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ORIGINAL PAPER

Environmental sensitivity to desertification in northern Mesopotamia; application of modified MEDALUS by using analytical hierarchy process

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Abstract
Poor management, low vegetation cover, and severe erosion are undermining the stability and sustainability of lands. In this study, modified Mediterranean Desertification and Land Use (MEDALUS) method was used to identify environmentally sensitive areas (ESA) to desertification in Tigris Basin, Turkey. Soil samplings (0–20 cm) and field observations were conducted within 3.752 km^2 land. Biophysical and anthropogenic parameters of sampling locations have been integrated and processed by geographic information systems obtaining soil, climate, vegetation, and management quality indexes. Additional six parameters for soil quality and one for management quality were used to adopt MEDALUS to the context of Tigris Basin. The weights for parameters and indicators were calculated using analytical hierarchy process (AHP). Tigris Basin was classified into one fragile and two critical areas using original method, whereas one fragile and three critical classes were defined with the modified method. In the original method, fragile areas represented 5.65% and low-degree critical areas 24.49% and moderate critical areas 69.86% of the study area, which are needed to be monitored for severe land degradation. Modifying MEDALUS allowed to define highly critical areas (51.41%) which have not been detected in the original method. The critical areas are primarily used for field crops with extensive tillage, medium degree of plant cover, low drought resistance, and erosion along with low management quality due to the lack of required environmental protection. The results revealed that adaptation of new parameters and weighting in MEDALUS improved the ability of classifying ESAs for a regional scale to desertification.

Keywords Land degradation · Desertification · MEDALUS · AHP · ESAI · Tigris

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Introduction

The Tigris Basin located on the northern part of the ancient Mesopotamian formed by Tigris River, the second largest river in western Asia, extends over approximately 221,000 km^2 of which 24.5% is located in Turkey, 0.4% is in Syria, 56.1% is in Iraq, and 19% is in Iran. Turkey has recently completed the construction of eight large dams and hydroelectric power plants over Tigris River and its tributaries (UN-ESCWA and BGR 2013). Majority of the population in this region depends on agriculture as their primary source of income. Intensive agricultural activities will start after the completion of irrigation infrastructure projects which will trigger and, in some places, increase the land degradation. Despite the importance of the problem, harsh geographical conditions and ongoing conflicts in the Tigris Basin prevented the conducting of detailed studies on land degradation and implementing necessary precautions.

Land degradation and desertification are the most detrimental environmental problems threatening the food and fiber supply in all agro-ecological zones (Nachtergaele et al. 2010). Desertification is a problem affecting very large areas of the world where soils have suffered from a loss the ability of biological production and resilience caused by both natural and anthropogenic factors such as aridity, soil characteristics, vegetation cover, land use changes ,and the socioeconomic factors (Bajocco et al. 2011; Salvati et al. 2015). Desertification is defined as the combination of a number of interacting factors dealing with environmental quality, landscape, and land degradation in arid, semiarid, and dry subhumid areas. Land degradation is a recyclable and controllable process. However, desertification is defined as a situation in which the ability of biological productivity of a land is completely lost and recovery of functioning ability in practice, is almost difficult or not worthy (UNEP 1997).

Identification of indicators causing deterioration in land quality as well as their changes over time should be monitored for adaptation of precautions to improve land quality. In order to combat with land degradation, implementation of models or methods allow the integration of environmental components, i.e., present climate, biophysical, vegetation, and management that interact and determine the land degradation are deemed necessary (Prăvălie et al. 2017). Environmentally sensitive area (ESA) approach was developed in the framework of the Mediterranean Desertification and Land Use (MEDALUS) project to investigate the adverse effects of desertification initially in Mediterranean countries and take necessary measures to mitigate the land degradation (Kosmas et al. 1999). Within the context of MEDALUS methodology, three indicators of biophysical factors (climate, land quality, and vegetation) and anthropogenic ones (management) including 15 variables were combined to identify areas potentially affected by land degradation (Salvati and Zitti 2009; Ladisa et al. 2012; Prăvălie et al. 2017; Zambon et al. 2017; Budak et al. 2018).

The simplicity and flexibility of input variables and rapid implementation and easiness of MEDALUS method led to a widespread use in the Mediterranean region (Bajocco et al. 2016; Coscarelli et al. 2016; Symeonakis et al. 2016) as well as outside the Mediterranean region (Jafari and Bakhshandehmehr 2016; Prăvălie et al. 2017; Sobhani et al. 2017). Implementation of methodology in various regions of the world enabled to compare the results of similar studies in other areas of the world, and further improved the methodology. Prăvălie et al. (2017) has recently published a paper with a new indicator (water quality) and six new parameters (rainfall erosivity, wind speed, soil salinity, soil alkalinity, drainage density, and groundwater depth) to spatially analyze the land degradation sensitivity in south-western Romania. In another study, modified MEDALUS method by including 10 additional parameters related to soil erosion, groundwater quality, demographic, and grazing pressure was successfully used to identify the land degradation and desertification hot spots in the island of Lesvos, Greece (Symeonakis et al. 2016). Jafari and Bakhshandehmehr (2016) combined fuzzy logic and ESA approach to map environmentally sensitive areas to desertification in central Iran. Comparison of original and modified methods mostly revealed that the land sensitivity to desertification is more realistically determined by the modified method which uses parameters or indicators relevant to the area of interest (Farajzadeh and Egbal 2007).

The weights for parameters in the original MEDALUS method were constructed for the assessment of environmentally sensitive areas in the Mediterranean region. However, application of MEDALUS to different environmental and socioeconomic context requires adaptation of new parameters and as well as assigning different weightings. Dutta and Chaudhuri (2015) modified MEDALUS method by designing weighting of parameters for different environmental conditions, including new parameters or indicators that lead to more satisfactory results. Analytical hierarchy process (AHP), a multicriteria decision-making method developed by Thomas L. Saaty (1990), was used to assign the weights of parameters to delineate the ESAs to desertification in the districts of Jhunjhunun and Sikar in Rajasthan, India (Dutta and Chaudhuri 2015), to determine the strategies and ethics of sustainability in agriculture and food systems in Iran (Veisi et al. 2016) and to quantitatively calculate a regional ecological vulnerability index in in Yan'an, China (Hou et al. 2016). This study reports a novel approach which includes new parameters for soil and management quality indicators and integrates AHP technique in assigning weights for parameters and quality indicators. Therefore, the aim of this paper is to map and assess land susceptibility to degradation in Northern Tigris Basin by means of a multifactorial approach using GIS techniques, MEDALUS method, and AHP technique.

Methods

Study area

Tigris Basin in Turkey is located in south-eastern Anatolia Region, between latitude 37° 56′ N and 38° 28′ N; longitude 40° 50′ E and 41° 30′ E. The study area is one of Turkey's most vulnerable regions to desertification due to recent land use changes in plains and population increase in sub-urban areas. The area comprises about 3752 km^2 land around the Batman Dam (Fig. 1). The altitude ranges from 620 to 1830 m, and area is highly fragmented by rivers and deformed by tectonism. Entisols, Inceptisols, Alfisols, and Vertisols are the commonly encountered soil orders of the study area. The Tigris River, which starts to flow in eastern

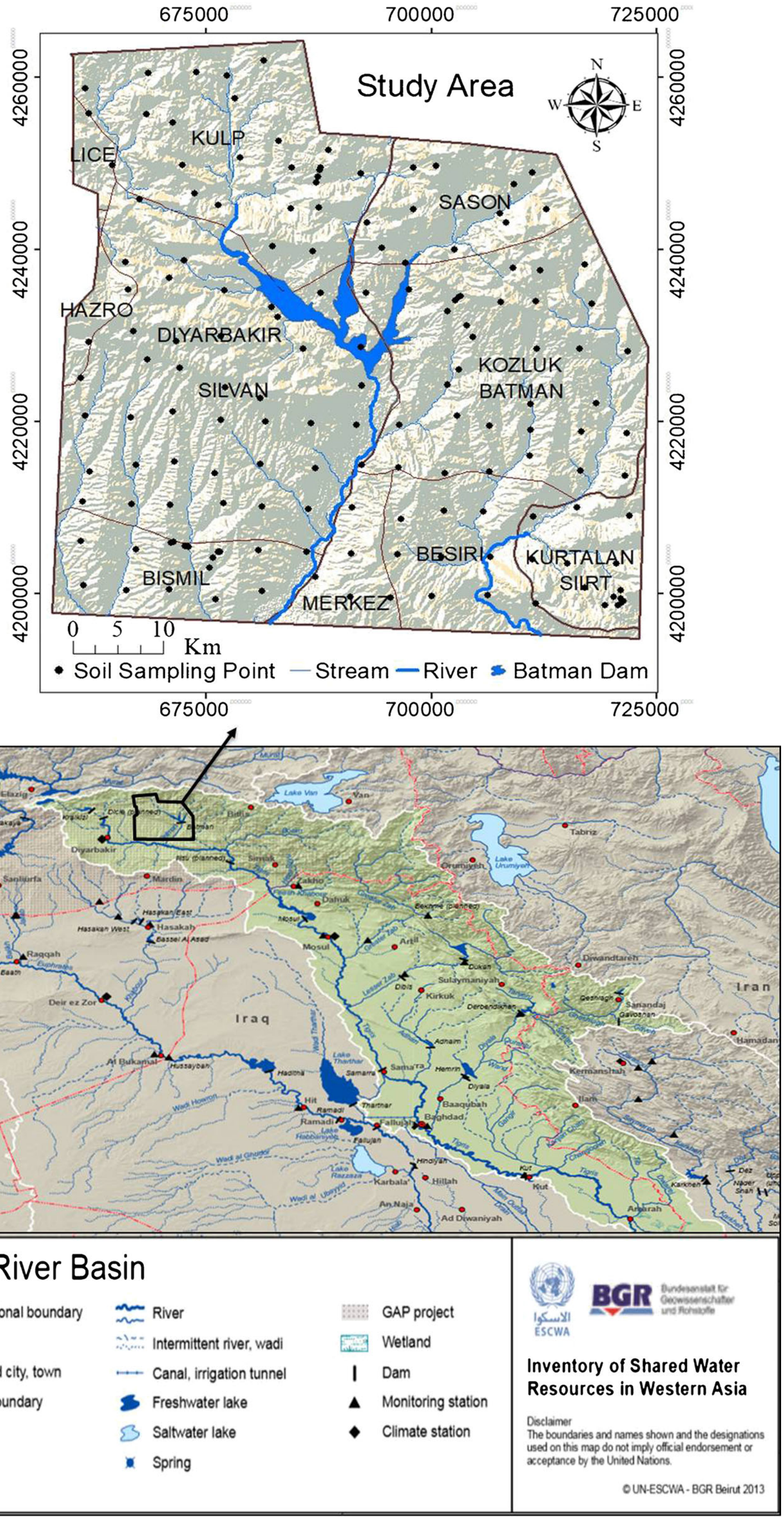

Fig. 1 Location of study area and sampling points within the Tigris River Basin

Turkey near Lake Hazar, is the major river in the study area. Tigris River is fed by Batman, Ilısu, Botan, and Garzan tributaries in Turkey and flows almost 1840 km till merging to Euphrates River in Iraq (Yıldız et al. 2016).

