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Hazard Assessment of Desertification as a Result of Soil and Water Recourse Degradation in Kashan Region, Iran

H. Khosravi[a*], Gh.R. Zehtabian[a], H. Ahmadi[b], H. Azarnivand[a]

[a] *Faculty of Natural Resources, University of Tehran, Karaj, Iran*
[b] *Science and Research Branch, Islamic Azad University, Tehran, Iran*

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Abstract

Desertification in arid, semi-arid and dry sub-humid regions is a global environmental problem. Considering the increasing importance of desertification and its complexity, the necessity of giving attention to desertification criteria and indices is essential. Models and methods such as MEDALUS, UNEP-FAO, and others have been proposed on local and national scales. In this research, IMDPA was selected from among different existing methods, and desertification intensity was evaluated on the basis of two criteria, soil and water, and 13 indices: soil depth, electrical conductivity of soil, texture, gravel percentage, drainage, sodium absorption ratio, type of geologic formation, slope, groundwater table fluctuation, electrical conductivity of water, color concentration, water crisis index, and water shortage for livestock and wildlife. Each criterion was assessed based on the selected indices which resulted in the qualitative mapping of each criterion based on the geometric average of the indices. Finally, a sensitive map of the region was extracted using the geometric average of all criteria. Thematic databases with a 1 :50000 scale resolution were integrated and elaborated in a GIS based on ILWIS and arcGIS. Analysis of desertification criteria in the Kashan region showed that, among the studied criteria, water criterion is a major problem in the study area. It has a geometric average of 3.59 which shows very high class, while soil criterion with a weighted average of 2.12 stands in the medium class of desertification. The results also showed that groundwater decrease and water crisis index with a quantitative value of 3.72 classified in a very high class of degradation and depth with quantitative value of 1.20 classified in a low class of desertification were the most and least effective factors, respectively, among the studied indices on land degradation.

Keywords: *Land Degradation; IMDPA Model; Index; Criteria; Kashan*

1. Introduction

Desertification is a great problem that affects most countries, especially developing ones. According to the latest FAO definition, desertification is land degradation in arid, semi-arid, and dry sub-humid regions due to climate and human factors. This phenomenon has a high rate in arid and semi-arid countries such as Iran. There are vast natural areas in Iran which have susceptible and fragile ecosystems and desert conditions. Based on the definition of desert, except for a narrow strip in northern Iran, other parts of the country face desertification problems.

As a process of degradation in arid ecosystems, desertification is widespread in the arid regions of the world. In Iran, where more than 85% of the country (total area of Iran is 164.8 million ha) is occupied by arid, semi-arid, and hyper-arid regions with 34 million ha of desert. Thus, a major part of the country is susceptible to desertification. Although the government has introduced many projects to combat desertification in recent years, it seems that they are not adequate due to the country's extensive arid regions. This problem

* Corresponding author. Tel.: +98 26 32223044,
Fax: +98 26 32249313.
E-mail address: hakhosravi@ut.ac.ir

needs more attention and effective cooperation on the national as well as the international scene over the long term (IRAN-UNEP-FAO 1990).

Because of the increasing importance of desertification and its complexity, the necessity of giving attention to desertification criteria and indices is essen tial. In order to challenge desertification, scientific research and assessments in different parts of the world are necessary. The results may help to con trol and reduce damages resulting from this phenomenon. Many regions of the world, especially arid and semi-arid ones, have been studied to assess th e land degradation rate, degradation status, and mapping. In this regard, studies were conducted which have provided land degradation assessment methods such as UNEP-FAO (FAO/UNEP, 1984; Grumblat, 1991; Harahsheh, 1998), TAXONOMY (Babaev *et al*., 1993; Kharin *et al*., 1985) ESAs[1] (Basso *et al*., 1999; Giordano *et al*., 2002; Ladisa, 2002; Joachim and Jacques, 2007; Rafiee, 2003), MEDALUS (European Commission, 1999; Kosmas *et al*., 1999; Khosravi, 2004; Khosravi 2005; Nicholas, 2001; Sepehr *et al*., 2007; Zehtabian *et al*., 2005, Zehtabian *et al*., 2008), ICD[2] (Ekhtesasi and M ohajer, 1994), MICD[3] (Ahmadi *et al*., 2005), IMDPA[4] (Ahmadi, 2004; Zehtabian *et al*., 2009).

