Multi-Criteria Evaluation Model for Desertification Hazard Zonation mapping Using GIS (Study Area: Trouti Watershed, Golestan, Iran)

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Abstract. Desertification is one of the major issues threatening human communities. Many methods have been developed for assessment and mapping of desertification hazards. In this research, multi-criteria evaluation method was used to investigate desertification process in Trouti watershed, Golestan Province, Iran. At the first step, major desertification factors were determined by doing field surveys. They were soil texture, aspect, rainfall, sensitivity of geological formation to erosion, hydrologic soil group, slope and land use. The next step, information layers were digitized in GIS environment and Digitized maps were converted to fuzzy standard maps using fuzzy membership functions in IDRISI software. Then, weight of each factor was determined with the contribution of Analytical Hierarchy Process. Finally, the susceptible areas to desertification in the study area were identified using Multi-criteria evaluation method. The results showed that 36.55, 15.21, 40.17 and 8.07 % of the study area were classified as severe, high, moderate and slow affected by desertification, respectively. It was concluded that land use and sensitivity of geological formations to erosion were the most important factors affecting desertification process in Trouti watershed of Golestan Province.

Key words: Desertification, Multi-Criteria Evaluation, Fuzzy, Analytical Hierarchy Process, Trouti Watershed, Iran.

Introduction

Desertification is one of the major issues threatening human communities. This phenomenon threatens about 40% of the global land surface (Veron *et al*., 2006) and has influenced the life of 785 million people (Rangzan *et al*., 2008). In recent years, desertification control and reduction have been the most important projects in national and international organizations. Different methods are presented for assessment and desertification of hazard zonation. The most important methods which can be noted are ICD[3] method (Ekhtesasi and Mohajeri, 1995), MICD[4] method with emphasis on wind erosion process (Ahmadi *et al*., 2005), FAO/UNEP method (1984), Turkmenistan academy of sciences method (Babaev, 1985), MEDALUS method (Kasmas *et al*., 1999) and desertification risk index (Dafang *et al*., 2006).

Desertification hazard Zonation methods are divided into two groups: 1) Methods based on extensive field operations such as FAO/UNEP and Turkmen academy of sciences methods. 2) Methods based on minimum field operations like MEDALUS[5] and desertification risk index methods. On the other hand, methods such as ICD due to qualitative assessment of desertification factors and doubling the environmental factors value in areas without vegetation cannot be used (Zehtabian *et al*., 2002 ; Ahmadi *et al*., 2005). In the methods which are based on minimum field operations, Statistical and mathematical models are used based on the relationship and importance of desertification factors as information layers and applied maps in desertification hazard Zonation. Some studies have been presented using GIS and mathematical models for desertification risk mapping (Kasmas *et al*., 1999; Dafang *et al*., 2006). Akbari *et al*. (2007) conducted a study on the desertification classification and assessment in the north of Esfahan, Iran using TM and ATM satellite images related to the years 1990 and 2001. The results showed that the most important factors in the desertification of study area are the replacement of pastures with agricultural lands, wrong patterns of agriculture and live-stock over-grazing leading to a poor economic situation. Servaty and Makhdumi (2006) reported that human activities such as creating dryland farming in the mountain slope, over grazing in the pasture, replacing of pasture into low-crop yield lands and road constructions are the crucial factors in degradation and erosion of Jigh meydan's watershed in the Northeast of Golestan province, Iran. Wang *et al*. (2008) presented a regional pattern for environmental vulnerability assessment in Tibetan plateau by the means of multiple criteria evaluation and GIS method. The results showed that Multi-criteria evaluation approach is of utmost importance for a desertification hazard zonation to reflect the complexity of desertification. Desertification in Trouti watershed has occurred due to area's special geologic, edaphical and ecological conditions. This study emphasizes on desertification mapping, assessment and monitoring in Trouti watershed of Golestan Province.

Materials and Methods

Study area

The study area is located in 54°56´ - 55°06´ eastern longitudes and 37° 30´ - 37° 39´ northern latitudes in northeastern Gonbad in Golestan Province, Iran (Fig. 1). In the study area, the weighted average altitude and slope are 78 meters and 2.6 percent, respectively. The climate is arid using De Martonne method with I=8.58. It is covered with hill and Ghere Makher village is the major population center near to watershed.