The region is characterized by a hot Mediterranean/dry-summer subtropical climate. Long-term (1963–2016) total annual average rainfall of the area ranges from 805 mm in Sason town of Batman province in the north-east to 557 mm in Diyarbakır province in center west.

Crop production of arable lands at the time of soil sampling was dominated by cereals, especially wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), lentil (*Lens culinaris* L.), and tobacco (*Nicotiana* L.). Orchards were dominated by pistachio (*Pistacia vera* L.), vineyards (*Vitis vinifera* L.), and followed by apple (*Malus domestica* L.) and cherry (*Prunus avium* L.) plantations. Vegetables were dominated by strawberry (*Fragaria vesca* L.), tomato (*Lycopersicon esculentum* L.), and pepper (*Capsicum annuum* L.). Farmers intensively tilled soils for weed management and moldboard is commonly used in tillage operations. *Quercus infectoria* L. is common among the oak species of the forest land of the study area (Fig. 2).

Geology of the study area

Tigris Basin contains different geological and topographical structures. The basin has a high plateau appearance and is composed of many bowl-shaped sub basins and low hilly lands. Karacadağ is a volcano in the midst of Euphrates and Tigris basins, which was active in the Pliocene age at the end of the third period. The study area, located on the east of Karacadağ is bordered by the metamorphic Bitlis mass from the north and east and the Midyat-Mardin formation from the south (Fig. 3). Basalts of Karacadağ are found in the south-western part of the study area, while the south, south-east, and eastern part consist mostly of conglomerate, claystone, sandstone, shale, and Şelmo formation with gypsum. The northern and north-western part consists mainly of Lice formation

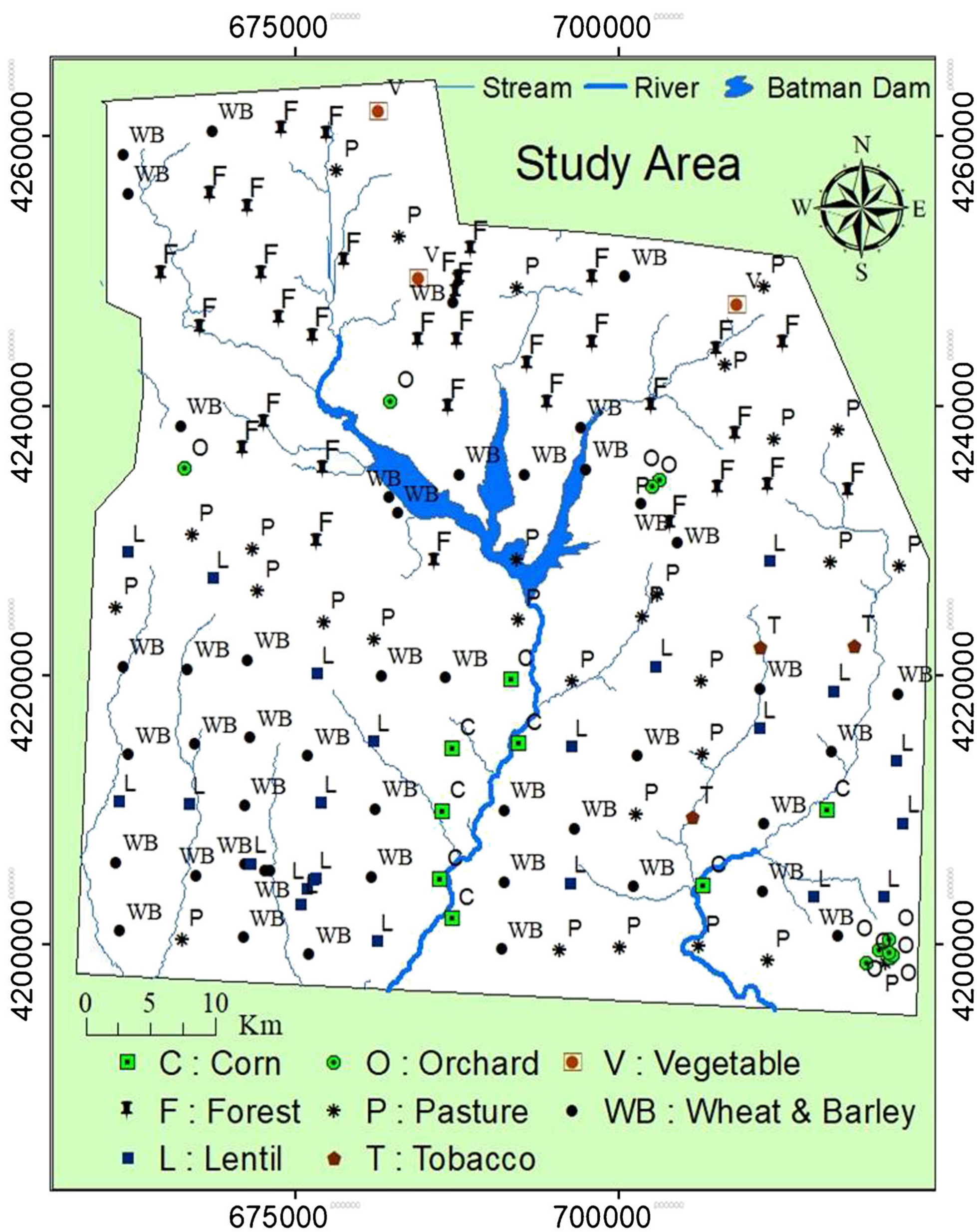

Fig. 2 Land use types of sampling locations

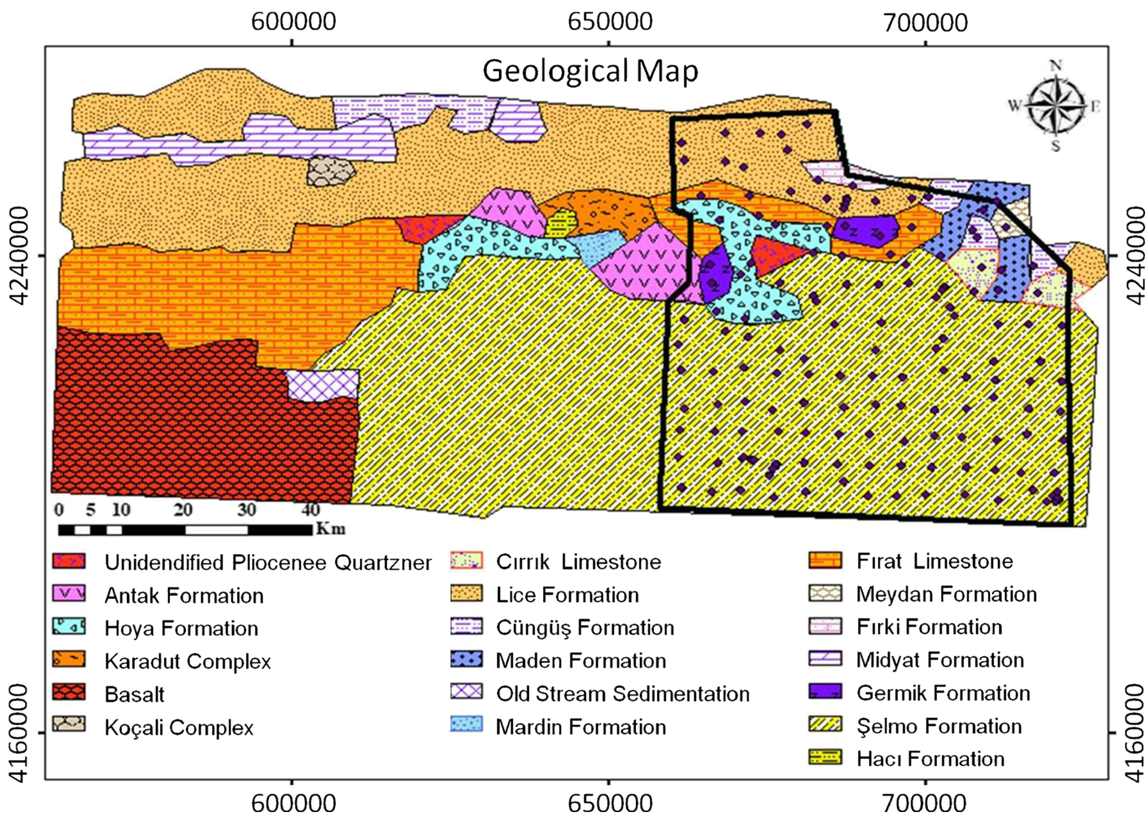

Fig. 3 Geological map of the study area

characterized by sandstone, claystone, siltstone, and limestone. The majority of the center part is composed of Neritic limestone, and in some places, Euphrates formation with marl (Sütçü 2008).

Physical and chemical soil analysis

Total of 139 disturbed and undisturbed soil samples from 0- to 20-cm depths were collected from approximately the corners of 5 km × 5 km size grid cells within 3752 km^2 land with different uses and parent materials. Additional soil samplings (18 more samples) at 250, 750, and 1750 m distances of six transects between the corners of main sampling points were placed at different locations of the study area to estimate the changes in soil properties shorter than 5 km. Physical and chemical soil properties of 157 soil samples were measured using standard laboratory methods. Particle size distribution was determined by the hydrometer method in a sedimentation cylinder, using sodium hexamethaphosphate as the dispersing agent (Gee and Bauder 1986). Aggregate stability (AS) was determined by wet sieving method (Eijkelkamp 08.13, Netherlands). Bulk density (BD) was determined on undisturbed soil samples using a steel cylinder of 100 cm^3 volume (5 cm in diameter, and 5.1 cm in height) (Blake and Hartge 1986). Organic matter (OM) was determined using the technique described by Walkley and Black (1934). Organic carbon was converted to soil organic matter content multiplying by the conversion factor of 1.72 (Nelson and Sommer 1982). The soil reaction (pH) and electrical conductivity (EC) were measured in a saturated paste (Rhoades 1982). In pH measurements, an electrode of pH meter calibrated with standard solutions at pH 3, 7, and 10. $CaCO_3$ was determined by using calcimeter method as mentioned by Allison and Moodie (1965).

