Assessing Environmental Sensitivity Areas to Desertification in North of Iran

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ABSTRACT

The sensitivity map to desertification of Chehel-chai basin (North of Iran) has been elaborated by the crossing of fives criteria including climate, water erosion, soil, vegetation, and management, which have the main impact on the evolutionary process of desertification. The methodology is resulted from the desertification model of MEDALUS, which use qualitative index to define the land sensitive area to desertification. According to the factorial scaling technique, score-ranging from 1(good condition) to 2(deteriorated condition) is assigned to each indicator. Each index was assessed based on selected indicators, which resulted in qualitative mapping of each index based on geometric average of the indicators. Thematic databases, with a 1:50000 scale resolution, were integrated and elaborated in GIS software based on arc view3.2, Ilwis3.1 and ArcGIS9.3. The obtained results indicate that 39.39% of Chehel-chai basin is highly sensitive to desertification, 2.13 % has moderate sensitivity, only 2.43% has low sensitivity and 56.05% is non-sensitive. Studying the mean weight of numerical value, it is distinguished that the intensity of desertification for the total area is 1.32 which is classified as fragile (2).

Key words: MEDALUS; ESAs; Desertification; Criteria; Index; Iran.

INTRODUCTION

Defined as the change of fertile and productive lands into non-productive desert areas, desertification remains as a major environmental concern in most arid, semiarid, and sub-humid areas of the world (Dregne, 1977; UNCCD, 1994; Herrmann & Hutchinson, 2005). Desertification may results from various natural and human-associated factors such as wind or/and water erosion, destruction of vegetation covers and water resources, water logging, soil salinization and alkalization, etc. (Kassas, 1977; Mainguet, 1994; Blum, 1998; Krishan *et al.*, 2009). Among these factors, unsustainable human activities, such as urbanization, overgrazing, over-cultivation, poorly drained irrigation systems, deforestation, etc. are currently considered as the most important factors accelerating the process of desertification (Barbero-Sierra *et al.*, 2013; Bo *et al.*, 2013). In addition to these direct effects, human activities may also indirectly contribute to desertification, for example through affecting environmental factors such as climate (Kassas, 1977; Khosravi, 2004).

The United Nations Convention to Combat Desertification (UNCCD), which is the only internationally legally organization, offers strategies to combat desertification and mitigate the effects of drought through national action programs that incorporate long-term strategies supported by international cooperation and partnership arrangements. Several models have been developed and a large number of studies have been carried out to assess the risk of desertification in different areas most of which are specialized to particular geographic areas (Santinia *et al*., 2010). To develop these models to local areas of interest, it is necessary to re-investigate and adjust them to local environments (Geeson *et al*., 2002).

During the last decades, many areas of Iran have been subjected to intense desertification because of drought, unsustainable land use, and increasing pressures on land and water resources (Amiraslani & Dragovich, 2011). In this study, we used the Mediterranean Desertification and Land Use (MEDALUS) project to assess and map desertification sensitivity in a watershed located at north of Iran. In this project, the focus is primarily on Mediterranean environments where physical loss of soil by water erosion, and the associated loss of soil nutrient status are identified as the dominant problem (Brandt & Thornes, 1996; Geeson *et al*., 2002; Arar *et al*., 2009). The MEDALUS project is a popular GIS-based technique which computes an index, such as the Environmentally Sensitive Areas (ESAs) index containing several environmental (e.g. climate, soil vegetation) and anthropogenic (e.g. management) parameters (Kosmas *et al*., 1999). The indicators selected to evaluate the sensitivity to desertification can provide an overview for evolution of ecosystems and environments, which can be applied as efficient tools for decision-making and planning (Basso *et al*. 2000). Results of this study would provide a map of desertification sensitivity exhibiting the area of degraded land, process type, dominant indicator involved, and intensity classes of desertification.

