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Land Sensitivity to Degradation and the Restoration Priorities in the Central Zagros, Iran

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ABSTRACT

Today, land degradation (LD) has become a socio-economic problem in various regions of the world. However, locally effective and up-to-date assessments that account for the LD spatial variability and operational prioritization of areas for restoration at the high-risk protected regions are scant. Given the high risk of LD and low productivity of the Zagros region of Iran, we used the Sheida Protected Region (SPR) as a test case for exploring the potential LD and identifying the restoration priorities to maximize conservation value and finding continued funding to improve the ecosystem resilience. Under the umbrella of the Modified Mediterranean Desertification and Land Use (MMEDALUS) approach, the land sensitivity to degradation was assessed based on five quality indices (soil, climate, physiography, vegetation cover, and land management) in four groups: low (100-120), moderate (121-135), severe (136-153), and very severe (more than 153) in the 16 land components. The Quantitative results showed that mean soil, climate, physiographic, vegetation, and land management quality indices are 140±5, 150±1, 134±4,135±18, and 135±13, respectively. About 43.81% of the SPR falls into the severe condition and other parts of it were categorized in the moderate class. FRAGSTATS software application showed that among the 70 available landscape metrics at the landscape level (Land-unit), 16 landscape metrics had a significant correlation (r>0.46; sig. <0.07) with LDI, emphasizing the high threat of LD in the region. Based on MMEDALUS results and various field visits of the area, appropriate and cost-effective solutions in terms of mechanical, biological, and management operations were proposed.

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1. Introduction

Land degradation (LD) is defined as a negative trend in land conditions caused by direct or indirect natural and anthropogenic processes, expressed as long-term reduction or loss of biological productivity, ecological integrity, or land value to human use (Diouf & Lambin, 2001; Kapalanga, 2008; Eswaran *et al*., 2019). LD is becoming one of the most important environmental hazards all over the world both in terms of intensity and magnitude. So that it affects directly more than 39% of the terrestrial ecosystems (Li *et al*., 2022).

Globally and regionally, several models, indicators, and criteria have been developed to investigate the effective factors, assess, and prepare maps concerning the LD. Each of these models has advantages and disadvantages, which must be modified to use them in other areas (Smiraglia *et al*., 2016). Mediterranean Desertification and Land Use (MEDALUS) is one of the most important projects that were carried out for nine years and in three stages from 1991 to 1999. In this model, four key quality indices of soil, climate, vegetation, and management were defined for LD assessment (Kosmas *et al*., 1999). This model has been highly regarded for evaluating desertification in different parts of the world and associated with positive results. This method has also found special applicability due to having a valuable information base and monitoring LD changes for future planning (Prăvălie *et al*., 2020). So far, this model has been successfully used for multi-criteria and interdisciplinary assessment of lands that have been subjected to degradation in different parts of the world, e.g. Europe (Lavado Contador *et al*., 2009; Salvati and Bajocco, 2011; Ladisa *et al*., 2012; De Paola *et al*., 2013; Salvati *et al*., 2013, Symeonakis *et al*., 2014; Karamesouti *et al*., 2015; Karamesouti *et al*., 2018), Africa (Bakr *et al*., 2012; Mohamed, 2013; Lamqadem *et al*., 2018), South America (Izzo *et al*., 2013; Vieira *et al*., 2015), Middle east (Sepehr *et al*., 2007; Hadeel *et al*., 2010; Hosseini *et al*., 2012; Jafari and Bakhshandehmehr, 2013), and Asia (Han *et al*., 2019; Xu *et al*., 2019; Leman *et al*., 2016). Assessment of land's sensitivity to degradation using the MEDALUS model in different regions has verified that the climate quality (Li *et al*., 2009; Abbasi *et al*., 2014; Kazeminia *et al*., 2017; Arabameri, 2019), soil quality (Yassoglou *et al*., 2000; García-Ruiz, 2010; Honardoust *et al*., 2011), vegetation cover quality (Poornazari *et al*., 2021; García-Ruiz, 2010), and management quality (Li *et al*., 2009) have been key indices of LDI. These results show that LDI can occur in all climatic conditions and its intensity depends on the moisture regime of that region, and the intensity of degradation is greater in dry climates than in humid climates.

Knowing and controlling the factors affecting LD in The Sheida Protected Region (SPR), located in Central Zagros, could play an essential role in mitigation of the soil erosion. Therefore, the objectives of this research include: a) identifying the key factors affecting land sensitivity, and b) providing appropriate implementation strategies to control LD in the Central Zagros rangelands.

2. Materials and methods

2.1. Case Study

Sheida Protection Region (SPR) with an area of 23562 ha is located in the north of Chaharmahal and Bakhtiari province and northwest of Ben City. SPR lies between the longitude of 50° 27´ 12´´ to 50° 43´ 35´´E and the latitude of 32° 32´ 12´´ to 32° 40´ 8´´ N (Fig. 1). The mean altitude of SPR is 2610 m, the highest point with a height of 3160 m is in the center of SPR and the lowest point is located at the northwest of SPR with an altitude of 2059 m. The lands of the region are divided into five physiographic units or land types based on field surveys and soil morphology. Each of the land types of the region according to the class type, profile evolution, formation origin, type and severity of erosion, elevation, soil morphology, land use, rock outcrops, topography, vegetation cover, slope, and geological formations have been separated into one or more land components.

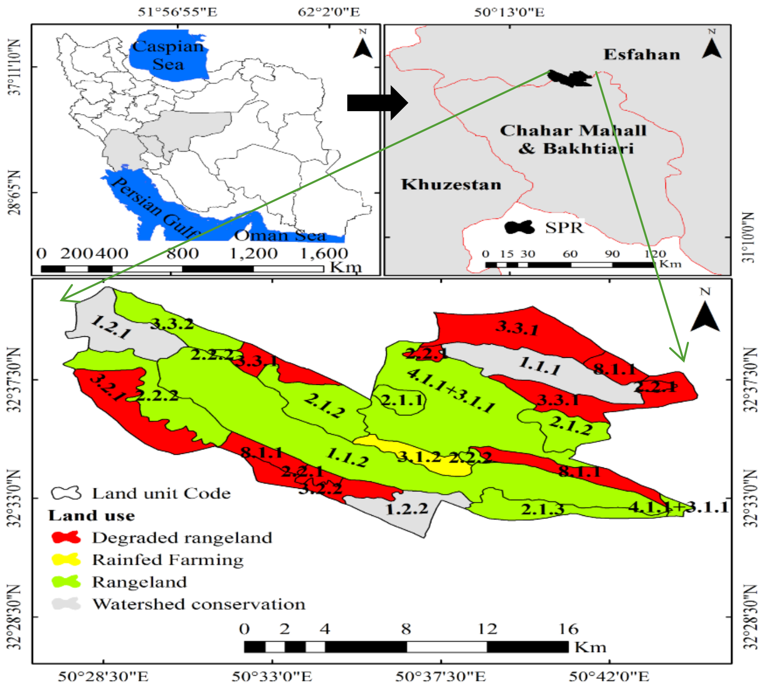


Fig. 1. Geographical location of Sheida Protection Region (SPR).
1: Mountains; 1.1: Mountains with slope and rock more than 75%; 1.2: Mountains with slope and rock between 50 and 75%; 2: Hills; 2.1: Hills with slope (25–50%) and rock (50–75%); 2.2: Hills with slope and rock between 20 and 30%; 3: Upper plateaux or terraces; 3.1: Upper plateaux or terraces with low topography; 3.2: Upper plateaux or terraces with high topography; 3.3: Upper plateaux or terraces with moderate topography and some stone; 8: Gravelly colluvial fans; 8.1: Gravelly colluvial fans with high topography and some stone; 4: Alluvial piedmont plain; 4.1: Alluvial Piedmont plain with low topography and some stone. Structure: vfg, very fine granular; vf, very fine.

2.2. Data Used

Basic information (soil, geology, vegetation, land use, and physiography) was obtained from existing maps (Agricultural Research Center, 2007a,b), field visits, and laboratory studies. The quantitative information obtained from SPR weather stations was also used. The database was analyzed in Excel 2016, IBM SPSS Statistics 26, and ArcGIS 10.8.