Methodology to determine the environmentally sensitive areas

Environmental sensitivity to degradation was evaluated with the concept identified in the MEDALUS project (Kosmas et al. 1999) which contains biophysical (soil quality (SQ), climate quality (CQ), vegetation quality (VQ)) and anthropogenic (management quality (MQ)) indicators. MEDALUS methodology is based on qualitative and quantitative estimate of four indicator qualities and classifies lands in critical, fragile, potential, and unaffected areas. In this study, two environmentally sensitive area indexes (ESAI-1 and ESAI-2) and four indicator scores were obtained by using original and modified MEDALUS methods.

In ESAI-1 calculation, classification and scoring of parameters were performed in accordance with the criteria proposed in the original MEDALUS method. The score of each indicator was computed with the geometric mean of parameters defined under particular indicator, i.e., the vegetation quality index (VQI) indicator was obtained based on the geometric mean of the parameters' scores, with the formula:

$$\mathrm{VQI} = (\text{plant cover} \times \text{fire risk} \times \text{erosion protection} \times \text{drought resistance})^{1/4}.$$

In ESAI-2 calculation, four different processes were performed apart from the original MEDALUS methodology. The modifications were (1) addition of new parameters relevant to the characteristics of the region, (2) assigning new scores for parameters based on the influence on land degradation in the Tigris Basin, (3) calculation of weights to the parameter and indicator scores using AHP technique, and (4) changing the calculation method of indicator scores and ESAI. Soil reaction (pH), electrical conductivity, OM content, $CaCO_3$ content, BD, and AS were added to soil quality indicator and population density was added to management quality as new parameters considered to be important attributes for Tigris Basin. The indicators and parameters assume a value ranging between 1.0 and 2.0 which indicating the lowest sensitivity to degradation (score of 1.0) and the highest sensitivity to degradation (score of 2.0). The descriptions and scores of new parameters included into soil quality, climate quality and management quality were presented in Tables 1, 2, and 3.

Soil quality

Soil characteristics, important for soil functioning, were selected as parameters of soil quality indicator. A total of 12 parameters were identified within soil quality indicator (Table 1). Data on soil depth, rock fragments, and drainage were obtained in situ during sampling of the sites. Parent materials were obtained from the geology map (Sütçü 2008). Data on topography was obtained from SRTM digital elevation data, which is a digital terrain model produced by NASA with a resolution of 90 m. The original data is obtained from CGIAR-CSI (http://srtm.csi.cgiar.org/) for free of charge. The slope and aspect were calculated from digital elevation model (DEM) data using the ArcGIS/3D analysis plugin. The scoring of new parameters for ESAI-2 was performed based on data obtained from literature given.

Climate quality

The climate quality was determined using variables of rainfall, aridity index, and aspect. The long-term (1975–2016) annual average rainfall data was compiled from daily climate data obtained from 265 meteorological stations. Aridity index parameter was calculated by using *P*/PET equation where *P* = annual precipitation (mm) and PET = annual potential evapotranspiration (mm) which was calculated using the Penman-Monteith method (FAO 1998). The annual total evapotranspiration values needed to calculate the aridity index were computed for each meteorological station using the data between 1980 and 2010 and converted into monthly and annual data. Long-term annual total mean precipitation and evapotranspiration data were interpolated according to ANUSPLINE (Hutchinson 1989) method which takes also into account the altitude of locations. The boundaries of the study area were cut from the layer interpolated and necessary data were obtained for each of the soil sampling site. The third parameter is aspect of the soil sampling site which is an important factor in land degradation processes. The aspect of each soil sampling site was determined using DEM data. The scores assigned for the parameters in original and modified MEDALUS methods were given in Table 2.

Management quality

The management quality indicator was analyzed based on the parameters of agricultural land use intensity, pasture grazing intensity, population density, and environmental protection policies of which population density was added and the other three belonged to the original MEDALUS method. Due to the long-lasting conflicts and harsh environmental conditions in the Tigris Basin of Turkey, inhabitants of remote villages and hamlets moved into larger villages (Ünal and Harmanci 2016). Abandonment of lands was reported to have diverse impacts on soil quality. Romero-Díaz et al. (2017) showed that following the abandonment in the western Mediterranean Mountains, quality of soils improved due to the recovery of vegetation. Similarly, Rodrigo-Comino et al. (2017) also observed a dense vegetation cover after the abandonment on the terraced orchards of citrus and olives; however, they have stated that crusts and rills and a negligible plant cover developed after the abandonment of sloping terrain of almonds and vineyards which led to higher erosion rates. Land abandonment in Tigris Basin may have variable influences on land quality depending on the geographical conditions of abandoned lands. Considering the specificity of the study area, the population density was thought to be highly relevant for assessing degraded lands in northern Tigris Basin, Turkey.

Improper management of rangelands accelerates soil erosion and land degradation. Overgrazing in pastures prone to soil erosion leads to soil loss which restricts storage of water and vegetation survival and growth (Kosmas et al. 2014). The number of livestock has substantially decreased in Turkey in contrast to the increased livestock density in southern Europe (Kosmas et al. 2014). In the study area, animals were not brought to the mountainous districts due to the security reasons which increased the grazing intensity of pastures in low lands. Therefore, pasture grazing intensity was also added as a factor into the management quality analyses (Table 3).

Table 1 Scoring of parameters included into soil quality indicator

Parameter	Class	Description	Score	Data sources
Parent material[c]	1	Shale, schist, basic, ultra-basic, conglomerates, unconsolidated materials	1	Geology map
	2	Limestone, marble, granite, Rhyolite, Ignibrite, gneiss, siltstone, sandstone	1.7	
	3	Marl, Pyroclastics	2	
Texture[a]	1	L, SCL, SL, LS, CL	1	Lab. analysis
	2	SC, SiL, SiC	1.2	
	3	Si, C, SiC	1.6	
	4	S	2	
Texture[b]	1	L	1	
	2	SCL, SiCL, CL	1.2	
	3	SL, SiL, LS, SC	1.5	
	4	SiC, C,	1.7	
	5	S, Si, and clay content > 60%	2	
Slope (%)[a]	1	< 6	1	Slope map
	2	6–18	1.2	
	3	18–35	1.5	
	4	> 35	2	
Slope (%)[b]	1	< 2	1	
	2	2–6	1.1	
	3	6–12	1.2	
	4	12–20	1.4	
	5	20–30	1.6	
	6	30–45	1.8	
	7	> 45	2	
Rock fragment (%)[c]	1	> 60	1	Field observations
	2	20–60	1.3	
	3	< 20	2	
Soil depth (cm)[c]	1	> 75	1	
	2	75–30	1.2	
	3	15–30	1.5	
	4	< 15	2	
Drainage[c]	1	Well drained	1	
	2	Imperfectly drained	1.2	
	3	Poorly drained	2	
Soil reaction[b]	1	< 5.0	2	Lab. analysis
	2	5.1–5.5	1.8	
	3	5.6–6.0	1.6	
	4	6.1–6.5	1.2	
	5	6.6–7.3	1	
	6	7.4–8.0	1.2	
	7	8.1–8.5	1.6	
	8	> 8.5	2	
Electrical conductivity (dS m^{-1})[b]	1	< 1.2	1	
	2	1.2–2.5	1.2	
	3	2.5–4.5	1.5	
	4	4.5–9.0	1.7	
	5	> 9.0	2	
$CaCO_3$ content (%)[b]	1	0–2	1.4	
	2	2–4	1.2	
	3	4–8	1	
	4	8–15	1.2	

Table 1 (continued)

Parameter	Class	Description	Score	Data sources
	5	15–30	1.6	
	6	> 30	2	
Organic matter (%)[b]	1	> 4.0	1	
	2	3.0–4.0	1.2	
	3	2.0–3.0	1.4	
	4	1.0–2.0	1.6	
	5	0.5–1.0	1.8	
	6	< 0.5	2	
Aggregate stability (%)[2]	1	< 25	2	
	2	25–50	1.6	
	3	50–75	1.2	
	4	> 75	1	
Bulk density (g cm^{-3})[b]	1 Sandy	< 1.40	1	Lab. analysis
		1.40–1.6	1.3	
		1.6–1.8	1.7	
		> 1.80	2	
	2 Silty	< 1.20	1	
		1.2–1.5	1.3	
		1.5–1.6	1.7	
		> 1.60	2	
	3 Clayey	< 1.10	1	
		1.10–1.3	1.3	
		1.3–1.5	1.7	
		> 1.5	2	

[a] Scores were used for ESAI-1

[b] Scores were used for ESAI-2

[c] Scores were used for both ESAI-1 and ESAI-2

Table 2 Scoring of parameters included into climate quality in original and modified MEDALUS

Parameter	Class	Description	Score	Data sources
Rainfall (mm)[c]	1	> 650	1	FAO Clim-NET
	2	280–650	1.5	
	3	< 280	2	
Aridity Index (P/PET)[c]	1	> 0.65	1	UNEP 1992
	2	0.5–0.65	1.2	
	3	0.2–0.5	1.5	
	4	0.05–0.2	1.7	
	5	< 0.05	2	
Aspect[a]	1	NW-NE and Plain	1	Aspect map
	2	SW-SE	2	
Aspect[b]	1	W-NW, W, W-SW and plain (slope < 5%)	1	
	2	NW, N-NW, N, N-NE, NE	1.3	
	3	E-NE, E, E-SE	1.7	
	4	SW, S-SW, S, S-SE, SE	2.	