MATERIALS AND METHODS

Study area

The Chehel-chai River is one of the largest branches of the Gorganrood River located at Golestan province, northeastern part of Iran. This river drains an area of about 250 km^2 across geographic coordinates ranging from 55°23´ E to 55°38´ E and from 36°59´ N to 37°13´ N (Figure 1).

The elevation of this watershed ranges from 190 to 2570 m (a.s.l) and the mean slope is 45.82%. Limestone formations, alluvial deposits near the streams and quaternary sedimentary formations, loess, dominate the underlying geology in the lowlands of the study area. The region has a Mediterranean climate with warm and dry summers and temperate and rainy winters. Falling occurs mainly in winter and spring with the mean annual precipitation is about 750 mm. Therefore, the river

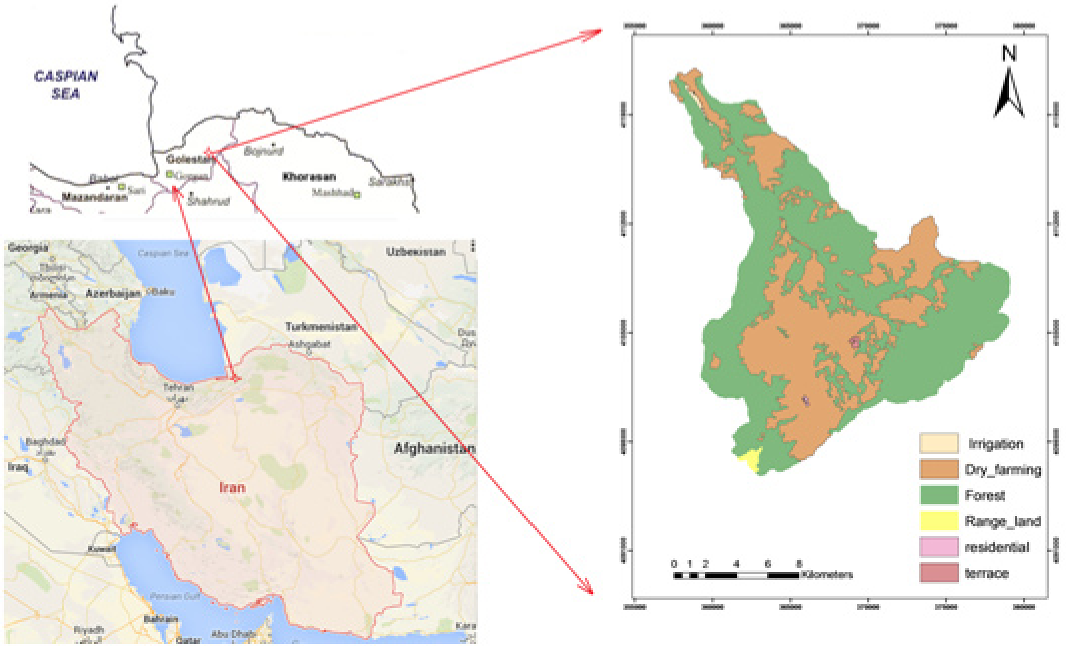

Fig. 1: The location of Chehel-chai watershed

has a relatively high discharge during winter and spring, but low during summer and autumn. Forests (60%) and croplands (40%) are predominant land uses in the watershed (Figure 2).

METHODOLOGY

We used the MEDALUS methodology, with slight modifications, to map vulnerable areas to desertification using means of environment-state and response indices (Geeson *et al*., 2002, Kosmas *et al*., 1999). This methodology has been presented as a manual of key indicators of desertification and mapping environmentally sensitive area to desertification (Kosmas *et al*., 1999).

Based on their applicability and susceptibility to environmental processes, the risk of desertification in Chehel-Chai watershed was evaluated on a regional scale by defining levels on the basis of some parameters or indices of five categories including climate, vegetation, soil, water erosion, and management trough field investigations and spatial data. Each parameter was weighted in relation to its impact and contribution to desertification process.

All data required for this method were elicited from previous studies or calculated or collected from field samplings (Table 1). These data were then introduced to GIS system to calculate required indices and visualize a desertification map for the study region (Rafiei Emam, 2003).