2.3. Research Methodology

The MEDALUS model (Kosmas *et al*., 1998) was used to explain the concept of land sensitivity to degradation in a part of the central Zagros rangelands. This model expresses the land's sensitivity to degradation (Kosmas *et al*., 1998) based on climate (annual precipitation, drought, field orientation variables), soil (parental material, slope gradient, drainage, soil depth), vegetation cover (fire risk, erosion protection, drought resistance, plant cover), and land management (annual population growth rate, population density, the road network density, livestock density). Soil formation and degradation varies in different land components according to time, climate, parent material, topography (relief), and organisms. Therefore, in each region, some of these factors play a decisive role in the process of soil formation and degradation. Within the existing conceptual frameworks, effective and various factors can be used to describe the quality indices of land sensitivity to degradation (Ferrara *et al*., 2020; Prăvălie *et al*., 2020; Poornazari *et al*., 2021). According to anecdotal observations and accordingly regional pedology, physiography, meteorology, geology, vegetation, hydrology, social, and economic studies, the factors affecting the land's sensitivity to degradation were identified. Then, according to the literature review and field visits, variables characterizing the soil quality (8 variables), climatic quality (4 variables), physiography quality (4 variables), vegetation quality (3 variables), and land management quality (2 variables) were extracted (Tables 1 and 2) and integrated to MEDALUS and then the modified MEDALUS (MMEDALUS) was developed for SPR.

2.3.1 MMEDALUS Indices

2.3.1.2. Climate Quality Index (CQI)

Among a set of potential climatic variables, precipitation, temperature, and wind are identified as important characteristics of a region that affect the LD of SPR. Precipitation can directly affect water erosion according to its shape and size, intensity and duration, time of occurrence, and time interval of the precipitation event. On the other hand, by supplying the water needs of plants, revivals the vegetation cover. Therefore, climate quality has a great impact on soil characteristics, including soil erosion, organic carbon, soil structure, nutrients, and soil salinity and sodicity (e.g., Kosmas *et al*., 1998; Arabameri *et al*., 2019; Ferrara *et al*., 2020; Prăvălie *et al*., 2020). Precipitation amount, aridity index, rainfall erosivity factor, and wind speed have been used to evaluate climate quality indicator (CQI) (Table 1). The base meteorological information (i.e., precipitation, wind speed, temperature, and evaporation) were collected from the Iranian Meteorological Organization (https://www.irimo.ir/eng/index.php). To calculate the rainfall erosivity factor (R), the monthly and annual rainfall in the study time period was reconstructed in the stations of the studied area. In the next step, using Eq. 1, the Fournier Index (F) and R factor were obtained for all stations (Nalder and Wein, 1998).

$$F = \frac{\sum_{i=1}^{12} {p_i}^2}{\sum_{i=1}^{12} p} \tag{1}$$

Where P_i is the mean monthly precipitation (mm) and p is the mean annual precipitation (mm). R-factor was calculated for areas without enough rainfall intensity data (Renard & Freimund, 1994) by Eq. 2, in which F was calculated for all stations, and by substituting F in Eqs. 2 and 3.

$$R - factor = \frac{0.07397 * F^{1.847}}{17.2} \qquad if: F < 55\,mm \tag{2}$$

$$R - factor = \frac{95.77 - 6.081F + 0.477F^2}{17.2} \qquad if: F \geq 55\,mm \tag{3}$$

The drought index (Eq. 4) was also prepared based on the ratio of precipitation (P) and reference evapotranspiration (ET_o) (Agricultural Research Center, 2007a).

$$AI = \frac{P}{ET_0} \tag{4}$$

2.3.1.1. Soil Quality Index (SQI)

Soil has various functions, including storing water and nutrients, the ability to grow and develop plants, storing carbon, exchanging gases with the atmosphere, and purifying pollutants (García-

Ruiz, 2010). The ability of soils to perform each of these functions is called soil quality. The characteristics affecting soil quality can include a set of physical, chemical, and biological characteristics of the soil or a combination of them. Different soils on the surface of the earth have different quality and as a result, their performance is not the same (Karamesouti *et al*., 2015; 2018).

Table 1. Characterizing the soil and climate quality indices in the MMEDALUS approach.

Soil quality index (Sepehr *et al*., 2007; Bakhshandehmehr *et al*., 2013; Poornazari *et al*., 2021)				Climate quality index (Sepehr *et al*., 2007; Bakhshandehmehr *et al*., 2013; Prăvălie *et al*., 2017; Poornazari *et al*., 2021)			
Variable	Class	Description	Score	Variable	Class	Description	Score
Soil texture	1	L, SCL, SL, LS, CL	100-125	Precipitation (mm)	1	>600	100-135
	2	SC, SiL, SiCL	125-150		2	250-600	135-170
	3	Si, C, SiC	150-175		3	<250	170-200
	4	S	175-200				
Soil structure	1	Granular	100-135	Aridity index	1	>0.65	100-135
	2	Blocky, Prismatic	135-170		2	0.5-0.65	135-170
	3	Platy, Massive	170-200		3	<0.5	170-200
Soil depth (cm)	1	100-150	100-125	Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1})	1	<90	100-135
	2	50-100	125-150		2	90-140	135-170
	3	25-50	150-175		3	>140	170-200
	4	>25	175-200				
Rock fragment (%)	1	<25	100-135	Wind speed (m s^{-1})	1	>2	170-200
	2	25-50	135-170		2	1-2	135-170
	3	>50	170-200		3	<1	100-135
Soil infiltration (cm d^{-1})	1	>12	100-125	L: Loam; Si: Silt; SiL: Silty Loam; SiCL: Silty Clay Loam; SCL: Sand Clay Loam			
	2	6-12	125-150				
	3	0.5-6	150-175				
	4	<0.5	175-200				
Hydrologic Soil Groups (cm h^{-1})	A	>7.5	100-125				
	B	3.8-7.5	125-150				
	C	1.3-3.8	150-175				
	D	<1.3	175-200				
Organic matter (%)	1	>3	100-125				
	2	1-3	125-150				
	3	0.5-1	150-175				
	4	<0.5	175-200				
Soil erodibility (ton ha hr MJ^{-1} ha^{-1} mm^{-1})	K1	0-0.05	100-125				
	K2	0.05-0.1	125-150				
	K3	0.1-0.2	150-175				
	K4	0.2-0.3	175-200				

Soil quality is not a stable feature and changes over time. If one or more soil functions are weakened, serious damage will be done to the surrounding nature. Degradation of the soil indicates its qualitative decline so that the ability of the soil to perform one or more functions is weakened or destroyed. One of the most important functions of soil is to support plant growth. Among the various factors affecting soil degradation, including aggregate breakdown, crusting, surface sealing, compaction, anaerobiosis, infiltration reduction, and soil erosion, which play the most important role in soil degradation. According to this study, SPR includes five land types, including mountains (1), hills (2), upper plateaux or terraces (3), gravelly colluvial fans (8), and alluvial piedmont plain (4), which are divided into 16 land components. SPR has a lot of relief, so more than 54.6% of it is made up of mountains and hills, and its plains are very small and limited to the plains of the mountains. The soils of the region in the mountains and hills include young soils without soil profile development and include the sub-groups of *Lithic Xerorthents* and *Typic Xerorthents*, and in physiographic units 3, 4, and 8 due to more stability in the soil in some parts, characteristic horizons of calcium carbonate and Argillic accumulation are observed. Among the important sub-groups in these lands, we can refer to *Typic Calcixerepts*, *Typic Haploxeralfs*, and *Typic Haploxerepts* (Zandi Baghche-Maryam & Shekaari, 2019). In this research, eight variables (texture, structure, depth, gravel percentage, infiltration, soil hydrological groups, organic matter, and erodibility) were considered and evaluated to assess soil quality (Table 1). Only, two of these variables are represented in the original MEDALUS model (soil texture and soil depth) (Kosmas *et al*., 1998). While, other six variables were added according to the conditions of parent material, relief, and organisms. The score for these variables is determined based on soil studies conducted for the SPR (Agricultural Research Center, 2007b).

2.3.1.4. Vegetation Quality Index (VQI)

Vegetation is the most important factor affecting the land's sensitivity to degradation (Agricultural Research Center, 2007b). Decreasing this factor multiplies the LD, through land use change, overgrazing, and fire occurrence (Arabameri *et al*., 2019). The presence or absence of plant species in a region mainly depends on temperature and moisture content factors. In the current research, three variables of vegetation percentage, erosion protection, and drought resistance were integrated into VQI processing to evaluate the land's sensitivity to degradation. Since the problem of fire in SPR has not been reported as natural and the fires that have occurred were of human origin, this variable was included in the land management quality index. Based on the SPR land use map (Fig. 1), the evaluated variables were scored to determine the VQI of SPR (Table 2).