[a] Scores were used for ESAI-1

[b] Scores were used for ESAI-2

[c] Scores were used for both ESAI-1 and ESAI-2

Table 3 Scoring of parameters included into management quality

Parameter		Class	Description	Score	Data sources
Land use intensity[a]	Cropland	1	Low land use intensity (LLUI)	1	Land cover map (CORINE) and In situ field observations
		2	Medium land use intensity (MLUI)	1.5	
		3	High land use intensity (HLUI)	2	
	Pasture	1	ASR < SSR	1	
		2	ASR = SSR to 1.5 × SSR	1.5	
		3	ASR > 1.5 × SSR	2	
	Naturel area	1	A/S = 0	1	
		2	A/S < 1	1.2	
		3	A/S = 1 or greater	2	
Policy[c]		1	Complete = > 75% of the area under protection	1	Field observations and data base of RTMFAL
		2	Partial = 25–75% of the area under protection	1.5	
		3	Incomplete = <25% of the area under protection	2	
Intensity of agricultural land use[b]		1	Low land use intensity	1	Field observations
		2	Medium land use intensity	1.5	
		3	High land use intensity	2	
Pasture grazing intensity[b]		1	< 1	1	Data base of RTMFAL
		2	1–1.5	1.3	
		3	1.5–2.0	1.7	
		4	> 2.0	2	
Population density[b]		1	< 25	1	Data base of TUIK
		2	25–50	1.2	
		3	50–100	1.4	
		4	100–200	1.6	
		5	200–400	1.8	
		6	> 400	2	

RTMFAL Republic of Turkey Ministry of Food, Agriculture and Livestock; *TUIK* Turkish Statistical Institute

[a] Scores were used for ESAI-1

[b] Scores were used for ESAI-2

[c] Scores were used for both ESAI-1 and ESAI-2

Vegetation quality

The vegetation quality index (VQI) was comprised of plant cover, fire risk, erosion protection, and drought resistance variables (Table 4). The vegetation quality data was determined using field observations, CORINE data as well as maximum green vegetation fraction (MGVF; Broxton et al. 1996) which was calculated from MODIS-NDVI (normalized difference vegetation index) satellite images combined with 8 and 15-day periods. During the field studies, the plant quality parameters were noted for each sampling point. The NDVI is an indicator of greenness of biomass and the most common method used to monitor vegetation cover. The NDVI is a simple spectral transformation process, which is the ratio of two electromagnetic wavelengths to the sum of differences. The NDVI is computed by $NIR - R/NIR + R$ equation, where NIR is the near infrared light reflected by the vegetation and R refers to the visible red light absorbed by vegetation. The NDVI values vary between (− 1) and (+ 1). Negative values indicate decreased plant density (soil, water, snow cover, etc.) while positive values indicate increased plant density (forest, cultivated land, green pasture, etc.) (Mao et al. 2012).

Plant cover is effective in preventing erosion to the extent that it absorbs the kinetic energy of raindrops and acts as a barrier against wind. The data for plant cover is assessed by in situ observations during soil sampling, classifying CORINE data based on the theoretical vegetation land cover, and NDVI data. In the original MEDALUS method, the lands with plant cover greater than 40% were assigned a score of 1.0 (Kosmas et al. 1999). Due to the specificities of the region's climate and land use, the density of vegetation cover in the Tigris Basin was considered to be very important, and a score of 1.0 was assigned to areas with 75% or more vegetation cover. Therefore, scoring ranges in the original MEDALUS method have been rearranged and presented in Table 4.

Computing the weights of indicators and parameters for ESAI-2

In the original methodology (Kosmas et al. 1999), the classes of parameters were weighted with certain scores between 1.0 and 2.0. Each of the four indexes taken individually is assumed to have equal influence to the final value of the ESAI. When several parameters are being given high scores, an area can only be assigned to a high sensitivity class. This concept does not directly consider the expert opinion into the decision. Therefore, in this study, AHP was used to assign appropriate weights to individual parameters of each indicator and also weights to indicators for final ESAI calculations. The

Table 4 Scoring of parameters included into vegetation quality

Parameter	Class	Description	Score	Data sources
Plant cover (%)[a]	1	> 40	1	Land cover map and field observations
	2	20–40	1.8	
	3	< 20	2	
Plant cover (%)[b]	1	> 75	1	
	2	50–75	1.3	
	3	25–50	1.6	
	4	< 25	2	
Fire risk[c]	1	Bare land; perennial agricultural crops; annual agricultural crops (maize, tobacco, sunflower)	1	
	2	Annual agricultural crops (cereals, grasslands); deciduous oak (mixed); mixed Mediterranean; macchia/evergreen forests	1.3	
	3	Mediterranean macchia	1.6	
	4	pine forests	2	
Erosion protection[c]	1	Mixed Mediterranean macchia/evergreen forests	1	
	2	Mediterranean macchia, pine forests, Permanent grasslands, evergreen perennial crops	1.3	
	3	Deciduous forests	1.6	
	4	Deciduous perennial agricultural crops (almonds, orchards)	1.8	
	5	Annual agricultural crops (cereals), annual grasslands, vines,	2	
Drought resistance[c]		Mixed Mediterranean macchia/evergreen forests, Mediterranean macchia	1	
		Conifers, deciduous, olives	1.2	
		Perennial agricultural trees (vines, almonds, orchard)	1.4	
		Perennial grasslands	1.7	
		Annual agricultural crops, annual grasslands	2	

[a] Scores were used for ESAI-1

[b] Scores were used for ESAI-2

[c] Scores were used for both ESAI-1 and ESAI-2

AHP method also allowed to assign intermediate values which corresponded to a precise interpretation of indicators and parameters. The parameters and indicators, one at each excel sheet were comparatively evaluated by four experts taking into account the impacts on land degradation for the study area (Table 5). Similar to our reasoning for integrating the expert opinion using AHP, Giordano et al. (2003) have also stated that expert judgment who have in-depth knowledge of the land and desertification improves the reliability of results obtained by applying MEDALUS methodology.

In order to create indicator maps of ESA, the layers of soil parameters were superimposed according to their respective weights. The weight of each indicator layer was determined through AHP technique, and final ESAI value for each of

Table 5 The fundamental scale of absolute numbers (Saaty 2008)

Intensity of importance		Explanation
1	Equal importance	2 activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate value	When compromise is needed

sampling point was computed by adding the weighted indicator scores in the modified method (Table 6). On the other hand, the indicator scores and final ESAI values in the original MEDALUS method were obtained by geometric mean values of the parameters' and indicators' scores.

Results and discussions

Descriptive statistics of parameters used in calculation of soil quality index were presented in Table 7. Soil pH ranged from 6.01 to 8.55, EC from 0.16 to 1.08 dS m^{-1}, OM content from 0.42 to 6.44% and AS from 10.56 to 95.50%. The highest coefficient of variation (CV) was occurred for the slope (83.78%) and $CaCO_3$ (83.46%) content. Although the mean $CaCO_3$ content was not very high (10.52%) and in some areas very low (1.07%), it reached to 44.43% depending on the parent material of the soils. Soils were mostly heavy clayey with a mean clay content of 41.8%.

The weights of ESA indicators and parameters of indicators derived by using AHP technique are presented in Table 8. The paired *t* test revealed significant differences ($P < 0.01$) between indicator scores and ESAI values obtained by using original and modified MEDALUS method (Table 9).

The CV is often used to represent the magnitude of variability in for a studied area. Coefficients of variation ranged from 4.2% for management quality index (MQI)-1 and ESAI-1 to 14% for climate quality index (CQI)-2, indicating low variability of all indicators and ESAI values within the study area (Table 9).

Table 6 Components and assessment of environmental sensitive area index

ESAI-1							
$(SQI \times MQI \times VQI \times CQI)^{1/4}$							
SQI-1		MQI-1		VQI-1		CQI-1	
$(S1 \times S2 \times ... \times S6)^{1/6}$		$(M1 \times M2)^{1/2}$		$(V1 \times V2 \times V3 \times V4)^{1/4}$		$(C1 \times C2 \times C3)^{1/3}$	
S1	Parent material[a]	M1	Land use intensity[a]	V1	Plant cover[a]	C1	Rainfall[b]
S2	Soil texture[a]	M2	Policy[a]	V2	Fire risk[a]	C2	Aridity index[b]
S3	Soil depth[b]			V3	Erosion protection[a]	C3	Aspect[a]
S4	Rock fragment[a]			V4	Drought resistance		
S5	Slope gradient[a]	land use intensity = $(\text{cropland} \times \text{pasture} \times \text{natural areas})^{1/3}$					
S6	Drainage[a]						
ESAI-2							
$(SQI \times A_{SQI} + MQI \times A_{MQI} + VQI \times A_{VQI} + CQI{*}A_{CQI})$							
SQI-2		MQI-2		VQI-2		CQI-2	
$(S1 \times A_{S1} + ... + S12 \times A_{S12})$		$(M1 \times A_{M1} + ... + M4 \times A_{M4})$		$(V1 \times A_{V1} + ... + V4 \times A_{V4})$		$(C1 \times A_{C1} + ...\ C3 \times A_{C3})$	
S1	Parent material[a]	M1	Intensity of agricultural land use[a]	V1	Plant cover[d]	C1	Rainfall[b]
S2	Soil texture[d]	M2	Pasture grazing intensity[e]	V2	Fire risk[a]	C2	Aridity index[b]
S3	Soil depth[a]	M3	Population density[g]	V3	Erosion protection[a]	C3	Aspect[d]
S4	Rock fragment[a]	M4	Policy[a]	V4	Drought resistance[a]		
S5	Slope gradient[e]						
S6	Drainage[a]						
S7	Organic matter[c]						
S8	Agr stability[d]						
S9	$CaCO_3$ content[d]						
S10	Soil reaction[d]						
S11	El. conductivity[b]						
S12	Bulk density[f]						

1 Original MEDALUS, *2* Modified MEDALUS, *A* The weight average obtained by AHP for the relevant parameter

[a] Scoring by Kosmas et al. 1999

[b] Bakr et al. 2012

[c] Sepehr et al. 2007

[d] Mutlu 2015

[e] Expert opinion

[f] Andrews et al. 2004

[g] Symeonakis et al. 2016

Table 7 Descriptive statistics of soil properties in study area

Properties	Unit	Min.	Max.	Mean	Std. Dev.	CV	Skew.	Kurt.
Clay	%	12.7	71.8	41.8	13.51	32.34	0.214	−0.511
Sand		9.1	77.1	32.5	14.53	44.77	0.465	−0.083
Silt		5.2	56.6	25.8	9.06	35.11	0.875	1.297
Aggregate stability		10.56	95.50	60.33	17.36	28.78	−0.334	0.170
Organic matter		0.42	6.44	1.94	0.80	41.22	1.722	6.022
$CaCO_3$		1.07	44.43	10.52	8.78	83.46	1.195	1.196
Slope		0.90	52.50	11.00	9.22	83.78	1.996	4.400
pH		6.01	8.55	7.43	0.46	6.13	−0.311	−0.596
Electrical conductivity	dS m^{-1}	0.16	1.08	0.49	0.16	31.82	0.912	2.005
Bulk density	g cm^{-3}	1.06	1.93	1.43	0.18	12.60	0.374	−0.345

Soil quality assessment

Although the mean soil quality index (SQI) values (1.24 for SQI-1 and 1.33 for SQI-2) obtained using both methods indicated somewhat low sensitivity to land degradation, the maximum values of 1.48 (SQI-1) and 1.54 (SQI-2) pointed out the locations with moderate soil quality in the study area (Table 9). The SQI map shows that 100% of the basin area has soils with moderate quality (Fig. 4). The moderate quality of soils in the basin is mainly due to the high slope, fine soil texture making them vulnerable to compaction, high $CaCO_3$ content, and low soil depth, whereas low SQI values which indicate better soil quality are resulted from low $CaCO_3$ content, loamy soil texture, and lower slope. Water erosion is of great concern in large parts of the northern section which is ragged with steep slopes that favor the development of runoff and severe soil erosion (Fig. 4a, b). Therefore, northern section of study area had slightly higher SQI values compared to the rest of the basin (Fig. 5).