To establish the relative scale of severity, those threshold values with critical conditions were selected to normalize outputs, and the results were then weighted using lands in the study area (Al-Adamat *et al*., 2003). Finally, a single index obtained via integrating all of these indices was selected as a representative of the desertification risk in the study area.

Five general indices (Quality indices) were considered by the model each containing various parameters (indicators) (Table 1). To calculate the individual indices, detailed studies were conducted on hydrologic, geomorphologic, erosion, and soil and vegetation cover characteristics of the region. The detailed information of the individual indicators and their scores has been summarized in Tables 2, 3, 4, 5, and 6.

For each index, a score ranging between 1, as good condition, and 2, as deteriorated condition, was assigned based on factorial scaling technique. Additionally, A zero value was assigned when the measure was not appropriate for an area or where that area was not classified. In most cases, a linear function ranging from 1 to 2 (extreme values) represents the variation of the indicators (score).

Fig. 2: The view of the Chehel-chai watershed

Although in some particular cases, a non-linear variation is possible. The value of quality index for each elementary unit within a layer was obtained as geometric average of scores of single indices according to the following formula:

$$\text{Index} - X = [(\text{Layer} - 1) \times (\text{Layer} - 2) \dots (\text{Layer} - n)]^{1/n}$$

Where Index-X is a given index, Layer is the indicators of each index and N is the number of indicators for each index.

The five quality indices were computed using ArcGIS software v. 9.3 as the geometric mean of the indicators related to each single index. The importance of each index in desertification was determined using the following formula:

- Water Erosion Index (WaEI) = (Erosion critical limit × Water erosion risk)$^{1/2}$

Table 1: Desertification indicators and quality indices used in ESAs model for visualization of the Chehel-chai desertification status map

Quality Indices		Indicators	Source
WaEI		Water erosion risk Critical limit Erosion	Published data and field sampling
VQI		Vegetation cover Drought resistance Protection against soil erosion Fire risk	Land use map 1/50000 scale, Landsat TM data, Multi-temporal Classification
SQI		Soil properties* Drainage Slope gradient Soil depth Rock fragments Parent Material Soil texture	published data at various scales for soils and geology and 100m control lines, digital evaluation map (DEM), field sampling
CQI		Aspect	Digital Evaluation Map (DEM)
		Aridity index**	Transeau ratio (P/ETP)
		Annual rainfall	Data published by Meteorological stations
MQI	Agriculture	Sloping agricultural land Principles of Agriculture Use of unsuitable Agricultural machinery and chemical pesticides Irrigation methods	Multi-temporal classification, landsat TM data, Field sampling, Land use map 1/50000 scale
	Management & Policy	Measures needed Desertification methods Operations performed public participation	Published data at various scales, field sampling
		Economic risk	Socioeconomic data and field sampling
		intensity land-use	Multi-temporal Classification, Landsat TM data, Land use map 1/50000 scale

* Nitrogen (N), Phosphate (P), and Potassium (K) content

** Defined as the means of Transeau ratio (P-ETP) where P is the average annual rainfall (mm) and ETP is the average annual potential evapotranspiration (mm)

- Vegetation Quality Index (VQI) = (Vegetation cover × Fire risk × protection against soil erosion × Drought resistance)$^{1/4}$
- Soil Quality Index (SQI) = (Soil texture × Rock fragments × Soil depth × Drainage × Slope × Parent Material × Soil properties)$^{1/7}$
- Climate Quality Index (CQI) = (Annual rainfall × Aspect × Aridity index)$^{1/3}$
- Management Quality Index (MQI) = (managerial policies × agriculture × land use intensity × economic risk)$^{1/3}$

The maps of abovementioned indicators were obtained based on modified model and a final desertification map was provided by multiplying the prepared maps. Here, the value of each index was

Table 2: Classes and corresponding weight assigned for calculation of the water erosion index (WaEI)