2.3.1.5. Management Quality Index (MQI)

The main destructive factors and processes of the environment generally include a set of human and natural factors. Humans when performing any action in the environment, systematically have mutual effects on it. In some cases, this set of effects takes place following the human's perception of the environment, without considering the unstable and stable effects. Among the human factors affecting the land's sensitivity to degradation are industrial and mining activities, animal husbandry and agriculture, development of cities and villages, and construction of infrastructures (dam, road). In SPR, there are five mines and they operate almost in a restrained manner from an environmental point of view. Although there are mines in the area, they are not harvested. But in the past, harvesting has been done for several years and has stopped. These mines in the region have many environmental effects. Due to mineral extraction and production of mineral waste, they destroy the landscape and have destructive effects on the environment. Animal husbandry activities, such as the imbalance of livestock with grazing capacity by disturbing and destroying the vegetation of the region, are considered one of the important factors in the LD. Invasion of livestock for grazing and converting low-yielding dry lands into planted rangelands for forage is considered one of the critical factors in disrupting the environmental balance and destroying the environment. The high duration of the livestock grazing period, the density of livestock in the pasture, and the use of pastures outside the grazing season have finally caused the destruction of the pasture ecosystem in SPR and will endanger wildlife feeding. Among the other factors of destruction in SPR is the indiscriminate and unprincipled exploitation of medicinal plants, threatening the shallot medicinal plant extinction.

Table 2. Characterizing the physiography, vegetation, and land management quality indices in the MMEDALUS approach.

Physiography quality index (PQI) (Prăvălie *et al.*, 2020)				Vegetation quality index (VQI) (Sepehr *et al.*, 2007; Bakhshandehmehr *et al.*, 2013)				Management quality index (MQI) (Sepehr *et al.*, 2007; Bakhshandehmehr *et al.*, 2013; Tavares *et al.*, 2014)			
Variable	Class	Description	Score	Variable	Class	Description	Score	Variable	Class	Description	Score
Slope steepness (%)	1	< 6	100-125	Vegetation percentage	1	>50	100-125	Land use intensity	1	Rangeland and watershed conservation	100-125
	2	6-18	125-150		2	35-50	125-150		2	Degraded rangeland	125-150
	3	18-35	150-175		3	10-35	150-175		3	Rainfed farming	150-175
	4	> 35	175-200		4	<10	175-200		4	Bare land	175-200
Slope aspect	1	N, NE, NW, V, flat areas	100-150	Erosion protection	1	Rangeland and watershed conservation	100-125	Policy enforcement	1	Adequate protected	100-125
	2	S, SE, SW, E	150-200		2	Degraded rangeland	125-150		2	Moderate protected	125-150
Plan curvature (radians m^{-1})	1	>0.11	100-135		3	Rainfed farming	150-175		3	Low protected	150-175
	2	-0.61	135-170		4	Bare land	175-200		4	No protected	175-200
	3	<-0.5	170-200	Drought resistance	1	Rangeland and Watershed conservation	100-125				
Profile curvature (radians m^{-1})	1	>0.02	100-135		2	Degraded rangeland	125-150				
	2	-0.41	135-170		3	Rainfed farming	150-175				
	3	<-0.39	170-200		4	Bare land	175-200				

The urban and rural populations along with the increase in per capita consumption (food, water, industrial goods, and car use) play a significant role in the production of waste and sewage in environmental destruction. With water resources consumption and harvesting, on the one hand, the water level is reduced, and on the other hand, wastewater generation plays a big role in polluting water and fields. The construction of infrastructures in natural areas, although it increases prosperity and food resources, by disrupting the structure of the area, it is considered one of the important factors of LD. The existence of communication routes in SPR should be given more attention as one of the factors that cause stress and pressure on wildlife. As much as possible, for more protection and security, cut off the roads that are not needed in the region and build another road outside the SPR area. To obtain the MQI, the same variables of the MEDALUS model (i.e., land use intensity and policy enforcement) have been used (Table 2). Land use intensity values were extracted from the land use map. The score for management policies is based on field visits and socioeconomic studies conducted for SPR (Agricultural Research Center, 2007b). As the MQI increases, it means that management policies and socio-economic conditions are not suitable.

2.3.1.3. Physiographical Quality Index (PQI)

Land physiography, directly and indirectly, is an important factor in land's sensitivity to degradation. The role of this factor can be seen in the influence of the land slope on receiving rainfall and producing runoff. Different characteristics of the slope, such as its degree, length, aspect, and shape, affect the land's sensitivity to degradation. This index is not considered in the MEDALUS model, but in some studies such as Prăvălie *et al*. (2020) has been considered. In general, steep, long, convex, and south-facing slopes are more sensitive to degradation (Agricultural Research Center, 2007a). In this study, according to the topographic conditions of SPR, PQI with four variables slope steepness, slope aspect, plan curvature, and profile curvature (Table 2) were considered (Prăvălie *et al*., 2020). These four variables were obtained using a digital elevation model (DEM) which was prepared for SPR.

2.3.2. Score Assigning and Index Calculating

The scores were assigned based on the impact and power of the relationship that the different variables have with the LD processes. The valid scores range from 100 (the best conditions) to 200 (the worst conditions). Each quality index is estimated as the geometric mean of its own variables. Similarly, the multiplicative aggregation (geomean) of quality indices was used to develop LDI (Eq. 5).

$$I_X = (W_1 \times W_2 \times \ldots \times W_n)^{1/n} \quad (5)$$

where I_X is the score for each quality index (or LDI), w (1, 2, ..., n) is the score for each variable (or quality index) and n is the number of variables (quality indices). Accordingly, four classes to divide the quality indices and LDI values were considered: low (100-120), moderate (121-135), severe (136-153), and very severe (154-200).

2.3.3. Correlation Analysis between LDI and Landscape Metrics

Landscape metrics are frequently applied as critical proxies for LD potential identification and analysis (e.g., Alaei *et al*., 2022; Kumar and Sharma, 2023; Curd *et al*., 2023). In this vein, to strengthen the MEDALUS results for LDI assessment, the landscape metrics were computed using FRAGSTATS (Spatial Pattern Analysis for Program for Quantifying Landscape Structure) (McGarigal and Marks, 1995) and interpreted for the generated land use map. In addition, their correlation was also done using the Pearson test (Pearson, 1986). The results showed that out of 70 available landscape metrics at the landscape level (Land-unit), 16 landscape metrics (Table 3) showed significant correlation at more than 99% confidence level. All formula calculations were adapted from McGarigal (2015).

Table 3. Landscape metrics showed significant correlation with LDI

Symbol*	Landscape metric	Description**	Value range	Units
PD	Patch density	PD equals the number of patches of the corresponding patch type divided by total landscape area (m), multiplied by 10,000 and 100 (to convert to 100 ha). Note: the total landscape area (A) includes any internal background present.	PD > 0, constrained by cell size	Number per 100 ha
AREA_MN	Patch area	AREA MN equals the sum of the areas of all patches in the landscape divided by the total number of patches.	AREA > 0	ha
AREA_AM		"This metric indicated the perimeter of the patch, including internal holes, regardless of whether the perimeter represents true edge or not."	PERIM > 0, without limit	m
AREA_MD		"The measure of patch extent; that is, how far across the landscape a patch extends its reach. All other things equal, the larger the patch, the larger the radius of gyration."	GYRATE ≥ 0, without limit	m
PARA_MN	Perimeter-area ratio	"It is equal to the ratio of perimeter to area."	PARA > 0, without limit	Dimensionless
PARA_AM				
PARA_MD				
CONTIG_MN	Mean contiguity index	"It measures the patch boundary configuration and patch shape equals. In addition, it assesses the spatial connectedness or contiguity."	0 ≦CONTIG_MN≦ 1	Dimensionless
CONTIG_AM				
CONTIG_MD				
ENN_RA	Euclidean nearest neighbor distance	"It is defined using simple Euclidean geometry as the shortest straight-line distance between the focal patch and its nearest neighbor of the same class. "	ENN > 0, without limit	m
ENN_SD				
ENN_CV				
PLADJ	Percentage of like adjacencies	"It is calculated from the adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type) appear side-by-side on the map. PLADJ measures the degree of aggregation of patch types."	0 ≦ PLADJ ≦ 100	-
MESH	Effective mesh size	"MESH equals 1 divided by the total landscape area (m) multiplied by the sum of patch area (m) squared, summed across all patches in the landscape. Note, total landscape area (A) includes any internal background present."	cell size ≦ MESH ≦ total landscape area (A)	ha
AI	Aggregation index	"This metric is computed simply as an area-weighted mean class aggregation index, where each class is weighted by its proportional area in the landscape. The index is scaled to account for the maximum possible number of like adjacencies given any landscape composition"	0 ≦ AI ≦ 100	%

3. Results and discussion

3.2. Climate Quality Index (CQI) Characterization

The quantitative results and spatial distributions of all variables used to characterize the CQI are illustrated in Table 4 and Fig. 2. As can be seen from the results, four variables are given in different units; hence they are not comparable in the given form. To proceed with the final variables, their commensurability was simply confirmed by transforming the datasets into standard divisions.