Some deficiencies of t hese methods include: ignorance of sp ecial conditions of lo cal ecosystems (precipitation shortage, continuous terms of drought and limitation of water resources and its effects on biological resources), usefulness only on a small an d local scale, qu alitative indices, the lack of po ssibility for dissociation of effective natural and human desertifi cation factors, and e xpertise error in the case of FAO-UNEP model (Veron *et al*., 2006). Other models were also calibrated in some regions, but they, too, had deficiencies.

In this research, the IMDPA model was tested to determine the areas su sceptible to desertification and provide a d esertification intensity map of the Kashan- Isfahan province of Iran with an emphasis on water and soil criteria. It was expected to calibrate the desertification related models for m apping a desert ification intensity map in arid, semi-arid, and humid semi-arid regions of Iran which will ease d ecision-making and recommendations for desertification control activities.

[1] Environment Sensitive Areas to Desertification
[2] Modified Iranian Classification Desertification
[3] Modified Iranian Classification Desertification
[4] Iranian Model of Desertification Potential Assessment

2. Materials and Methods

2.1. IMDPA Model

Since various factors are responsible for desertification, it is neces sary to determine relevant criteria and indices for desired land uses as well as for desertification control. To achieve the above-mentioned objective and based on a review of international/national desertification models in literature, the IMDPA mo del, a comprehensive desertification model, was presented by the Faculty of Natural Resources, University of Tehran, as the result of a proj ect entitled *Determination of Methodology of Desertification Criteria and Indices in Arid and Semi-arid Regions of Iran*. Nine criteria and 130 indices were introduced, the quantitative and weighted values which would determine the desertification intensity in each region.

In this project, some international models of desertification, such as FAO-UNEP (FAO/UNEP, 1984), GLASOD, LADA, AOOSD, and MEDALUS (European Commission, 1999), as well as national models including ICD (Ekhtesasi and Mohajer, 1994) and MICD (Ahmadi *et al*., 2005) were reviewed, and 9 criteria were chosen based on previous experiences in mapping desertification intensity (Ahmadi, 2004).

All IMDPA criteria as well as the selected indices for soil criteria are shown in Figure 1.

A score ranging from 1 to 4 was assi gned to each index based on the weight of each factor. Finally, the value of each criterion was ob tained as a geometric average of scores of single indices according to the formula:

$$Index-X = \left[(Layer-1).(Layer-2)...(Layer-n)\right]^{1/n}$$

where Index-X = a given criteria; Layer = index of each criterion;_N = number of indices for each criterion. Next, desertification intensity resulted from the geometric average of 9 c riteria as follows:

desertification intensity = (water × so il × water erosion × wi nd erosion × cl imate × veget ation cover × agriculture × technological development × management) $^{1/9}$

Finally, the risk of desertification (final map) was classified in 4 subtypes according to Table 1.

Table 1. Classification of desertification intensity

Order	1	2 3		4
Numerical value	1-1.5	1.6-2.5	2.6-3.5	3.6-4
Class	Low	Medium	High	Very High

2.2. Methodology

Kashan is located at 51°27' E and 33°51' N and has an arid climate with annual average precipitation of 133.5 mm. This region is in the Isfahan province, south of Tehran, and has a mean annual temperature of 18.8°C .The risk of desertification in the studied area was evaluated on the basis of wat er and soi l criteria. Each criterion includes the following indices:

2.2.1. Soil criterion

The role of so il criterion in the desertification process is rel ated to available water and soil erodibility. Soil properties such as depth, electrical conductivity (E C), texture, gravel percentage, slope, drainage and t ype of geologic formation, and sodium absorption ratio (SAR) can be defined as soil indices.