	WaEI			
Critical limit Erosion	**4-5.5**	**3.9 -2.5**	**8.5-6.1**	**6- 5.6**
Scores	1.21 – 1.5	1.2 - 1	1.8 - 2	1.8 –1.51
Water erosion risk	Lower limit (normal)		Higher limit (risk)	
Scores	1		2	

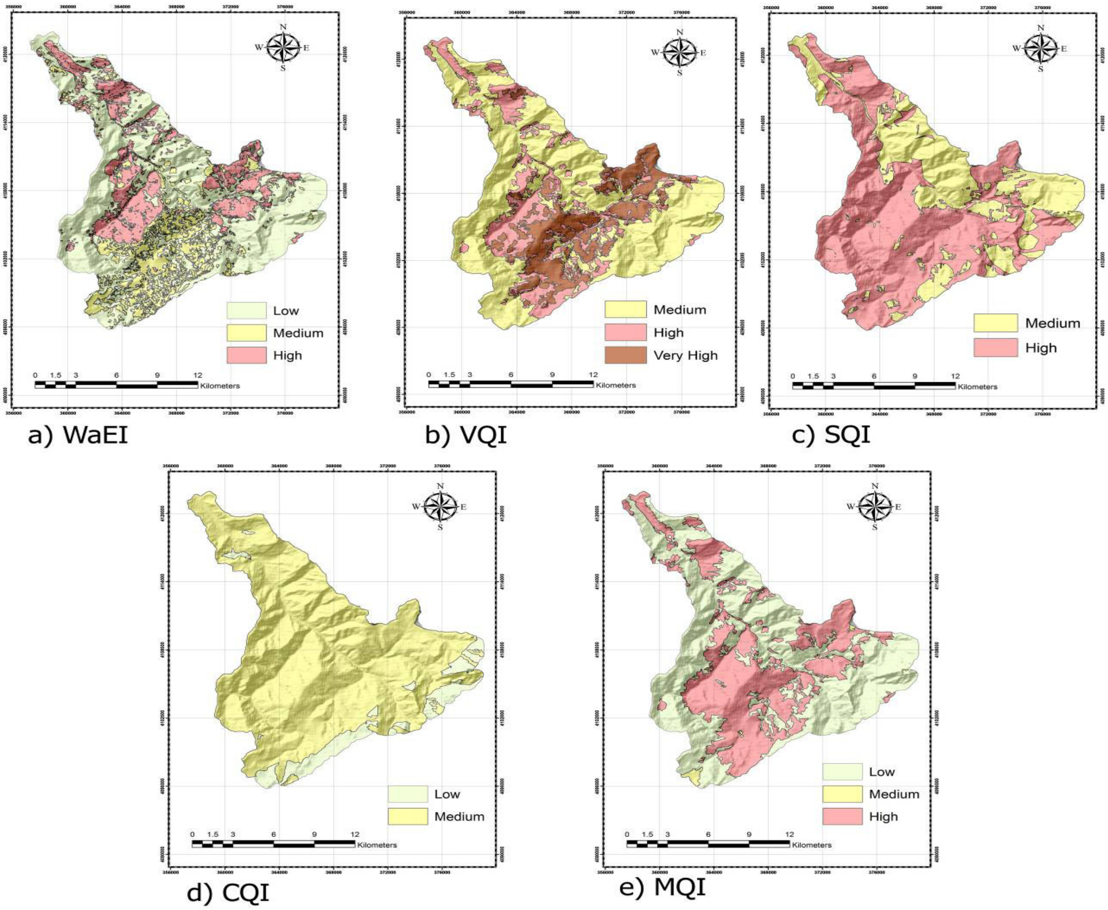

Fig. 3: Maps of water erosion index (a), vegetation quality index (b), soil quality index (c), climate quality index (d) and management quality index (e)

Table 3: Classes and corresponding weights assigned for calculation of the vegetation quality index (VQI)