In SPR, the precipitation regime is such that most of the precipitation occurs in the second half of the year and mostly in the winter season. The seasonal, monthly, and annual distribution of precipitation has a significant effect on the land's sensitivity to degradation. The mean precipitation is 469±7.75 mm, so that the highest (46.3 %) and lowest (1.3 %) precipitation is in winter and summer, respectively. Besides, mean evaporation, aridity index, rainfall erosivity factor, and wind speed were 1463±19.17 mm, 0.32±0.001, 108±3.7 MJ mm ha^{-1} h^{-1} y^{-1} and 0.94±0.04 m s^{-1} respectively. In SPR, the mean daily precipitation is 3.4 mm, and snow is expected on 18 days of the year. Snowfall coefficient values higher than 50% in two months of the year indicate relatively heavy snowfall in the region. The mean minimum monthly temperature of different stations is 19.66 °C and the mean annual temperature is 9.2 °C.

The occurrence of frost from November to April for six months of the year is one of the notable limitations in the region. The dominant wind direction of SPR is the southwest, which has frequencies between 2.5% in January and 20% in April. The climate of the region is considered to be part of the climate of the highlands according to the Ambergris method, which has a cold arid to semi-arid cold climate. The climate of the region has a semi-humid climate based on the Dumarten climate profile.

Table 4. Summary of used variables for CQI assessment of the Sheida Protection Region (SPR).

Land-unit	Rainfall (mm)	Aridity index	Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1})	Wind speed (m s^{-1})	CQI
1.1.1	457.17	0.31	109.28	0.90	151
1.1.2	475.76	0.33	106.17	0.85	148
1.2.1	467.33	0.32	107.70	0.98	151
1.2.2	478.92	0.34	107.13	0.88	148
2.1.1	463.82	0.31	111.43	0.96	151
2.1.2	467.52	0.32	101.64	0.93	149
2.1.3	478.22	0.33	107.87	0.92	149
2.2.1	467.40	0.32	106.46	0.94	150
2.2.2	476.11	0.32	110.06	0.96	150
3.1.2	475.43	0.33	110.98	0.92	150
3.2.1	474.54	0.32	100.04	0.99	149
3.2.2	477.86	0.33	109.44	0.91	149
3.3.1	455.60	0.31	106.49	0.98	151
3.3.2	459.57	0.31	112.51	1.01	152
8.1.1	470.36	0.32	114.53	0.95	151
3.1.1+4.1.1	463.69	0.31	107.24	0.99	151

1: Mountains; 1.1: Mountains with slope and rock more than 75%; 1.2: Mountains with slope and rock between 50 and 75%; 2: Hills; 2.1: Hills with slope (25–50%) and rock (50–75%); 2.2: Hills with slope and rock between 20 and 30%; 3: Upper plateaux or terraces; 3.1: Upper plateaux or terraces with low topography; 3.2: Upper plateaux or terraces with high topography; 3.3: Upper plateaux or terraces with moderate topography and some stone; 8: Gravelly colluvial fans; 8.1: Gravelly colluvial fans with high topography and some stone; 4: Alluvial piedmont plain; 4.1: Alluvial Piedmont plain with low topography and some stone. Structure: vfg, very fine granular; vf, very fine.

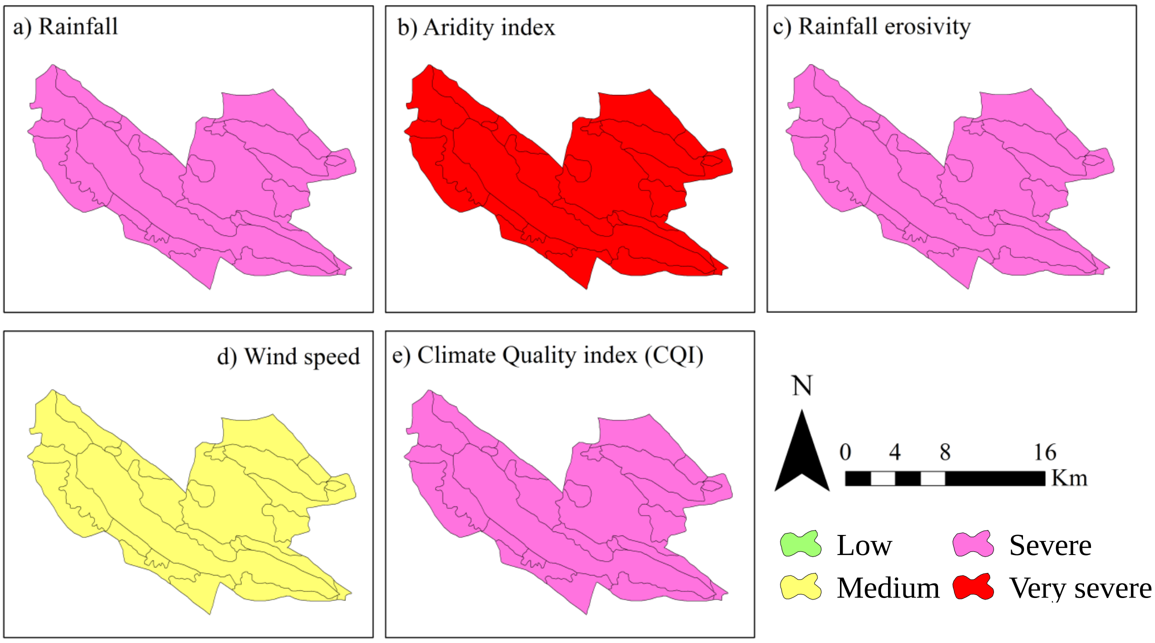


Fig. 2. Land sensitivity to degradation based on climate quality index (CQI) and its variables.

The results of MMEDALUS (Table 4 and Fig. 2) based on the CQI indicate that the entire SPR is in a severe class. Also, three variables of precipitation, aridity index, and rainfall erosivity factor were placed in the severe class and the mean wind speed lies in the medium class. The variability range of the CQI is between 152 and 148, belonging to land-units 1.2.2 and 3.3.2, respectively. MEDALUS application in other regions such as dust hotspots of Southeastern Ahvaz (Poornazari *et al*., 2021) showed a very severe class for CQI. Prăvălie *et al*. (2020) reached similar results in Romania with climatic variables of precipitation, aridity index, rainfall erosivity factor, and wind speed. Bakhshandehmehr *et al*. (2013) stated that evaporation is 20 times higher than precipitation in the study area and it is the main reason for very severe degradation in terms of CQI. The amount of evaporation in this center is reported to be 12 times the amount of precipitation. In addition, Kazeminia *et al*. (2017) reported a very severe situation in terms of CQI for the entire studied area in the west of Ahvaz. They evaluated the climate quality of the region based on the available water for plants, the amount of precipitation, air temperature, and drought of the region. In addition, they stated that the strong winds and the increase in stormy and dusty days were the main cause of the severe degradation of the study area.

3.1. Soil Quality Index (SQI) Characterization

The SPR lies among five types of land, including mountains (1), hills (2), upper plateaux or terraces (3), gravelly colluvial fans (8), and alluvial piedmont plains (4), which are divided into 16 land components. Table 5 shows the factors affecting the SQI including texture, structure, depth, gravel percentage, infiltration, soil hydrological group, organic matter, and erodibility of soil in different land components in SPR. The results showed that more than 80% of the soil texture of the region belongs to the loam group. The structure of the soil in SPR was also observed as fine granular. In different land components in SPR, mean and standard deviation of soil depth, gravel amount, infiltration organic matter content, and soil erodibility are 72±29 cm, 13±12%, 4.8±2.1 cm d^{-1}, 0.87±0.36%, and 0.021 ± 0.014 t ha hr MJ^{-1} ha^{-1} mm^{-1}, respectively. According to the structural geology and the impact of faults and the creation of many rock cracks, these rock units have shown almost different resistances against destruction, erosion, and sedimentation. The presence of marl formations in the region increases the erodibility in its outcrop area and the carbonate-external igneous unit is very sensitive to erosion. In the parts where limestone is exposed, the resistance to erosion is very high, and the presence of marl interlayers reduces permeability. Based on the variables of soil texture (18.69%), soil depth (48.69%), soil organic matter (89.48%), soil infiltration (96.86%), and soil drainage (97%), SPR has severe and very severe sensitivity to degradation (Fig. 3).

