on FAHP | Prioritization Ranks |
|---|---|---|
| SW1 | 0.411 | 8 |
| SW2 | 0.501 | 4 |
| SW3 | 0.364 | 9 |
| SW4 | 0.532 | 2 |
| SW5 | 0.473 | 5 |
| SW6 | 0.661 | 1 |
| SW7 | 0.431 | 7 |
| SW8 | 0.459 | 6 |
| SW9 | 0.510 | 3 |

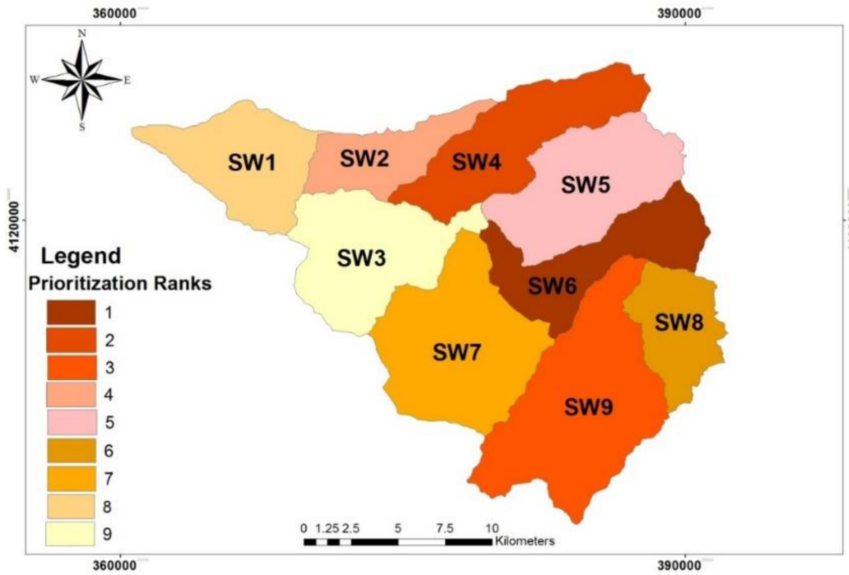


Figure 3. Prioritization of the sub- basins by the FAHP analyzes
Figure 3. FAHP analizine göre alt havzaların öncelik sıralaması

Table 4. FAHP scores for different priorities
Tablo 4. Farklı öncelikler için FAHP değerleri

| S. No. | Priority Types | Priority Levels | Sub-watersheds | Percentage of Area |
|---|---|---|---|---|
| 1 | Very High | >0.568 | SW6 | 11.11 |
| 2 | High | 0.567 – 0.514 | SW4 | 11.11 |
| 3 | Medium | 0.513 – 0.454 | SW2, SW5, SW8, SW9 | 44.44 |
| 4 | Low | 0.453 – 0.397 | SW7, SW1 | 22.22 |
| 5 | Very Low | 0.396 – 0.057 | SW3 | 11.11 |

The purpose of the application of multi-criteria decision-making techniques, is to exercise a proper approach to identify areas of high-priority to management. The best decisions are made through completing management activities such as soil and water conservation engineering measures, afforestation and so on.

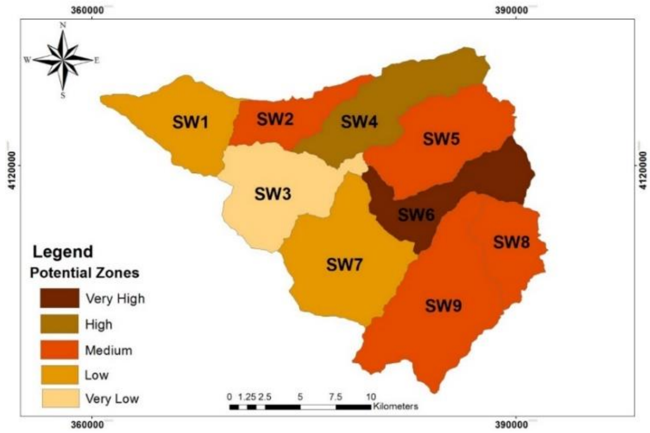


Figure 4. Determination of zones, sensitive to degradation (potential zones)
Şekil 4. Bozulmaya duyarlı potansiyel alanlar

## 4. DISCUSSION AND CONCLUSIONS

This research underlines the capabilities of remote sensing, GIS and multi-criteria decision in the prioritization of sub-basins for planning and managing natural resources. In this study, a new approach and logical process comprised of MCDM, in other words the FAHP analysis, has been successfully implemented for sub-basins prioritization. MCDM and GIS techniques have displayed their capabilities in the prioritization of sub-basins. When used together, they compensate each other's shortcomings in order to better inform management planning. This is in agreement with the results Fazelnia et al. (2012) and Ghafari Gilandeh et al. (2014). This technique is very effective in the watershed the case lack of data. Also when there exist complications due to a number of qualitative and quantitative criteria, MCDM plays an important role. The results show that the FAHP technique can be beneficial in the planning for the potential zones to implement effective management strategies at the watershed level, to various stakeholders such as farmers, rural communities, natural resource managers, and so forth. Watershed behaviour varies according to the morphometric characteristics for conservation factors. For that reason, the prioritization of critical areas for the implementation of conservation measures was determined. The watershed shape and other morphometric parameters were respectively, positively and negatively, correlated with risk assessement factors including runoff, and soil erosion. This agrees to the findings of Thakkar and Dhiman (2007). Integrated multi-criteria decision making (MCDM) and GIS have high capabilities in addressing spatial issues. Because on the one hand, in this method, multi-criteria decision approach can be used to establish a systematic framework for including influential criteria of spatial issues and their relative scoring. on the other hand, with a prevailing analytical tool such as GIS, huge quantities of data can be analyzed which is consistent with Bakhtiarifar studies (2011).

Finally, it can be argued that, sub-basins could be prioritized based on morphometric parameters without needing remarkable cost and time to implement watershed protection measures and to seek to protect natural resources. This is consistent with the results of Aher and colleagues (2013). However, due to high capacity of multi-criteria decision-making methods and GIS in the prioritization of sub-basins, the stronger the experts' opinions are and more accurate and updated the data, the more welcome and positive outcomes are to be expected.

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