Vegetation	**40%>**	**40%-10%**		**10%<**	
Score	**1.33-1**	**1.66-1.34**		**2-1.67**	
Fire risk	Evergreen forest (except conifers), Mixed Mediterranean Macchia, Bedrocks	Mediterranean Macchia, Conifer forests, Perennial grasslands, Pastures, Shrublands	Deciduous forests (oak)	Almonds, Orchards	Vines, Horticulture, Annual crops, Rangelands, Low vegetated and bare soils
Scores	1.24 - 1	1.49 – 1.25	1.74 –1.5	1.84 –1.75	2 – 1.85
Protection against soil erosion	Soils, exposed rocks and very low vegetated, Permanent agriculture (olive, vines, orchard), Croplands	Cereals, Grassland, Deciduous (oak,mixed); Mixed Mediterranean Macchia	Mediterranean Macchia	Conifer	
Scores	1.24 - 1	1.49 – 1.25	1.74 –1.5	2 – 1.75	
Drought resistance	Evergreen forest (except conifers), Mediterranean Macchia, Mixed Mediterranean Macchia, Bedrocks, Bare soils	Conifer forests, Deciduous forests, Olives	Almonds, Orchards, Vines	Perennial grasslands, Pastures, Shrublands	Annual crops, Horticulture, Very low vegetated
Scores	1.24 - 1	1.49 – 1.25	1.74 –1.5	1.84 –1.75	2 – 1.85

Table 4: Classes and corresponding weight assigned for calculation of soil quality index (SQI)

Soil texture	SC - SiC	L – SCL – SiCL- SiL	LS – SL	S – C > %60
Scores	1.24 -1	1.49 – 1.25	1.74 – 1.5	2 – 1.75
Rock fragments	20%<	20%-60%	60%>	
Scores	1.33 - 1	1.66 – 1.34	2 – 1.67	
Soil depth (cm)	<75	75 – 31	30 – 15	15<
Scores	1.24 - 1	1.49 – 1.25	1.74– 1.5	2 – 1.75
Drainage	Well drained	Average drained	Imperfectly	Poor drained
Scores	1.24 - 1	1.49 – 1.25	1.74 – 1.5	2 – 1.75
Slope gradient	>%6	18% -6%	35% – 18%	<35%
Scores	1.24 - 1	1.49 – 1.25	1.74 – 1.5	2 – 1.75
Parent Material	Shale, schist, basic, ultra basic, conglomerates, unconsolidated, clays, marl (with natural veg)	Limestone, marble, granite, rhyolite, ignibrite, gneiss, siltstone, sandstone, dolomyte	Marl, Pyroclastics	
Scores	1.24 - 1	1.69 – 1.25	2– 1.70	

N (%)	0.35>	0.29 – 0.35	0.19 – 0.3	0.2-0.14	0.15- 0.03
P (%)	16>	12 - 16	8 - 12	4 - 8	0.4 - 4
K (%)	350>	299-350	249-300	199-250	96-200
Scores	1– 1.24	1.49– 1.25	1.74– 1.5	1.84 – 1.75	2– 1.85

Table 5: Classes and corresponding weight assigned for the calculation of the climate quality index

Annual rainfall	**280 mm>**			**650 – 280 mm**			**650 mm<**
Scores	**2–1.67**			**1.66–1.34**		**1.33– 1**	
Aspect	S	SE - SW	E	NE	W	NW	N
Scores	2	1.85	1.7	1.6	1.4	1.2	1
Aridity index (P/ETP)	0.05>	0.2 – 0.05	0.45– 0.19	0.65– 0.44	0.65<		
Scores	2 – 1.80	1.79 – 1.60	1.59– 1.40	1.39– 1.20	1.19- 1		

Table 6: Classes and corresponding weight assigned to calculate of management quality index (MQI)