The soil depth in majority of northern highlands is moderate or shallow, although large parts, mainly in the southern part, have deep soils. Slightly higher values of SQI-2 compared to SQI-1 are due to high pH (7.5–8.5) and low organic matter content which both were not considered as soil parameters in original method. High bulk density (1.60–1.90 g cm^{-3}) of soils in the south-east part has also contributed to the higher SQI values.

The SQI-2 values highlighted the risky conditions in the center-west, south-east, and north-east part, where the area with a highly moderate soil quality (score range between 1.38 and 1.46, moderate-4) was only 7.78% of the study area (Fig. 5). The SQI of study area showed a higher soil quality when original MEDALUS method was used. However, inclusion of new regionally specific parameters to SQI and weights determined by AHP in modified MEDALUS helped to better define lands susceptible to land degradation in terms of soil quality.

Climate quality assessment

The CQI values were ranged from 1.00 to 1.88 with a mean value of 1.29 indicating moderate conditions (Table 9). The CQI map indicated that high and moderate CQ area occupy 30.7 and 69.3% of the basin, respectively, based on modified MEDALUS. While the coverage of moderate CQ areas was higher according to original MEDALUS method (Table 10 and Fig. 6). The results of both methods indicated that the whole basin is vulnerable due to its low precipitation and high evaporation. The main difference between original and modified methods was shown in the high and moderate III classes, which both indicated higher coverage areas in the study area compared to the original method. Although the same parameters were used in both methods, the differences in weights of indicators caused change in CQI values. Parameter weights were equally shared among rainfall, aridity index, and aspect in original method, whereas the AHP based on experts' opinion showed that aridity index (weight = 0.49) is the most important parameter in the study area followed by rainfall (0.43) and aspect (0.08) (Table 8).

High values of CQI are located on the lowlands in the southwest which indicate vulnerability to degradation due to the mainly the effects of low precipitation (550 mm) and high evaporation (1260 mm). The lands with higher precipitation (> 800 mm) and lower evaporation (< 1000 mm) had lower CQI values, considered as resistant to the degradation, and these areas are mostly located on the northern section of the study area (Fig. 6).

Management quality assessment

The MQ shows the intensity of anthropogenic activity and implementation of agricultural policies to prevent from degradation (Kosmas et al. 1999). The MQI values, based on parameters used, indicated a low quality or high anthropogenic stress on the entire study area (Fig. 7). The MQI values ranged from 1.35 (MQI-1) to 2.0 (MQI-1 and MQI-2) with a mean MQI value of 1.89 (MQI-1) and 1.78 (MQI-2) (Table 9).

Table 8 Weights obtained with analytical hierarchy process (AHP)

Indicators	Parameters	Min.	Max.	Mean	Std Dev.	CV[a]%	Weights[b]
SQI-1	Parent material	1.00	1.70	1.20	0.30	26.80	
	Texture	1.00	2.00	1.40	0.40	26.70	
	Slope	1.00	2.00	1.20	0.20	18.80	
	Rock fragments	1.00	2.00	1.70	0.40	26.30	
	Drainage	1.00	2.00	1.00	0.10	9.60	
	Soil depth	1.00	2.00	1.20	0.20	19.20	
SQI-2	Parent material	1.00	1.70	1.20	0.30	26.80	0.04
	Texture	1.00	2.00	1.50	0.31	20.79	0.11
	Slope	1.00	2.00	1.27	0.20	16.12	0.10
	Rock fragments	1.00	2.00	1.70	0.40	26.30	0.05
	Drainage	1.00	2.00	1.00	0.10	9.60	0.03
	Soil depth	1.00	2.00	1.20	0.20	19.20	0.10
	Aggregate stability	1.00	2.00	1.28	0.24	19.12	0.10
	Bulk density	1.00	2.00	1.53	0.30	19.70	0.08
	Organic matter	1.00	2.00	1.38	0.19	13.91	0.21
	Soil reaction	1.00	2.00	1.14	0.16	13.85	0.11
	Electrical conductivity	1.00	1.00	1.00	0.00	0.00	0.05
	$CaCO_3$ content	1.00	2.00	1.26	0.21	16.42	0.03
CQI-1	Rainfall	1.00	1.50	1.29	0.25	19.20	
	Aridity index	1.00	2.20	1.23	0.19	15.32	
	Aspect	1.00	2.00	1.43	0.50	34.78	
CQI-2	Rainfall	1.00	1.50	1.29	0.25	19.20	0.43
	Aridity index	1.00	2.20	1.23	0.19	15.32	0.49
	Aspect	1.00	2.00	1.66	0.43	25.83	0.08
MQI-1	Land use intensity	1.33	2.00	1.80	0.13	7.29	
	Environmental protection policies	1.00	2.00	1.99	0.08	4.00	
MQI-2	Land use intensity	1.00	2.00	1.59	0.28	17.55	0.31
	Environmental protection policies	1.00	2.00	1.99	0.08	4.00	0.42
	Pasture grazing intensity	1.00	2.00	1.84	0.35	18.97	0.20
	Population density	1.00	2.00	1.18	0.23	19.65	0.07
VQI-1	Fire risk	1.00	1.60	1.28	0.14	10.97	
	Erosion protection	1.30	2.00	1.89	0.19	10.27	
	Drought resistance	1.20	2.00	1.73	0.33	18.91	
	Plant cover	1.00	1.00	1.00	0.00	0.00	
VQI-2	Fire risk	1.00	1.60	1.28	0.14	10.97	0.15
	Erosion protection	1.30	2.00	1.89	0.19	10.27	0.26
	Drought resistance	1.20	2.00	1.73	0.33	18.91	0.18
	Plant cover	1.00	1.60	1.13	0.15	13.27	0.40

[a] Weights computed by AHP, and used in modified method

[b] Coefficient of variation

Extensive areas with low management quality (100%, MQI-1 and 99.9%, MQI-2 of the total) are mainly due to the arable lands used for field crops with intensive conventional practices and degraded pastures. In the original method, only two parameters are used in MQI calculation whereas four parameters are used in the modified method (Table 8). The parameters used in original method equally contributed to final MQI value. However, these two parameters contributed 73% of MQI in original method and rest was contributed by the new parameters. Therefore, slightly lower MQI-2 values resulted from the inclusion of pasture grazing intensity and population density parameters into the analyses of MQ. Mean pasture grazing intensity parameter was 1.84 and the weight used to calculate MQI was 020 which shows 20% contribution of

Table 9 Descriptive statistics of indicators and environmental sensitivity area index (ESAI) values

	Min.	Max.	Mean	Std. Dev	CV	Skew	Weight*	Paired S. T Test
SQI-1	1.08	1.54	1.24	0.09	7.3	0.74	–	0.000
SQI-2	1.16	1.48	1.33	0.07	5.3	− 0.08	0.22	
CQI-1	1.00	1.65	1.29	0.17	13.2	0.49	–	0.800
CQI-2	1.00	1.88	1.29	0.18	14.0	0.07	0.30	
MQI-1	1.35	2.00	1.89	0.08	4.2	− 2.44	–	0.000
MQI-2	1.42	2.00	1.78	0.11	6.2	− 0.43	0.38	
VQI-1	1.22	1.51	1.42	0.10	7.0	− 0.57	–	0.000
VQI-2	1.23	1.73	1.46	0.10	6.8	− 0.27	0.11	
ESAI-1	1.30	1.56	1.44	0.06	4.2	0.04		0.000
ESAI-2	1.29	1.68	1.52	0.08	5.46	−0.41		

1 original MEDALUS method, *2* modified MEDALUS method

*Weights computed by AHP and used in modified method

grazing intensity parameters into the MQI value (Table 8). Dominant land degradation phenomena observed during field studies was water erosion that was mainly linked to grazing as reported in rangelands of south-west Spain (Lavado Contador et al. 2009). Local people graze especially sheep and goats in pastures throughout a year which causes soil compaction and results in reduction of soil porosity and increasing bulk density (Greenwood and McKenzie 2001).

Mean population density score was 1.18 (Table 8) which indicates the low population density in the rural part of the region decreased the pressure on lands. Therefore, low population in rural areas caused to have lower MQI values, while population close to the cities are high due to migration from rural to urban which led to the higher MQI values. Although mean population density score indicated lower pressure on land, low weight (0.07) used to calculate MQI prevented the MQI from being lower. High population in urban areas engenders a significant land use change from agricultural and natural vegetation to urbanized areas (Abu Hammad and Tumeizi 2012). In contrast to the positive effect of low population on management quality in Tigris Basin, partial or complete land abandonment resulted in discernible land degradation in the central part of the Palestinian Mountains (Abu Hammad and Borresen 2006).