Soil texture index: It is related to erodibility and water holding capacity of soil. Availability of water also depends on soil texture and structure. Soil texture classes are categorized based on water holding capacity as shown in Table 2.

Surface gravel percentage index: Surface gravels with diameters greater than 6 mm were classified into three groups based on the percentage of surface c overage and soil conservation against the erosion process (Table 2). Soil depth index: It is categorized into four classes based on the soil depth profile (Table 2).

Slope index: It is classified into four classes using topographic maps and the effect of slope on soil erosion (Table 2).

Soil drainage index: Drainage condition is defined based on the hydromorphic process to Fe, Mn, and the depth of ground water. In this case, three classes of drainage were determined based on its effect on soil salinization (Table 2).

EC Index: Electrical conductivity is a major factor of soil degra dation that is categoriz ed in four classes (Table 2).

Sodium Absorption Ratio Index: It is categorized into four classes (Table 2).

2.2.2. Water criterion

The role of water criterion on the desertification process is related to the quality and quantity of water. Groundwater table decrease, el ectrical conductivity (EC), Cl con centration, water crisis index, water shortage for livestock and wildlife were defined as water indices.

When the scores are assigned, the val ue of the quality index for each elementary unit within an index is obtained as t he geometric average of scores for single indices.

Consequently, 13 maps representing the condition of each index were produced to stud y the role and effect of each inde x on desertification. Then, criteria maps (water and soil) were ge nerated as the geometric average of the mentioned indices showing the desertification condition in four classes.

Two maps representing the condition of each criterion were then produced to study the role and effect of each index in desertification.

According to the factorial scaling technique, a score ranging from 1 (good condition) to 4 (deteriorated condition) was assigned to each index. Value "Zero" was assigned to areas where the measure was not appropriate and/or those which were not classified.

Table 2. Water Resourced Degradation Indices

Index: Class	Low	Medium	High	Very high (a)	Very high (b)
Value	*1.00-1.50*	*1.51-2.50*	*2.51-3.5*	3.51-3.75	3.76-4.00
Groundwater table decrease (cm/year)	0-10	10-20	20-30	30-50	>50
EC (µmhos/cm)	<250	250-750	750-2250	2250-5000	>5000
CL (Mgr/liter)	<250	250-500	500-1500	1500-3000	>3000
Water resources shortage for people and livestock	enough for livestock and wildlife requirement	reasonably enough for livestock and wildlife requirement	meets live stock and wildlife needs proportionally	less than livestock and wildlife requirement	much less than livestock and wildlife requirement
The Index of Sustainable Development Committee of International Union	10 >I_{UN}	10<IUN< 20	20<IUN<40	40<IUN<60	60<I_{UN}