Management & Policy						
Measures needed	<75	75-50	50-25	>25		
Desertification methods	Desert greening is done automatically by using proper management	Desert greening is possible only via mechanical and biological practices or is moderately costly	Desert greening is possible only via mechanical and biological practices or is very costly	Desert greening is very difficult and impossible, unexplainable ecologically and economically		
Operations performed	no desert greening practices has been needed	desert greening practices has been successful	desert greening practices has been relatively successful	desert greening practices has not been successful		
public participation	Proper cooperation between local groups and experts	Disregarding of local groups to expertise practices	Implementing expertise practice regardless of local groups	Conflict between local groups and experts		
Scores	1.24 - 1	1.49–1.25	1.74 – 1.5	2 – 1.75		
Agriculture						
Principles of Agriculture	Farming principles is applied properly. Garden and perennial farming	Farming principles is applied relatively. perennial farming	Inappropriate Farming principles. Improper farming periodicity with fallows shorter than 6 months	Farming principles is not applied. without farming periodicity, very intense plowing and fallows longer than 6 months		
Use of unsuitable agricultural machinery and chemical pesticides	Use of modern machinery with proper efficiency and normative usage. Toxins and fertilizers are not applied	Use of new machinery with almost proper efficiency and normative usage. use of fertilizer and toxins properly	Use of depreciatory machinery with almost very low efficiency and Non-normative usage. Non-normative use of toxins	Use of depreciatory machinery with very low efficiency and Non-normative usage. Non-normative use of toxins		
Irrigation methods	irrigation methods appropriate for the region	irrigation methods relatively appropriate for the region	irrigation methods relatively appropriate for the region	Inappropriate irrigation methods		
Sloping agricultural land	Forest, Dry farming with slope 6%>, Terrace	Grassland, Irrigated with slope %6>, Dry farming with slope %6-18	Irrigated with slope 6%-18, Dry farming with slope %18-35	Irrigated with slope %18>, Dry farming with slope %35>		
Scores	1.24 - 1	1.49–1.25	1.74 – 1.5	2– 1.75		
Land use						
Land use intensity	Forest	Terrace	Dry farming	Irrigated	Grassland	Barren
Scores	1	1.2	1.4	1.5	1.6	2

calculated from geometric mean of its indicators. Finally, the desertification intensity was determined by calculating the geometric average of the five indices as follow:

$$DM = WaEI \times VQI \times SQI \times CQI \times MQI)^{1/5}$$

Where DM is desertification mapping and the other abbreviations are the same as the above five formula.

The intensity ranges of desertification sensitivity for each class have been shown in Table 8.

In order to better clarify the boundaries between each fragile and critical classes, they were divided by three sub-groups ranging from 1 as low sensitivity to 2 as high sensitivity.

RESULTS

The maps of sensitivity to desertification of different indices, provided by the ESAs model, have been shown in Figure 3.

The geometric average and qualitative classes of indicators of each index have been also summarized in Tables 9 and10.

Analysis of desertification indices in Chehel-chai basin showed that soil quality index was the major problem of desertification in the study area with a geometric average of 1.57, which shows very high desertification class. The vegetation quantity index with a weighted average of 1.53 was the second major factor underlying desertification in the studied area.

Table 7: Quantitative scores and qualitative classes of five major indices

Scores	2 (high)	1.5 (moderate)	1 (low)	
WaEI -Classes	>1.6	1.6-1.3	1.3>	
Scores	2 (high)	1.6(moderate)	1.3 (low)	1(non-threatened)
VQI -Classes	1.75<	1.74 - 1.5	1.49-1.25	1.24>
Scores	2 (high)	1.5 (moderate)	1 (low)	
Classes-SQI	1.46<	1.13-1.45	1.13>	
Scores	2 (high)	1.5 (moderate)	1 (low)	
Classes-CQI	1.81<	1.15-1.80	1.15>	
Scores	2 (high)	1.6 (moderate)	1.3 (low)	1 (non-threatened)
Classes-MQI	1.75<	1.74 - 1.5	1.49-1.25	1.24<

Table 8: Desertification sensitivity classification of ESAs on Present condition

Range of values	Symbol	Qualitative classification Desertification sensitivity
1-1.17	N	non-threatened
1.18-1.22	P	Potential
1.23-1.26	F1	Fragile (1)
1.27-1.32	F2	Fragile (2)
1.33-137	F3	Fragile (3)
1.38-1.41	C1	Critical (1)
1.42-1.53	C2	Critical (2)
1.53-2	C3	Critical (3)

Based on five studied indices, the assessment of frequency distribution classes in terms of desertification risk for current statues showed that mean weight of quantitative values was 1.32 for all study area compared to ESAs table (Table 9) implying that this area has a desertification class of fragile (class 2) (Figure 4).