[1]. Iranian classification of desertification
[2]. Modified Iranian classification of desertification
[3]. Mediterranean desertification and Land use

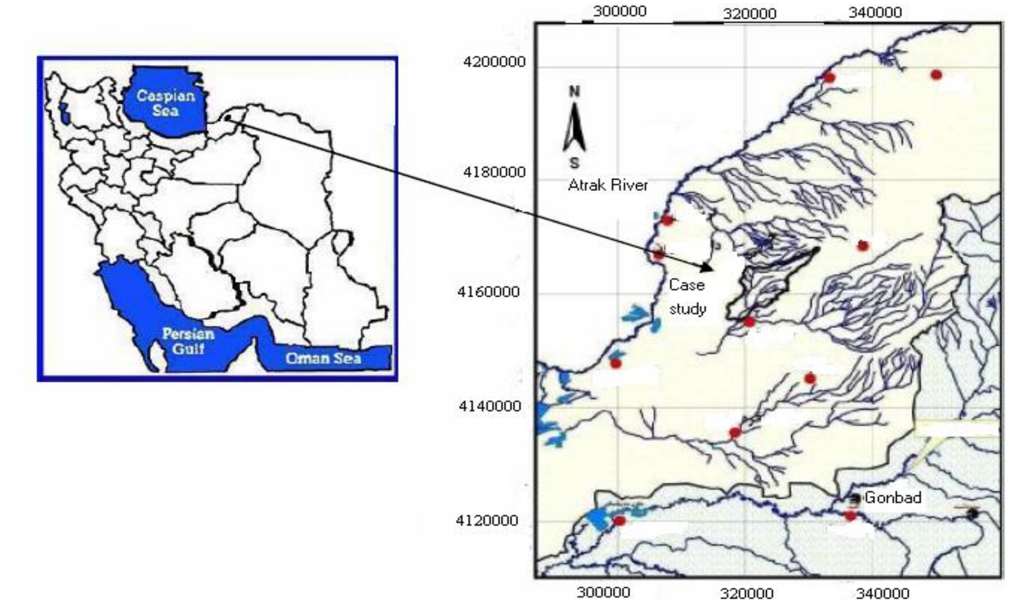

Fig. 1. The study area on a map of Iran and Golestan province

Identification of desertification factors (information layers)

Seven major factors in the study area including soil texture, aspect, rainfall, sensitivity of geological formation to erosion, hydrologic soil group, slope and land use was used based on field operation and selected to desertification hazard zonation in Trouti watershed.

Digitizing information layers

The information layers were digitized in GIS environment using ARCGIS 9.1 software. Information layer standardization using fuzzy membership functions each map pixel has a numerical value from zero to one in fuzzy logic with one representing complete certainty of membership and zero representing non-membership. The fuzzy membership function can have different shapes. Symmetrical reducing and increasing linear membership functions are used in order to standardize information layers in IDRISI software environment. Thus, seven fuzzy layers including soil texture, aspect, rainfall, geological formation, hydrologic soil group, slope and land use in the area were prepared. (Table 1), shows the importance of various information layers for desertification based on the ratio value.

Weighting each information layer using analytical hierarchy process (AHP) [6]

One of the mathematical models in multi criteria evaluation method is WLC[7] mathematical model. Weighting each of the desertification factors is the first step in WLC model (Wang *et al*., 2008; Wei-Dang *et al*., 2009). The weight of each factor (W) in this method represents the importance of each factor compared to the other factors. Fifteen local experts were invited to fill in the pair-wise comparison matrices to generate the weighting matrix which is shown in (Table 2).

Mapping the desertification status in Trouti watershed

In this step, desertification factors in GIS environment are combined and the desertification hazard zonation map is obtained using WLC mathematic model equation1) (Wang *et al*., 2008). Fig. 2 shows the schematic representation of the research.

DM=Σi=1 to n Wi Xi (1)

[6]. Analytical Hierarchy Process
[7] Weighted Linear Combination

Where:
DM = Desertification map of the region
Wi = weight of each information layer
Xi = Fuzzy map of each information layer

Tbale 1. Importance of individual topographic attributes for desertification based on the ratio value