Table 5. Results of calculated variables for soil quality index (SQI) assessment.

Land-unit	Area (%)	Texture	Structure	Depth (cm)	Rock Fragment (%)	Infiltration (cm d^{-1})	Soil drainage	Organic matter (%)	Soil erodibility (ton ha hr MJ^{-1} ha^{-1} mm^{-1})	SQI
1.1.1	4.77	L	FG	40.0	27.0	3.1	D	0.52	0.011	144
1.1.2	7.30	SiCL	FG	50.0	8.0	5.4	B	1.34	0.011	134
1.2.1	3.10	L	FG	30.0	30.0	3.6	C	0.52	0.015	141
1.2.2	21.16	L	FG	30.0	30.0	3.6	C	0.52	0.015	141
2.1.1	2.59	L	FG	90.0	10.0	3.0	A	1.08	0.044	125
2.1.2	12.36	SL	FG	50.0	10.0	3.0	B	0.81	0.064	139
2.1.3	5.44	CL	FG	100.0	15.0	3.75	B	0.93	0.023	134
2.2.1	15.26	SiCL	FG	60.0	40.0	3	C	0.93	0.014	136
2.2.2	3.22	SiCL	FG	100.0	2.0	3.585	C	1.72	0.014	128
3.1.2	3.14	SiC	FG	55.0	0.0	11.235	D	1.46	0.009	132
3.2.1	6.11	CL	FG	80.0	2.0	6.5	C	0.79	0.033	133
3.2.2	1.99	C	FG	60.0	5.0	6.35	C	0.51	0.016	137
3.3.1	1.23	C	FG	100.0	2.0	4.735	B	0.52	0.012	138
3.3.2	5.82	SiC	FG	100.0	0.0	3.46	B	0.84	0.015	138
8.1.1	4.99	SiC	FG	120.0	10.0	5.95	B	0.71	0.032	140
3.1.1+4.1.1	1.52	clay	MG	100.0	5.0	6.19	B	0.81	0.017	134

L: Loam; Si: Silt; SiL: Silty Loam; SiCL: Silty Clay Loam; SCL: Sand Clay Loam; FG: fine granular; MG: Moderate granular

1: Mountains; 1.1: Mountains with slope and rock more than 75%; 1.2: Mountains with slope and rock between 50 and 75%; 2: Hills; 2.1: Hills with slope (25–50%) and rock (50–75%); 2.2: Hills with slope and rock between 20 and 30%; 3: Upper plateaux or terraces; 3.1: Upper plateaux or terraces with low topography; 3.2: Upper plateaux or terraces with high topography; 3.3: Upper plateaux or terraces with moderate topography and some stone; 8: Gravelly colluvial fans; 8.1: Gravelly colluvial fans with high topography and some stone; 4: Alluvial piedmont plain; 4.1: Alluvial Piedmont plain with low topography and some stone. Structure: vfg, very fine granular; vf, very fine.

Based on the MMEDALUS method, the results of the SQI showed that SPR has a mean and standard deviation of 140±4.74 (Fig. 3). So, 90 and 10 % of SPR are in severe and moderate degradation, respectively. The land sensitivity to degradation in the physiographic units of upper plateaux or terraces (3), gravelly colluvial fans (8), and alluvial piedmont plain (4) were more than that in the physiographic units of the mountain (1) and hill (2). The most important soil restrictions in land components include water erosion, which exists in all land components in the form of rills, gullies, and landslides. Soil depth, low soil infiltration capability, the presence of stones and gravel are the limitations of these land components, which are observed in most land components. The results of this research are in agreement with the results of other researchers such as Prăvălie *et al.* (2020) and Poornazari *et al.* (2021) who reported the different classes of particularly severe and very severe SQI.

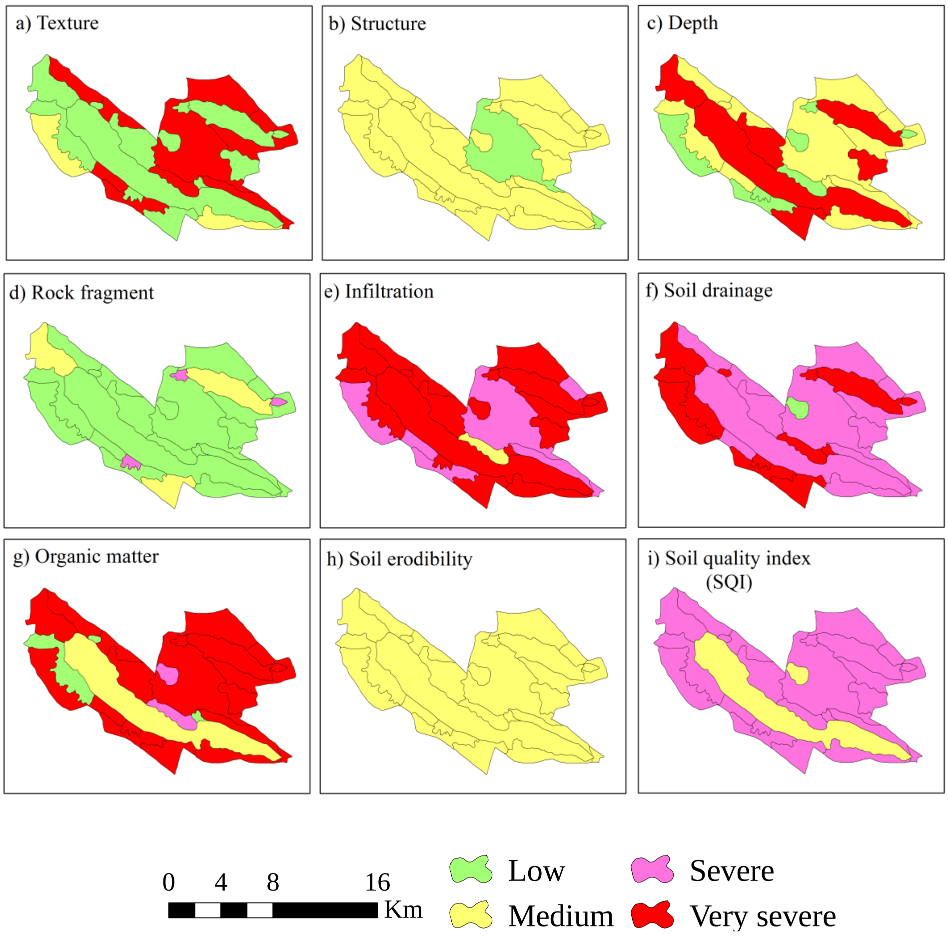


Fig. 3. Land sensitivity to degradation based on soil quality index (SQI) and its variables.

3.3. Physiography Quality Index (PQI) Characterization

The mean scores of the slope steepness, slope aspect, and PQI are 143.6±14.6, 153.7±12.5, and 134.8±4.25, respectively (Table 6). The scoring map (Fig. 4) shows that 74.18 and 91.87% of SPR respectively in terms of slope and aspect have severe and very severe conditions. Furthermore, 48% of SPR has a severe condition in terms of PQI. The presence of igneous and sub-volcanic rocks in some parts of the region has caused the behavior of the rocks to be different against weathering and erosion, and as a result, the relief of the region and its overall morphology is not the same in different parts.

Table 6. Results of the variables used for physiography (PQI), vegetation (VQI), management (MQI), and land degradation index (LDI) assessment.