In addition, the result showed that 56.05% of the area fits into “absent class” of no sign of desertification. 2.43% of the region was allocated in low class, which means that land degradation has some little effect on it. This area should be considered as a sensitive area. 2.43% of the region was allocated in the medium class where desertification has obvious effects. Finally, 39.39% of the region was allocated to high classes of desertification. These areas, mainly located in the south and southwestern part of the region, are critically sensitive to desertification (Figure 5).

DISCUSSION

In this study, we used the MEDALUS method to assess risk of desertification in Chehel-Chai watershed. The ESAs model is very advantageous and user-friendly model for determination of different classes of vulnerable areas to desertification (Arar

Table 9: Geometric average and class of indicators related to each index.

WaEI

Indicator	Score	Class
critical limit Erosion	1.62	High
[illegible]	[illegible]	[illegible]

VQI

Indicator	Score	Class
Vegetation cover (%)	1.5	Moderate
Fire risk	1.8	High
protection against soil erosion	1.25	Moderate

SQI

Indicator	Score	Class
Soil texture	1.45	Moderate
Rock fragments)%(	1.3	Low
Soil depth)cm(	1.26	Moderate
Drainage	1.45	Moderate
Slope gradient)%(	1.42	Moderate
Parent Material	1.81	High

CQI

Indicator	Score	Class
Annual rainfall	1.25	Low
Aspect	1.57	Moderate

MQI

Indices	Sub-indicators	score	class
Management & Policy	Measures needed	2	Extremely High
	Desertification methods	1.4	Moderate
	Operations performed	1.2	Low
	public participation	1.7	High
Agriculture	Principles of Agriculture	1.27	Moderate
	use of unsuitable agricultural machinery and chemical pesticides	1.35	Moderate
	irrigation methods	1.25	Moderate

et al. 2009; Brandt & Thornes 1996). This model has been frequently proposed to be more helpful than other methods because of its accuracy, particular weighting of layers, use of geographical information systems in overlaying of maps, use of geometric mean instead of arithmetic one or sum to compute indices and representation of the final desertification map (Brandt & Thornes 1996; Basso *et al*. 2000).

This Chehel-Chai watershed is believed to be exposed to high rates of desertification, such that more than 57% of the total surface had an ESAs value of more than 1.5. This has been attributed to a combination of factors including land weakening and degradation as a result of unprincipled human activities, low qualities of vegetation surfaces, and low quality soils. The low-quality vegetation surfaces occur predominately in southern part of the region, but move upward to northern parts representing ongoing decline of vegetation in the study area. Factors such as growing population, environmental pollutions, forest fire, exploitation of natural lands

Table 10: Geometric averages of the quantitative values and qualitative classes of indices

Class	Scores	Index
Moderate	1.46	WaEI
High	1.57	SQI
Moderate	1.32	CQI
High	1.53	VQI
Moderate	1.48	MQI