Criteria	Description	Desertification Intensity class	Fuzzy Membership
Soil texture (Kosmas *et al.*1999)	L, Scl , Ls, Cl	Low	0.1
	Sc, Sil, Sicl	Moderate	0.40
	Si, C, Sic	High	0.70
	S	Very-high	1.00
Aspect (Kosmas *et al.*1999)	N	Very Low	0.10
	NE, NW	Low	0.20
	S	Very High	1.00
	SE, SW	High	0.80
	W	Low	0.40
	E	Moderate	0.60
Annual Rainfall (mm) (Ahmadi *et al.*2004)	≥ 280	Low	0.10
	150-280	Moderate	0.30
	75-150	High	0.70
	0-75	Very high	1.00
Sensitively of geological formation to erosion (Ahmadi *et al.*2004)	Granite, Quartzite	Low	0.10
	River formation	Moderate	0.40
	Loess, Non-evaporated Marl	High	0.70
	Evaporated Marl	Very high	1.00
Hydrologic Soil Group	A (Soil with low runoff potential)	Low	0.10
	B (Soil with moderate runoff potential)	Moderate	0.40
	C (Soil with high runoff potential)	High	0.70
	D (Soil with very high runoff potential)	Very high	1.00
Land use (Ahmadi *et al.*2004)	High density range, Garden	Low	0.10
	Moderate range	Moderate	0.40
	Poor range	High	0.70
	Degraded range	Very high	1.00
Slope (%) (Zehtabian *et al.* 2002)	< 6	Low	0.10
	6-18	Moderate	0.40
	18-35	High	0.70
	> 35	Very high	1.00

Table 2. Comparison of relative preference with respect to expert thoughts for desertification

Topographic attributes	Land use	Sensitively Geological Formation to erosion	Rainfall	Hydrologic soil group	Aspect	Slope	Soil texture
Land use	1	2	3	3	3	3	3
Sensitively of geological formation to erosion	0.5	1	2	2	3	3	3
Rainfall	0.33	0.5	1	3	2	3	3
Hydrologic soil group	0.33	0.5	0.33	1	3	2	2
Aspect	0.33	0.33	0.5	0.33	1	2	3
Slope	0.33	0.33	0.33	0.5	0.5	1	2
Soil texture	0.33	0.33	0.33	0.5	0.33	0.5	1
Final weight	0.294	0.208	0.169	0.118	0.09	0.067	0.054