Land-components	Slope	Aspect	Plan curvature	Profile curvature	PQI	Vegetation cover	VQI	Land use intensity	MQI	LDI
1.1.1	29.45	157.53	0.02521	-0.00284	141.28	5	131	Watershed conservation	122	137
1.1.2	38.63	138.91	0.02194	-0.00022	142.97	20	125	Rangeland	122	133
1.2.1	18.34	193.66	0.01011	-0.00222	138.47	5	131	Watershed conservation	122	136
1.2.2	13.17	171.44	0.00599	0.01508	135.23	5	131	Watershed conservation	122	135
2.1.1	16.79	152.48	0.02597	0.00260	136.50	30	122	Rangeland	130	134
2.1.2	13.15	117.18	0.00573	0.00733	131.65	45	113	Rangeland	130	132
2.1.3	14.31	180.97	0.00150	0.01849	136.03	50	115	Rangeland	130	134
2.2.1	7.19	192.32	0.00297	0.00307	133.55	10	179	Degraded rangeland	147	150
2.2.2	13.04	225.46	0.00863	0.01480	138.49	20	143	Rangeland	130	139
3.1.2	13.23	96.02	-0.00306	0.02438	130.08	40	152	Rainfed Farming	172	148
3.2.1	10.35	221.54	0.00130	0.00317	136.42	3	151	Degraded rangeland	135	142
3.2.2	6.49	237.27	-0.00400	0.00869	135.42	12	147	Degraded rangeland	147	145
3.3.1	7.90	169.37	-0.00054	0.01056	132.44	13	146	Degraded rangeland	147	144
3.3.2	7.23	102.36	-0.00036	0.00706	127.96	50	115	rangeland	130	133
8.1.1	12.34	96.97	0.00139	0.01901	129.97	4	150	Degraded rangeland	147	145
3.1.1+4.1.1	4.80	161.15	-0.00088	0.00688	130.56	40	116	Rangeland	135	134

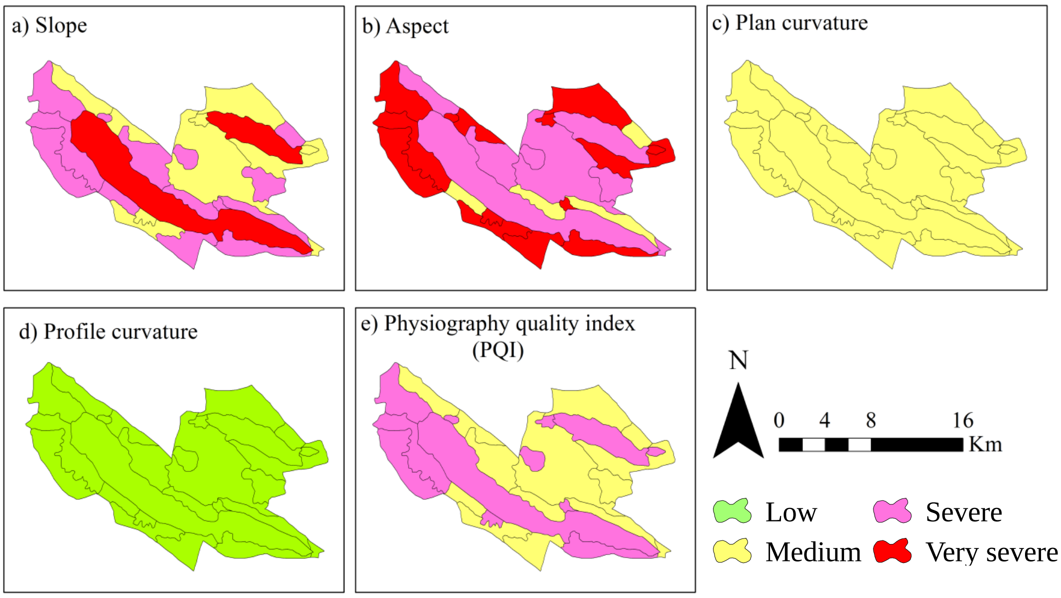


Fig. 4. Land sensitivity to degradation based on physiography quality index (PQI) and its variables.

3.4. Vegetation Quality Index (VQI) Characterization

The land use of SPR (Fig. 1) includes watershed conservation (29.03%), rangeland (38.25%), degraded rangeland (29.58%), and rainfed farming (3.14%). As it can be concluded the dominant land use is rangeland, and part of this rangeland was destroyed due to human activities or changed to dry farming. The vegetation percentage map (Fig. 5a) shows that 69.13% of this region has a very severe condition (159 ± 25). Besides, the results of Table 6 and Fig. 5 showed that 35% of SPR has severe and very severe conditions in terms of VQI. The mean score of VQI throughout different land components was 135±18. The results of the present study are consistent with the results of Tavares *et al*. (2015). They concluded that the vegetation percent is the most important variable in the assessment of regional LDI located in the Cape Verde country in Africa.

Considering the annual precipitation of 466 mm (Table 4), SPR has a good ability to enjoy vegetation in good condition and a positive trend. One of the main limitations and problems of the region is the presence of livestock farmers and the large number of livestock units that graze in the region. The imbalance of livestock with grazing capacity, lack of attention to the exploitation of the area only in the grazing season, and lack of proper monitoring by the executive bodies have caused the pastures to move with a negative trend. According to the conditions of the region and its potential, it is necessary to apply biological plans. Also, special measures and policies should be applied in the study area so that ranchers follow the policies of natural resources, including the time of entry and exit of livestock to pastures and the balancing of livestock with grazing capacity. Considering that it is not possible to reduce the number of livestock in the region, it is necessary to take steps in this direction by applying compatible economic policies. Premature grazing and out-of-season grazing are other important factors in the destruction of SPR pastures. SPR has a high diversity of species and bee-favorite plants such as *Astragalus*, *Apiaceae,* and *Lamiaceae* families grow in SPR. It is possible to boost the beekeeping industry in SPR by revoking a number of livestock grazing licenses and granting them low-interest bank facilities. In this case, financial poverty will disappear and the people of SPR will be encouraged to preserve natural resources.

In SPR, the vegetation and young seedlings that are not yet fully established are uprooted and the plants cannot set their seeds on the ground for next year's growth. To solve this problem, it is necessary to specify the time of exploitation of the grazing carefully and not to allow the livestock farmers to import livestock before the appointed time. Unauthorized plowing and conversion of rangelands to rainfed agriculture in the past years have destroyed the vegetation of these areas. As a result, these lands cannot restore themselves naturally without restoration plans. Therefore, by planting medicinal plants (such as *Allium stipitatum, Rheum family,* and *Apiaceae*) in SPR, it could be used as a seed production station with the aim of reviving the area and even similar other regions.

The existence of limitations such as human activities and conflicts, including the development of villages around the region, the development of production industrial units, the number of livestock exceeding the grazing capacity, and excessive grazing in the pasture ecosystem caused protection practices cannot be applied more widely and comprehensively in SPR. Moreover, the existence of grazing projects that have already been assigned by the General Administration of Natural Resources and the existence of mines owned by the Organization of Industries and Mines in the region are considered other conflicts in the region.

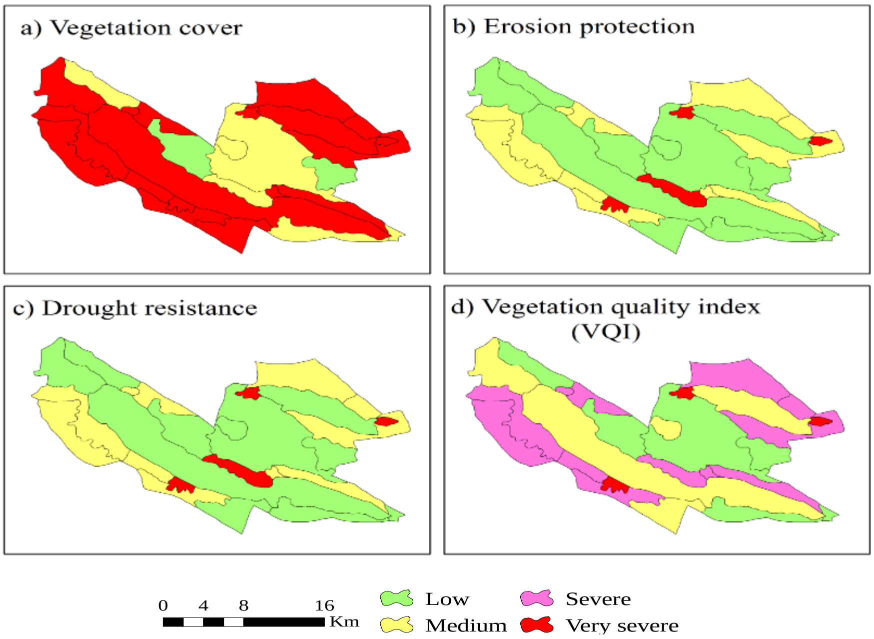


Fig. 5. Land sensitivity to degradation based on vegetation quality index (VQI) and its variables.