Since irrigation facilities in a large part of the region are limited at the moment, single crop is grown in a year that means low pressure on lands and lower MQI values. The lands on the south of Batman Dam are being irrigated and extensively being used for agricultural production. Thus, majority of lands on this part have high MQI values. High employment opportunities in places where agricultural production is intense caused to increase in population density. The anthropogenic activities are the major causes of land degradation, though the availability of parameters is important in accurately assessing the management quality. Abu Hammad and Tumeizi (2012) also indicated the importance of data availability in the assessment of the environmental and socioeconomic causes and consequences of land

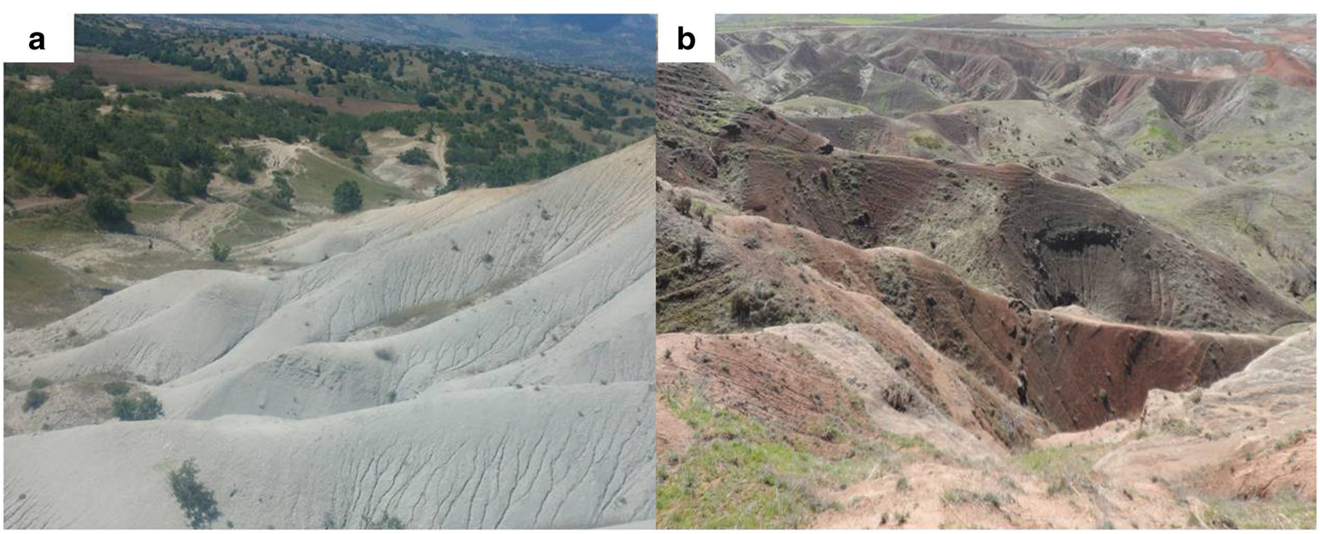

Fig. 4 High slope and severe soil erosion on the northern section of the study area

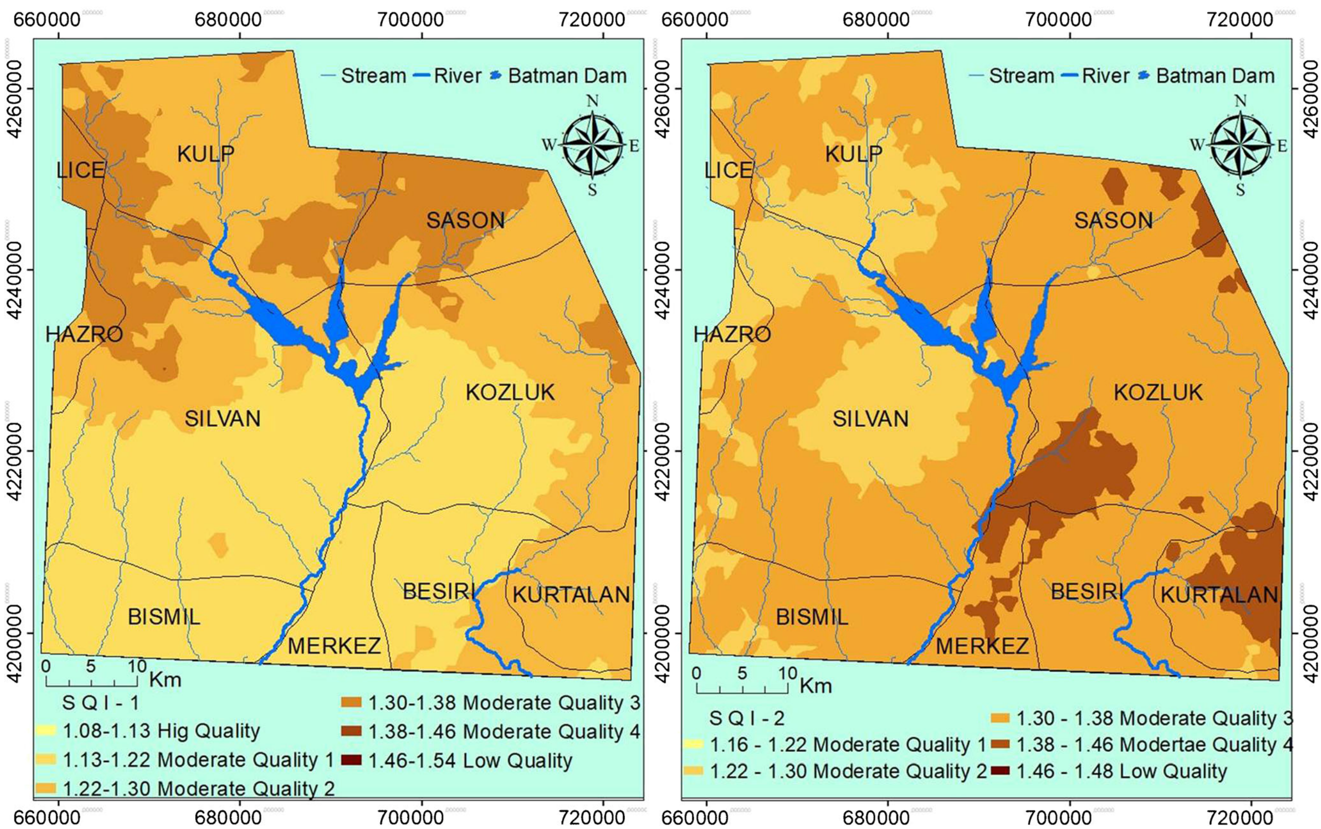

Fig. 5 Spatial distribution of soil quality index (SQI) values within the study area

degradation especially in the Mediterranean countries. Unavailability of reliable data such as pasture grazing intensity and policies restricted to put forward the picture of land degradation.

Vegetation quality assessment

The VQ defines the resilience to climatic changes and the functioning potential to resist to soil erosion (Prăvălie et al. 2017). The same parameters were used in VQI calculation of both original and modified methods. However, the weights used were different and caused slight differences in the final VQI values. Due to the importance of plant cover in VQ of study area, the weight of plant cover was determined as 40% in the modified method (Table 8). The VQI analyses of study area using both MEDALUS methods highlighted the existence of vulnerability to land degradation due to the low and moderate VQ. The original method showed that 33.47% of study area had moderate VQ, while the coverage area for moderate VQ was only 13.46 in the modified method. In the modified method, the areas with low VQ correspond to more than 86% of the entire study area (Figs. 8, 9). The low vegetation quality is related mainly to the extensive annual agricultural crops (cereals), slightly lower vegetation cover, and low drought resistance of lands used for agricultural crops (Fig. 8b). Similar to our finding in Tigris Basin, the areas with low drought resistance due to agricultural production and low percentage of vegetation cover have been mapped as highly sensitive in terms of their vegetation quality in Lesvos Island of Greece (Symeonakis et al. 2016).

Vegetation cover of the study area was assessed by field observations conducted at approximately corners of 5 km × 5 km square grids, NDVI data, and CORINE data base. Additional soil samplings and field observations at 250, 750, and 1750 m distances between two grid corners increased the reliability of data used in VQI calculation. However, in majority of previously published studies, the NDVI (Albalawi and Kumar 2013; Symeonakis et al. 2016) or CORINE data base (Prăvălie et al. 2017) was utilized to obtain regional scale vegetation cover. Low resolution of satellite images used to obtain NDVI or CORINE data restricts the possibility to estimate reliable data for plant cover and land use status. In situ correction of these data may help to overcome the uncertainty degree associated with the low resolution of satellite images.

The fire risk parameter in original MEDALUS method was scored by grouping land covers based on reestablishment potential of vegetation in case of a fire disturbance (Kosmas et al. 1999). Fire potential or possibility of fire is not the main factor of scoring, thus annual agricultural crops, i.e., cereals are given 1.3 score which indicates low tendency to degradation. However, stubble burning, particularly wheat and barley, is a common practice to remove harvest residues in Turkey (Celik et al. 2011) and increased with the second crop production

Table 10 The scores and coverage area (absolute and percentage) of quality indicators and environmentally sensitivity area indexes (ESAI)

Indicator	Class	Quality description	Sub-class description	Score range	Original MEDALUS		Modified MEDALUS	
					Total area (km^2)	Total area (%)	Total area (km^2)	Total area (%)
SQI	1	High		< 1.13	0	0	0	0
	2	Moderate	Moderate 1	1.13–1.22	1649.23	43.95	0	0
			Moderate 2	1.22–1.30	1497.72	39.92	2735.88	72.90
			Moderate 3	1.30–1.38	605.73	16.14	724.75	19.32
			Moderate 4	1.38–1.46	0	0	292.05	7.78
	3	Low		> 1.46	0	0	0	0
CQI	1	High		> 1.15	313.68	8.35	1152.73	30.72
	2	Moderate	Moderate 1	1.15–1.32	2013.97	53.67	602.50	16.06
			Moderate 2	1.32–1.48	1397.65	37.25	1367.14	36.43
			Moderate 3	1.48–1.65	27.38	0.73	621.15	16.55
			Moderate 4	1.65–1.81	0		9.16	0.24
	3	Low		> 1.81	0	0	0	0
MQI	1	High		< 1.25	0	0	0	0
	2	Moderate		1.25–1.50	0	0	2.46	0.07
	3	Low	Low 1	1.50–1.65	13.20	0.35	150.71	4.02
			Low 2	1.65–1.80	243.37	6.49	2252.59	60.02
			Low 3	1.80–1.90	1265.49	33.72	1246.72	33.22
			Low 4	1.90–2.00	2230.62	59.44	100.20	2.67
VQI	1	High		< 1.13	0	0	0	0
	2	Moderate	Moderate 1	1.13–1.30	0	0	0	0
			Moderate 2	1.30–1.38	1255.95	33.47	504.96	13.46
	3	Low	Low 1	1.38–1.44	711.83	18.97	941.19	25.08
			Low 2	1.44–1.51	1784.90	47.56	1379.17	36.75
			Low 3	1.51–1.60	0		927.36	24.71
ESAI	1	Non-affected	N	< 1.17	0	0	0	0
	2	Potential	P	1.17–1.23	0	0	0	0
	3	Fragile	F1	1.23–1.27	0	0	0	0
			F2	1.27–1.33	0	0	0	0
			F3	1.33–1.37	211.99	5.65	18.13	0.29
	4	Critical	C1	1.37–1.42	919.01	24.49	451.72	12.04
			C2	1.42–1.53	2621.68	69.86	1360.79	36.26
			C3	> 1.53	0	0	1929.32	51.41

following the irrigation (Korucu et al. 2009). Although cereal fields are considered as safe in the original MEDALUS method, the fire risk in the wheat and barley grown fields at harvest period should also be taken into account for the degradation due to the potential fire risk.