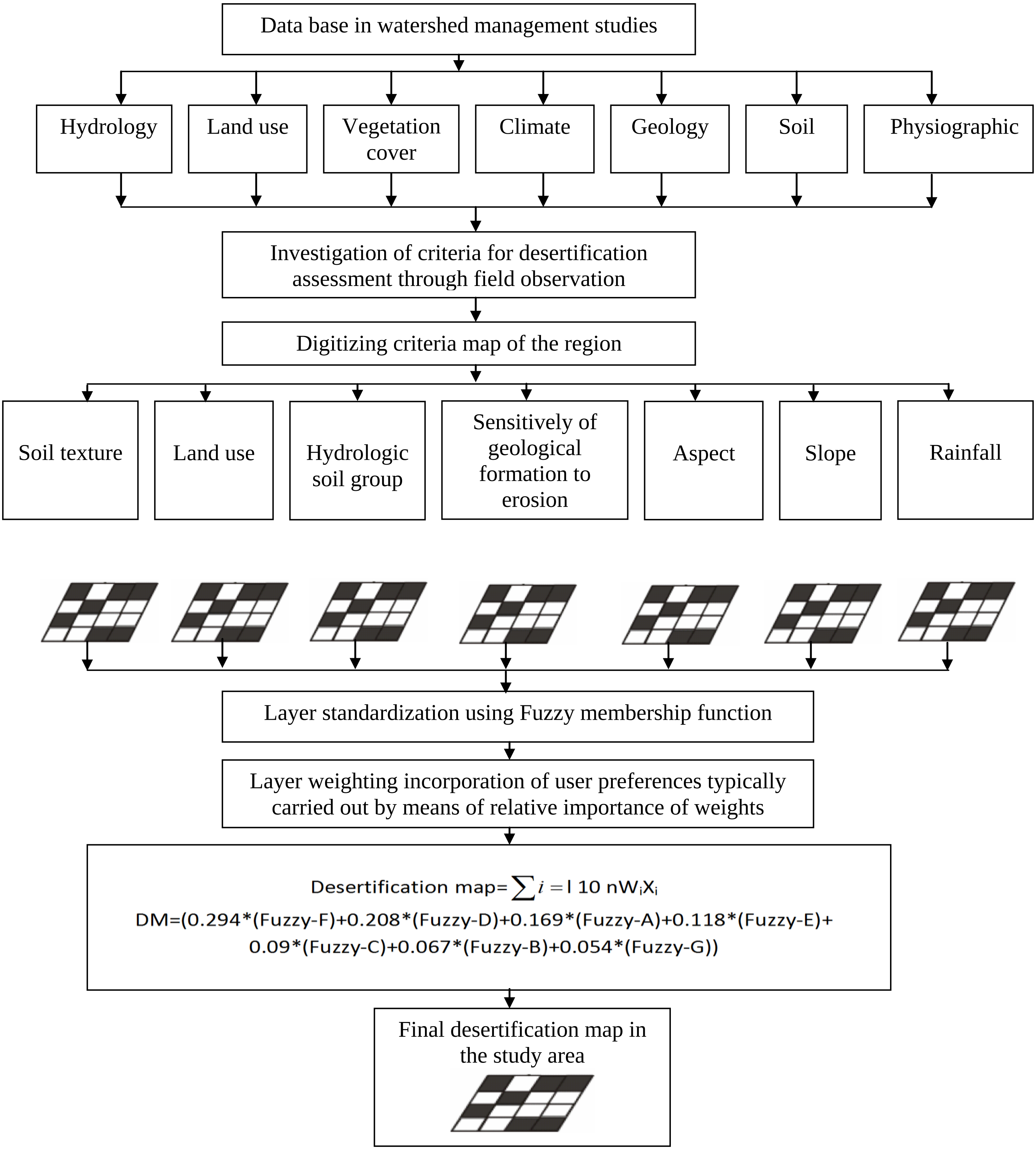

Fig. 2. The schematic representation of the research

Results and Discussion

Seven information layers including soil texture, aspect, rainfall, sensitivity of geological formation to erosion, hydrologic soil group, slope and land use are presented in Table 3.

Table 3. Frequency distribution of criteria for desertification assessment in the study area

Criteria	Sub-Criteria	Area (ha)	Area (%)
Soil texture	Silty-loam	6411	100
Aspect	North	155.93	2.43
	Northeast and Northwest	827.79	12.91
	South	972.64	15.17
	Southeast and Southwest	1615.37	25.2
	West	438.54	6.84
	East	397.86	6.2
	Flat	2002.7	31.24
Annual Rainfall(mm)	≥ 280 (mm)	5976	93.21
	< 280 (mm)	435	6.79
Sensitively of geological formation to erosion	Loess	6111.3	95.32
	Terrestrial sediments	299.7	4.68
Slope	< 6%	6255	97.57
	6-18%	156	2.43
Hydrologic soil groups	Soil with high runoff potential	4840.64	75.51
	Soil with moderate runoff potential	1570.36	24.49
Land-use	Moderate range and agriculture	3214.33	50.14
	Degraded range	3196.67	49.86

According to Table 3, the soil texture of the whole study area is Silty-loam, which is located in the middle level in terms of soil erosion and desertification. Over 46% of the watershed is located in south-facing slopes that are commonly less humid. Annual mean precipitation is 238 mm. The results showed that dominant formation of study area is loess. So that over 95% of the region has loess constructive formations, which are susceptible to destruction, erosion, and only 4.68% of the region contains river sediments. Owing to poor management and excessive exploitation of the available resources in the watershed, approximately 50% of the region has been destroyed or contains poor pasture. Table 4 shows the final weight of each information layer calculated by means of analytical hierarchy process. On this basis, land use and sensitivity of geological formation to erosion are more important in the desertification of study area.

In this study, inconsistency rate is less than 0.1 (0.06), so paired comparison of information layers has a good stability (Fig. 3).

Table 4. The weighting of layers using AHP

Layers	Weight
Land use	0.294
Sensitively of geological formation to erosion	0.208
Rainfall	0.169
Hydrologic soil group	0.118
Aspect	0.09
Slope	0.067
Soil texture	0.054

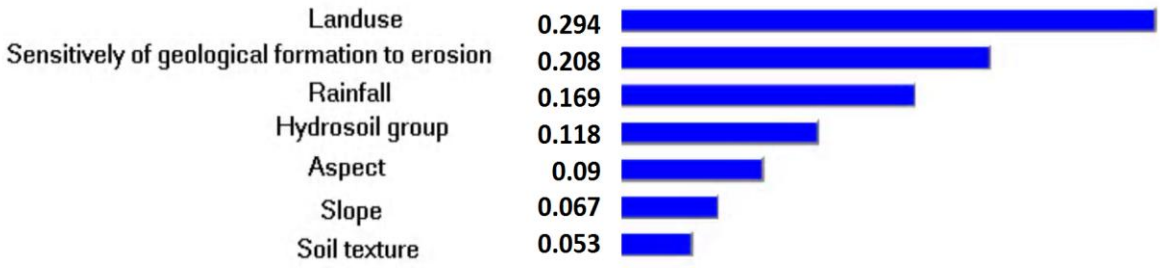

Fig. 3. The results of data analyzed in expert choice software (Inconsistency Ratio= 0.06)

The desertification hazard zonation map in the studied area was prepared from WLC mathematical model according to equation 2 in GIS environment.