3.5. Management Quality Index (MQI) Characterization

Land management and conservation are supported by the people when the need for natural resources such as water, soil, and vegetation protection is felt by the people themselves. The mean scores of land use intensity, management policies, and MQI are 127.18±13.28, 144.37±15.47, and 135.43±13.57, respectively. The results of Table 6 and Fig. 6 show that 32.72% of SPR has a severe or very severe condition in terms of MQI. Considering the geographical location and the protection history of the region, the conservation of soil and water has a suitable background. Our anecdotal observations showed that the most important social and economic factors that can have a destructive effect on the degradation of SPR include insufficient knowledge of people in the field of natural resources, lack of inclination and interest of people in natural resource protection projects, youth unemployment, a high number of livestock and property disputes.

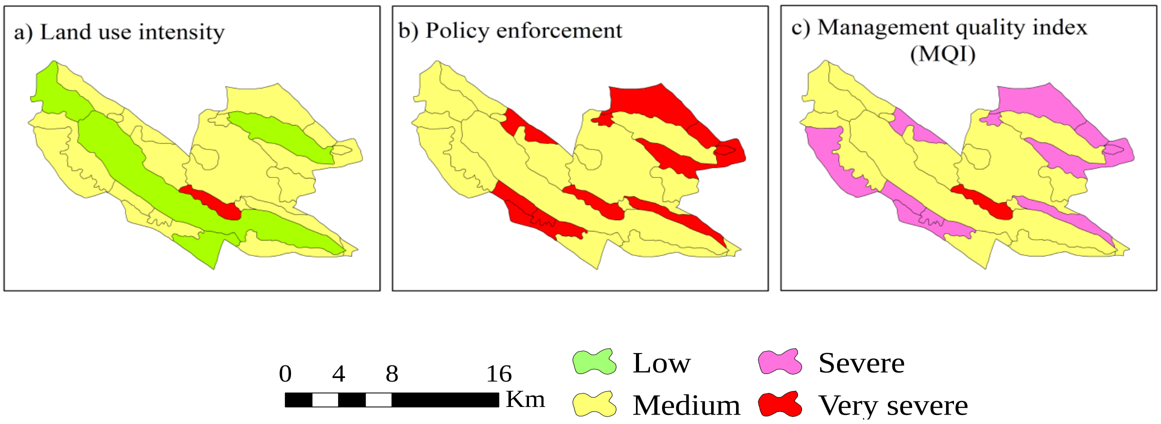


Fig. 6. Land sensitivity to degradation based on land management index (MQI) and its variables.

3.6. Land Degradation Index (LDI) Characterization

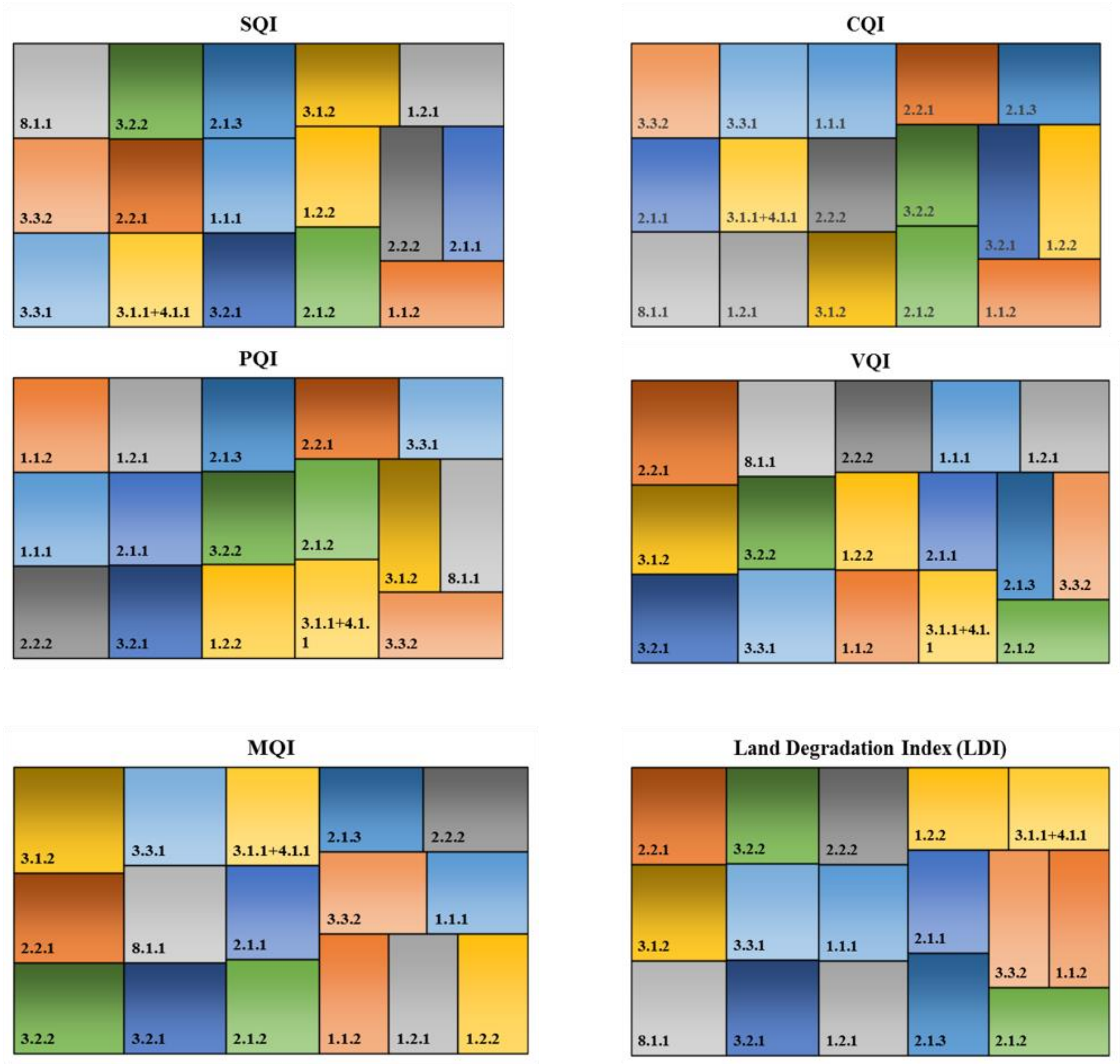
By calculating the effective factors in LD and drawing a map of LD based on each index, these layers were combined and the final map of LD was obtained. The descriptive results obtained from the LD assessment for SPR based on the MMEDALUS method are shown in Table 7 and Fig. 7. The result of the geometric mean of the study indices and their influence in the LDI assessment showed that SPR with a mean score of 138.80±5.94 is in the moderate and severe classes. So only about 43.81% of SPR is in severe condition and 56.19% were categorized in moderate class. In addition, comparing the quality of climatic indicators (2±150), soil (4.74±140), management (135.43±13.57), physiography (134.8±4.25), and vegetation (135±18) show that in SPR, human and natural factors play almost the same role in land sensitivity to degradation.

The results of Sepehr *et al*. (2007), which evaluated LD for the Fidoye-Garmusht plain in the south of Iran using the MEDALUS method, are consistent with this study. Their results showed that the vegetation variable had the greatest role than soil, climate, erosion, underground water, and land management. Besides, about 93% of the area sensitive to desertification has been identified. Bakhshandehmehr *et al*. (2012) also reported the highest score for CQI with a score of 195 and MQI with a score of 164 in Segzai plain of Isfahan. They evaluated 63% of the region in the very severe class, 35% in the severe class, and only 2% of the entire region in the moderate class. Tavares *et al*. (2015) assessed the degradation condition of 50% of the study area located in Africa as critical using the MEDALUS. Although they reported significant spatial variability among different classes of LDI and based on all the investigated indices. According to the analysis done in SPR, the MEDALUS approach can be generalized in determining the LD intensity in areas similar to the study area, which is consistent with the findings of other researchers (Bakhshandehmehr *et al*., 2012; Momirović *et al*., 2019). The MEDALUS method is superior to other LD evaluation methods by considering appropriate and relatively sufficient indicators in arid and semi-arid regions, as well as due to the simplicity of application and weighting. The natural factors affecting the Land’s sensitivity to degradation in SPR include soil erosion, steep slope, shallow soil with rocks, high outcrops, low infiltration, and hardpan.