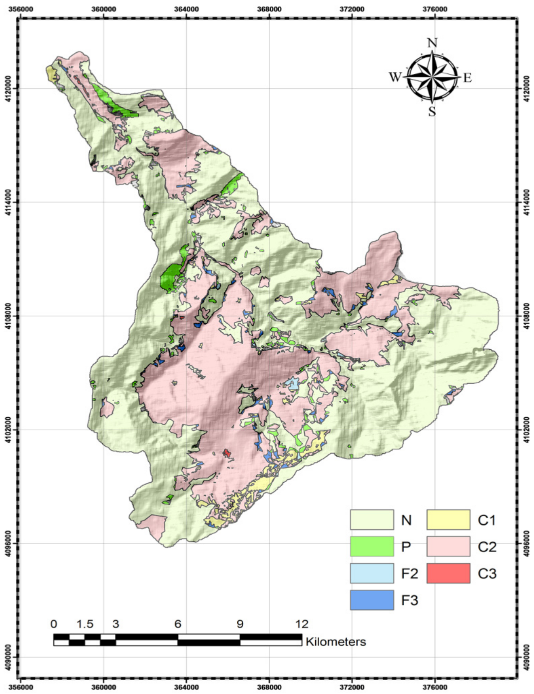

Fig. 4: Characterization of the area sensitive desertification in chehel-chai with a whole set of supplementary indices

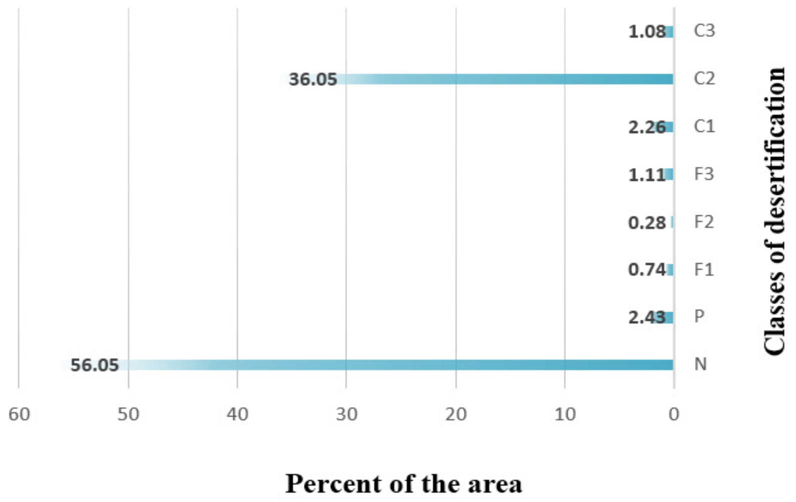

Fig. 5: Desertification of Frequency classes of in Chehel-Chai

for agriculture and overgrazing which represents human activities are the main factors underlying desertification and land degradation (Brandt & Thornes 1996; Breckle *et al*. 2002; Hostert *et al*. 2003; Geist & Lambin 2004; Yassoglou & Kosmas 1997). Although, in recent decades, climate change has been also considered as a predominant factor causing rapid decline of ecosystem biomass and leading to desertification in semi-arid ecosystems (Nicholson 2002; Allen *et al*. 2003).

Results of this study showed that the use of GIS is helpful in assessing areas at risk of desertification because of saving time, providing precision, and reliability in future studies. This system provided a general overview of desertification status as a map of desertification vulnerability (Chenchouni *et al*., 2010). This approach will be worth for decision makers for developing the best guidelines to combat against desertification in sensitive lands. Of course, some other detailed studies are still required to recognize the most sensitive areas to desertification. Human-related factors seem to be currently the most important factors influencing desertification in Chehl-Chai basin, since environmental limitation such as rainfall inadequacy, prolonged dry periods, extreme temperature and evaporation, salinity and soil alkalinity do not exist in this area. The role of climate changes in desertification is more evident in arid and semi-arid regions. Deforestation and conversion of forests to rain-fed lands is one of the main causes for starting the process of land degradation and desertification in the study area. Of course, other natural factors such as climatic factors like storms, early cold, drought, geological factors like landslides (mass erosion) also plays a role in the destruction of the forest of basin.

Improper management of land use in a watershed has undesirable effects on the available resources. Optimization of land use is one of the most useful strategies for achieving sustainable development and reducing wasted resources (Jalili *et al*., 2007). Use of lands based on their potential in proper managerial planning can reduce destruction and losses of land (Chapi, 1997).

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