DM= Σi=1 to n WiXi = [0.294* (Fuzzy-F) + 0.208* (Fuzzy-D) + 0.169* (Fuzzy-A) +0.118* (Fuzzy-E) + 0.09* (Fuzzy-C) + 0.067* (Fuzzy-B) + 0.054 * (Fuzzy-G)] (2)

Severity of the desertification in the area is correlated with land use indices and sensitivity of geological formation to erosion so that the levels of moderate to very high desertification hazards are seen in areas with loess formation. According to the desertification status map in Trouti watershed (Fig. 4), there are different levels of desertification hazard for the whole area so that approximately one third of the whole watershed (2343 ha) is located at the very high desertification level.

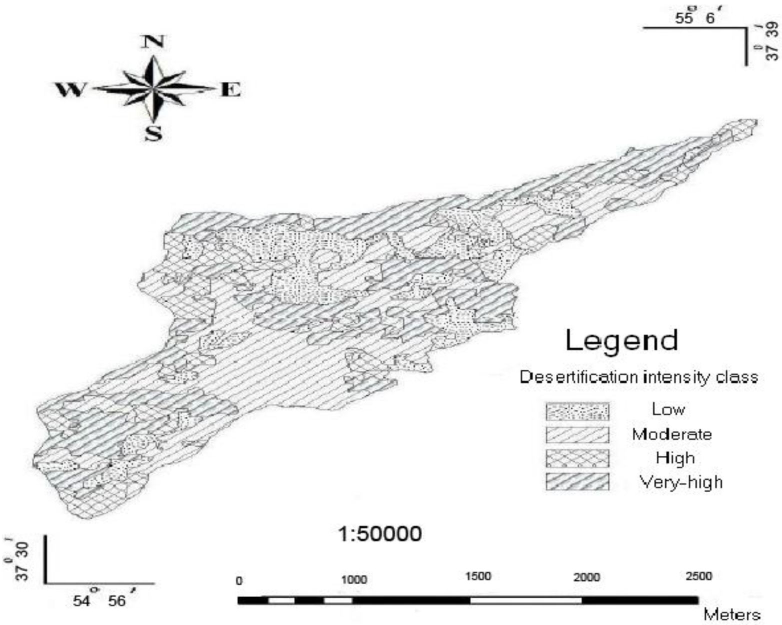

Fig. 4. Map of current desertification status in the study area

According to table 5 and figure 4, moderate and very high levels with 40.17 and 36.55% had the most common levels of desertification hazard in the study area, respectively.

Conclusion

Few studies were conducted to map desertification using such tools and methodology. Multi criteria evaluation method and fuzzy logic with the contribution of the geographical information system are utmost important for desertification study which reflect the complexity of desertification process.

According to desertification status map from multi-criteria evaluation method, it is specified that a large part of Trouti watershed be placed in low to very high intensity levels in terms of desertification intensity. Therefore, we conclude that 8.07% of study area is slightly desertified, 40.17% is moderately desertified, 15.21% is severely decertified and 36.55% is very severely decertified. Without doubt, these results show the gravity of desertification problem in the study area. Therefore, the results indicate that over 91% of the study area is susceptible to desertification. The most important factor in desertification of study area is pasture destruction and over 95% of the region has loess constructive formations which are susceptible to destruction and erosion which similar finding have been reported by Akbari *et al*. (2007) and Servati and Makhdumi (2006). Multi criteria evaluation method can be used to assess desertification status of a watershed due to its minimum cost and field operations, contrary to FAO/UNEP (1984), academy of sciences of Turkmenistan (Babaev, 1985) and MEDALUS (Kasmas *et al*., 1999).

Table 5. Extent of desertification class on the basis of output fuzzy membership unctions in Trouti watershed

Desertification intensity class	Fuzzy membership function	Desertification status Area (ha)	Desertification Status Area (%)
Low	0- 0.45	517.33	8.07
Moderate	0.45-0.64	2575.55	40.17
High	0.64-0.80	974.74	15.21
Very-high	0.80-1	2343.38	36.55

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