Environmental sensitivity area index

The analysis of 15 in ESAI-1 and 23 in ESAI-2 biophysical and social-economic parameters and the evaluation of four quality indicators allowed the classification of the study area into two land classes based on ESAI values obtained by each of the method applied. The map given in Fig. 10 shows the distribution of ESAI values within the study area. More than half of the study area presents high ESAI values indicating high sensitivity to land degradation. Only the lands in the northern section dominated by forests and highlands have lower ESAI values representing low degradation risk compared to the southern section of study area.

Land classes and coverage area of each class in original MEDALUS method defined one fragile and two critical areas, whereas one fragile and three critical classes were defined with the modified method. In the ESAI-1, the results showed that fragile areas represent (F3) 5.65% of study area and low-degree critical areas (C1) represent 24.49%, and moderate critical areas (C2) 69.86%, which are needed to be taken into account due to the severe land degradation status (Sepehr et al. 2007; Prăvălie et al. 2017). The areas with low critical desertification are mostly

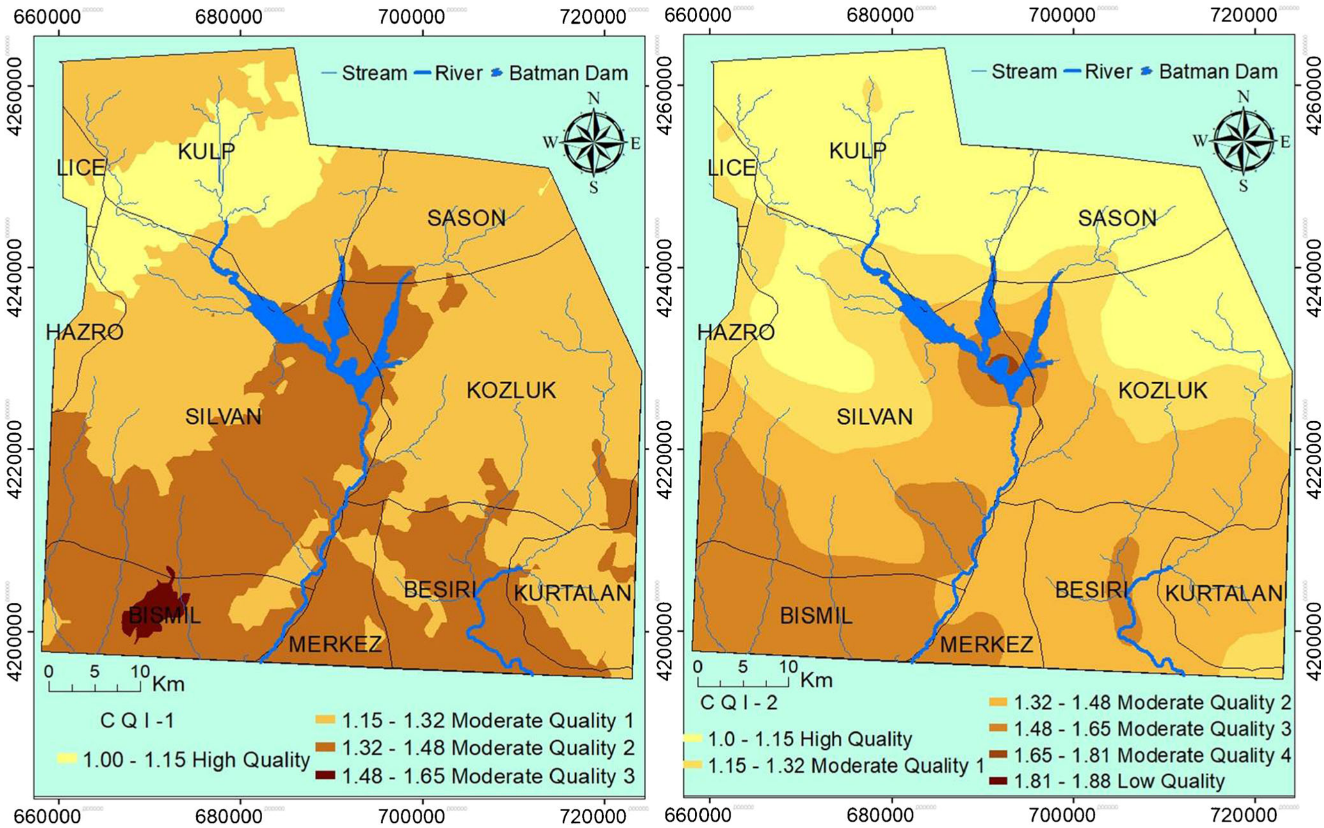

Fig. 6 Spatial distribution of climate quality index (CQI) values within the study area

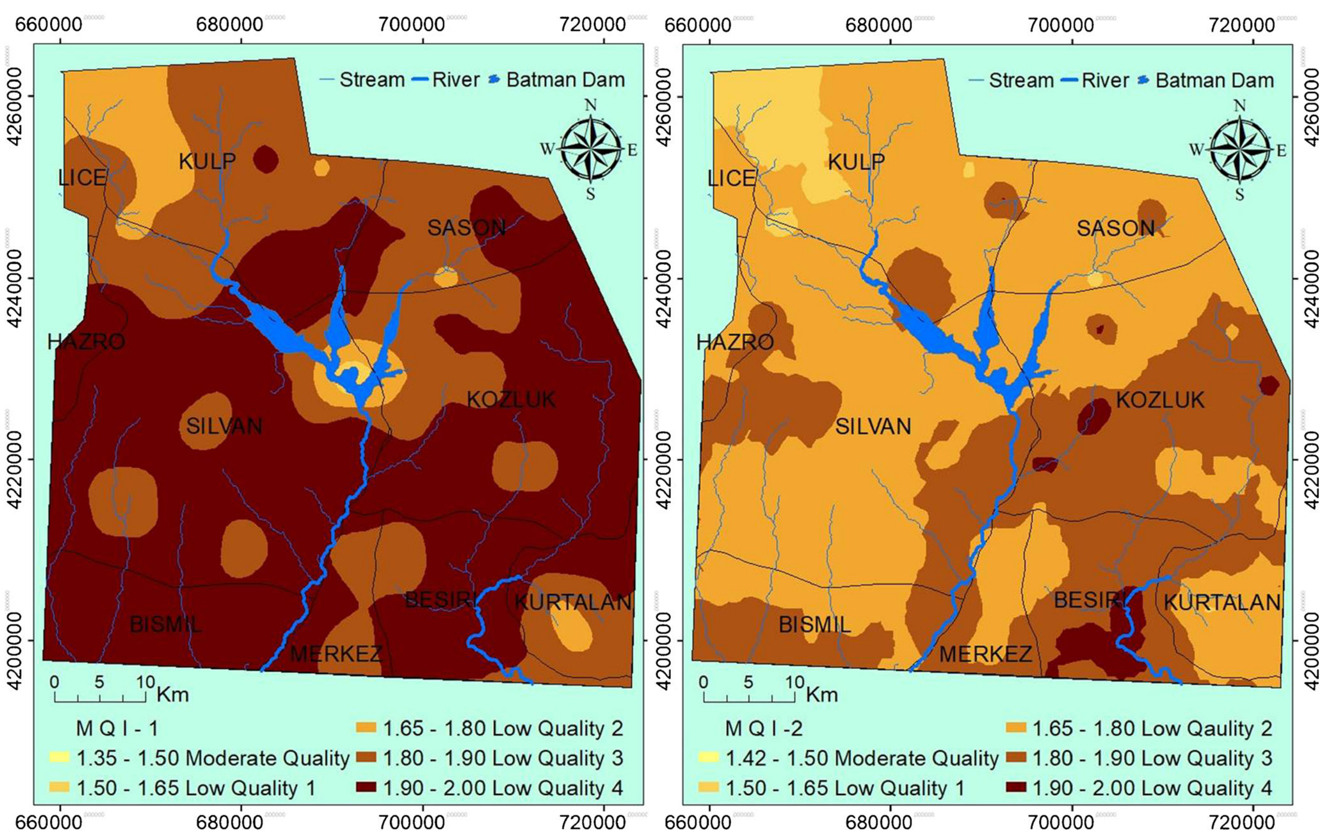

Fig. 7 Spatial distribution of management quality index (MQI) values within the study area

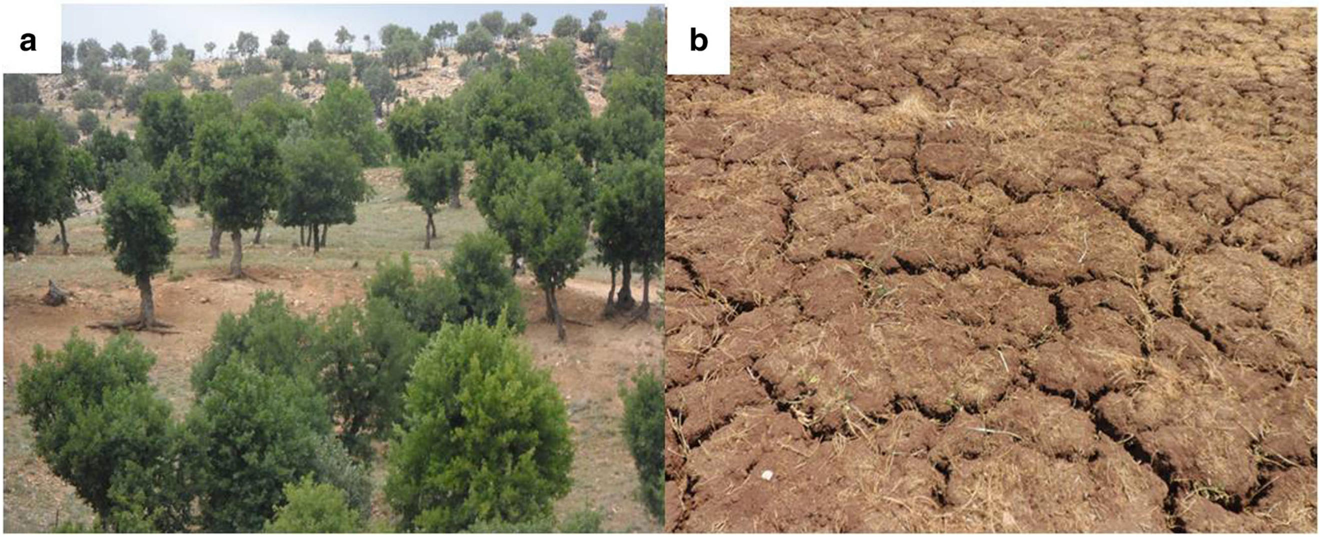

Fig. 8 Low vegetation cover and severe drought resistance in the study area

located in the center and the southern part and areas with moderate critical desertification are located on the northern section.