Table 7. Correlation between landscape metrics and LDI.

Landscape metric	PD	AREA_MN	AREA_AM	AREA_MD	PARA_MN	PARA_AM	PARA_MD	CONTIG_MN	CONTIG_AM	CONTIG_MD	ENN_RA	ENN_SD	ENN_CV	PLADJ	MESH	AI
Correlation coefficient	0.61*	-0.61*	-0.46**	-0.60*	0.63*	0.72*	0.60*	-0.63*	-0.71*	-0.60*	0.53**	0.53**	0.53**	-0.72*	-0.47**	-0.65*
Sig. (2-tailed)	0.01	0.01	0.07	0..01	0.01	0.00	0.01	0.01	0.00	0.01	0..03	0.03	0.04	0.00	0.07	0.01

Note: *and ** represent significant correlations at the 0.01 and 0.05 levels, respectively



The size of the square from large to small indicates the values of the indices from high to low and the numbers inside the squares indicate the number of land components.

Fig. 7. Variation of land degradation indicators in the Sheida Protection Region (SPR).

3.7. Linkage between LDI and Landscape Metrics

Using Pearson's correlation coefficient (r), highly significant relationships were displayed between LDI and landscape metrics values (Table 8). Nine landscape metrics out of 16 cases exhibited significant negative correlations across case study land-units, with correlation coefficient (r) ranging from 0.464 to 0.72. Seven landscape metrics including PD, PARA_MN, PARA_AM, PARA_MD, ENN_RA, ENN_SD, and ENN_CV had significant positive correlations with LDI. In this vein, Ghosh *et al*. (2012) used landscape metrics to investigate the changes in Himalayan Foothills. The landscape metrics analysis verified the strong deforestation and urbanization. They also found increasing PD and ENN during the deforestation period. The ENN quantifies the patch isolation and is classified into an Isolation/ proximity group of landscape metrics (Matsushita *et al*., 2006; Ghosh *et al*., 2012). Similar findings were reported for a semi-arid watershed in northwestern Iran by Alaei *et al*. (2022) indicating the LD with increasing PD, and decreasing AREA–MN as landscape configuration metrics. AI and MESH defining a contagion/ interspersion state of a given land had correlation coefficients (r) of -0.464 and -0.649, respectively. Besides, the correlation coefficient between LDI and CONTIG-based metrics which defined the shape of a landscape ranges from -0.599 to -0.707 (Table 8). In addition, in line with our results, Shi *et al*. (2013) referred to AI as one of the primary metrics controlling soil erosion and sediment yield as the main indicators of LD in China. A close relationship was obtained between soil erosion, sediment yield, and land cover patterns.

Table 8. Correlation coefficient of landscape parameters with LDI.

Landscape metric	PD	AREA_MN	AREA_AM	AREA_MD	PARA_MN	PARA_AM	PARA_MD	CONTIG_MN	CONTIG_AM	CONTIG_MD	ENN_RA	ENN_SD	ENN_CV	PLADJ	MESH	AI
Correlation coefficient	0.61*	-0.61*	-0.46**	-0.60*	0.63*	0.72*	0.60*	-0.63*	-0.71*	-0.60*	0.53**	0.53**	0.53**	-0.72*	-0.47**	-0.65*
Sig. (2-tailed)	0.01	0.01	0.07	0..01	0.01	0.00	0.01	0.01	0.00	0.01	0..03	0.03	0.04	0.00	0.07	0.01

Note: * and ** represent significant correlations at the 0.01 and 0.05 levels, respectively.

3.8. Land Limitation and Potential Executive Solutions for SPR

Fig. 8 shows the most important limitations of each land component, which causes land degradation and landslides. According to the structural geological situation of the region, the faults effect, the creation of many cracks in the rocks of the region, and the transformation phenomenon that occurred, these rock units show almost different resistances against degradation, erosion, and sedimentation.

Fig. 8c shows the implementation solutions for restoration in each of the land components. These solutions include biological operations, biomechanical, and managerial operations. Biomechanical measures include range survey methods, balancing livestock with grazing capacity, control of entry and exit of livestock, grazing systems, supplying the drinking water for livestock, improving vegetation composition with sowing, planting, pit-seeding, fertilization, and long-term enclosure, the increase of forage by converting low-yielding dry lands into planted rangelands, improving the livelihood of local communities by exploiting rangelands sub-products, pitting, farrowing with seeding, and agroforestry.

Management solutions include a set of methods that only have strategic aspects and are intended to facilitate the implementation of biotechnical and mechanical educational solutions in the project. Management solutions are divided into four fields of financial management, supervisory management, executive management, and strategic management. Financial management brings the plan to its final goal through financing. Executive management includes a part of management that plays the main role in the executive operations of the plan. In other words, there are a number of executive solutions that still require the supervision of government management, and due to the economic structure and social and cultural conditions of the community, non-governmental sectors are not able to manage it. Supervisory management requires only the control and supervision of the public administration department over the private sector. Strategic management deals only with providing standards, laws, and documents to achieve comprehensive management. In other words, it is necessary to direct the different parts of the plan in line with the overall goal of the plan, and this is only possible through strategic management.

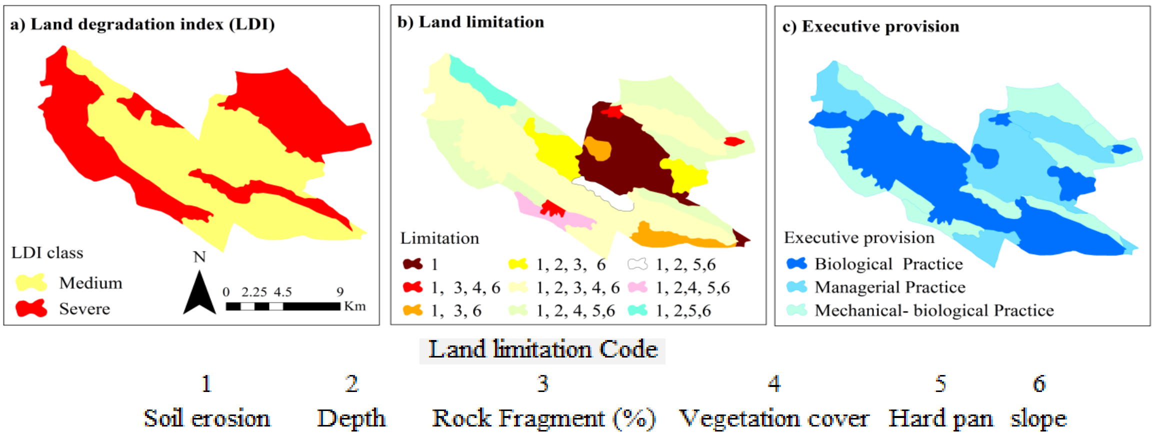


Fig. 8. Land degradation index (LDI) (a), existing land limitation (b), and potential executive solutions (c) for Sheida Protection Region (SPR).

4. Conclusion

Land-degradation information and mapping play a central role in planning effective ecosystem-restoration strategies by offering clear snapshots of current conditions and guiding informed, systematic actions for the future. In this study, the MMEDALUS indicator-based framework was adapted to the specific environmental characteristics of the Sheida Protected Region (SPR), integrating soil, climate, physiography, vegetation, and land-management factors across 16 land components. The findings indicate that approximately 43.81% of the SPR—primarily plateau-type units—falls within the "severe" land-degradation class (LDI 136–153). Accordingly, a set of targeted conservation and management measures was proposed to support urgent restoration and prevent further degradation. Given the prominent role of human activities in driving land degradation, it is crucial to actively involve all relevant stakeholders—including local communities, landowners, policymakers, and conservation authorities—through participatory platforms that encourage dialogue, knowledge sharing, and collaborative decision-making. Such engagement should be reinforced by well-designed outreach, education, and extension programs that raise awareness of sustainable land-management practices, highlight the ecological and socio-economic consequences of degradation, and provide practical guidance for restoration initiatives. Establishing these inclusive and informed frameworks before implementing any management or operational interventions ensures that proposed actions are context-sensitive, widely supported, and more likely to achieve long-term ecological and social sustainability.

Author Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Ethical considerations

The authors confirm that data were collected, analyzed, and reported honestly, without fabrication, falsification, or misrepresentation.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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