In the ESAI-2 evaluation, critical areas were divided into three sub-classes, which were C1 with 12.04% coverage area, C2 with 36.26% coverage area, and C3 with 51.41% coverage area. The most critical areas clearly showed up by integrating new parameters and weightages into the calculation of indicator scores and final ESAI-2 value. Almost half of the entire study area is defined with the most critical class (C3, 51.41%), indicates to significant land degradation potential. In contrast to modified method, the most critical areas could not be defined by using the original method. The original method employs equal weight to each of indicator in calculation of final ESAI values, whereas the highest emphasis was given to management quality (38%), followed by climate quality (30%), soil quality (22%), and vegetation quality (11%) (Table 9). The lands prone

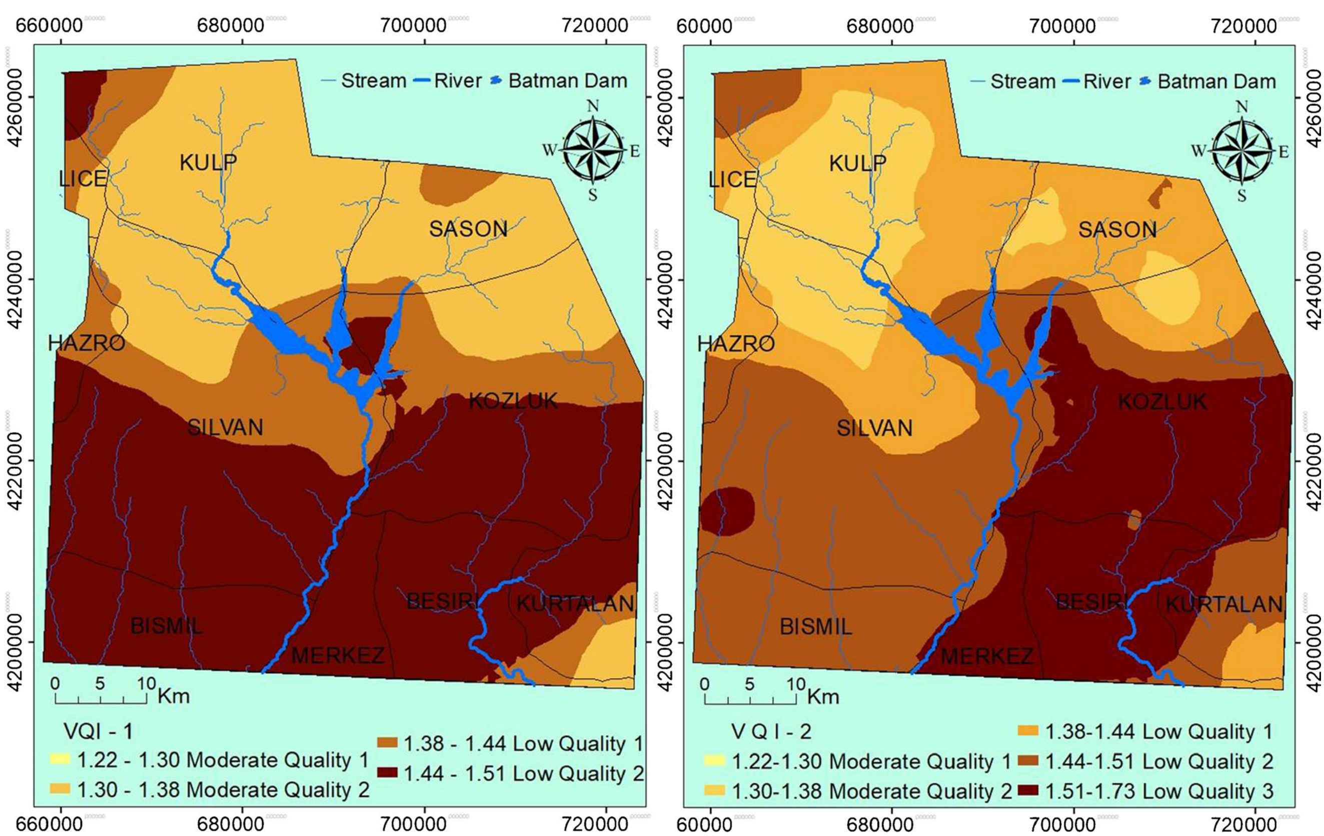

Fig. 9 Spatial distribution of vegetation quality index (VQI) values within the study area

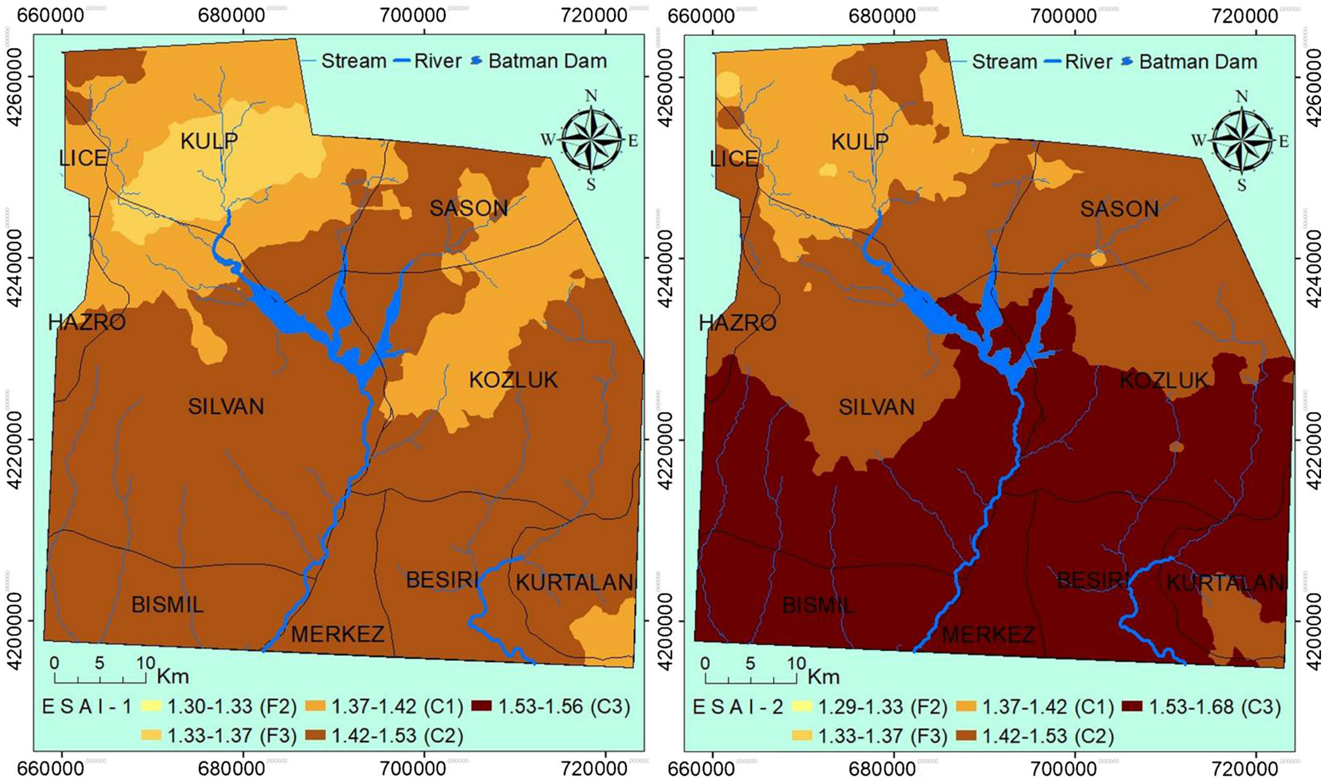

Fig. 10 Spatial distribution of environmental sensitive area index (ESAI) values within the study area

to degradation classified as C3 (ESAI score of > 1.53) are located on the center and entire southern part of the study area (Table 10). The critical areas are primarily used for the production of field crops with extensive conventional tillage practices. These areas had a medium degree of plant cover and very low resistance drought and erosion along with low management quality due to the lack of required environmental protection policies. While minimal land (0.29%) is made up of areas with highly fragile (F3) to desertification. ESAI analyses in both methods showed the non-existence of non-affected, potential, slight and moderate fragile areas within the study area.

Conclusions

Integrating multi natural and anthropogenic factors into MEDALUS methodology made possible to preciously identify the environmentally sensitive areas to desertification in the northern Tigris Basin. The results revealed the pronounced sensitivity of northern Tigris Basin to land degradation. More realistic investigation of lands prone to deterioration was accomplished by adjusting the MEDALUS using new parameters by expert opinion and weights by AHP method to address the environmental conditions and region-specific social structure. The AHP method helped to uncover the most important factors contributing to land degradation. The weights obtained by AHP helped adjust the scores of parameters and indicators into the region of interest. Tillage practices, high grazing intensity, lack of protection policies, and low plant cover are the major causes of land degradation in the study area.

The ESA map provides an overview to environmentally sensitive areas and causes of land degradation. The maps constructed for ESAs to desertification can be used for planning sustainable developmental programs in the Tigris Basin which will be opened to intensive agricultural production in the near future. Necessary actions can be taken for preventive measures to sustain the productivity of natural resources by using the spatial distribution of ESAI and indicator maps. Improved methodology that relies on identification of ESAs by integrating the new parameters, indicators, and adjusting the scores of parameters and indicators by weightages by expert opinions can also be adapted to the areas vulnerable to land degradation in other parts of the world.

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