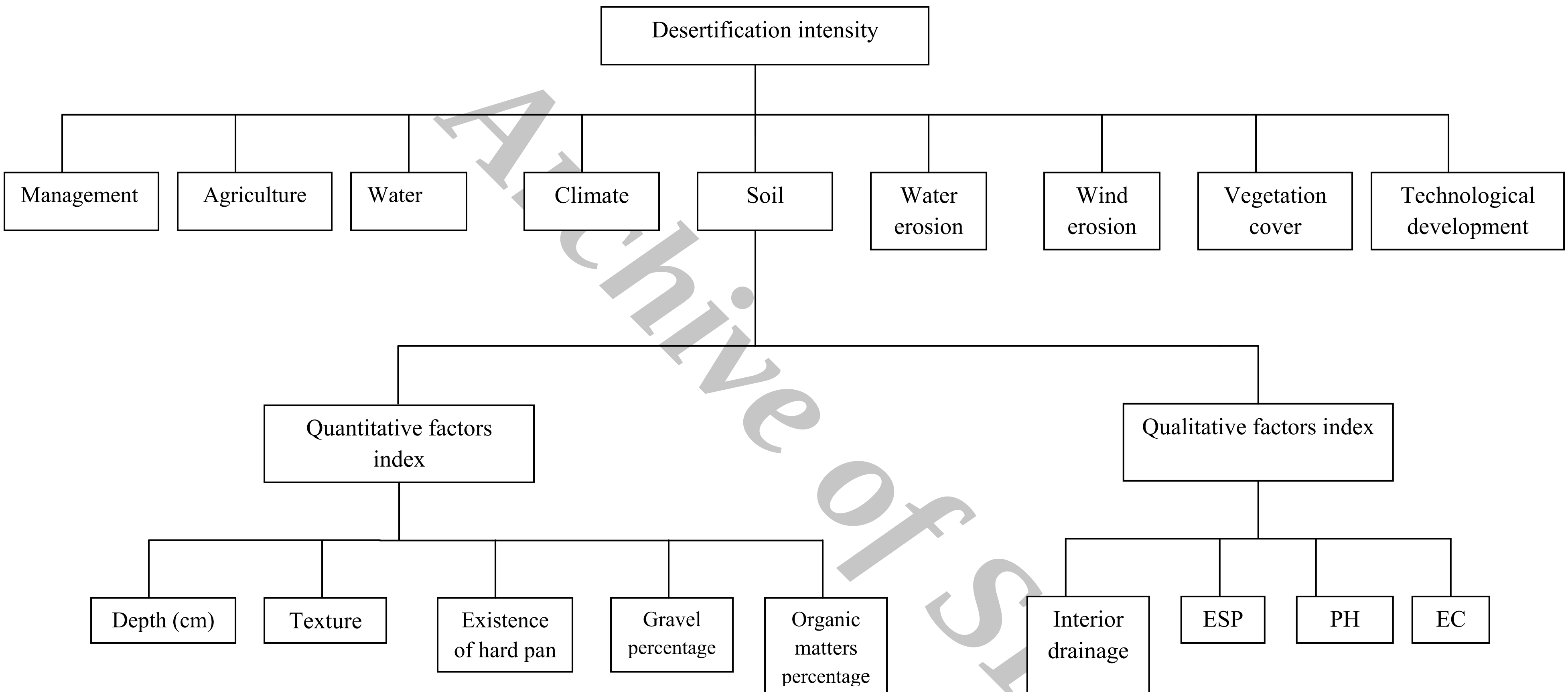

Fig. 1. Chart of IMDPA Model

Table 3. Soil Degradation Indices

Index	Class	Low	Medium	High	Very high
	Value	*1.00-1.50*	*1.51-2.50*	*2.51-3.5*	3.51-4.00
Texture		SC – SiC	L – SCL – SiCL- SiL	LS – SL	S – C>%60
Percentage of under ground gravel sand		>65	35-65	15-35	< 20
Depth (cm)		>75cm	30-75	15-30	<15cm
Drainage		Fe, Mg in depth of >100cm, water penetration is very fast, soil is moist during the growth period	Fe, Mg in depth of 60-100cm, water penetration is moderate, soil is relatively moist	Fe, Mg in depth of 30-60cm, water penetration is slow, soil is moist	Fe, Mg in depth of <30cm,water penetration is very slow, soil is moist for a long time
Slope		<6%	6-18	18-35	35%<
Type of geologic formation		Sedimentary and soil unit constant in front of destructive factors	Sedimentary and soil unit relatively constant in front of destructive factors	Sedimentary and soil unit relatively sensitive in front of destructive factors	Sedimentary and soil unit very sensitive in front of destructive factors
EC		<8	8-16	16-32	>32
SAR		<13	13-30	30-70	>70

3. Results

To assess the method proposed in this study with respect to all information mentioned in the methodology and evaluation method, this method was used for up to 91385 ha in the Kashan region and the data was analyzed.

3.1. Analysis of indices

3.1.1. Indices of water criterion

In order to determine the level of desertification of the region using the groundwater criterion and regarding the information in Table 2 and field surveys, the indices considered in the unit map of the region were graded. Figure 2 presents maps of the water resource indices.

Studying mean values of factors involved in the deterioration of water resources indicated that groundwater decrease and water crisis index with a geometric average of 3.72 which shows a very high class is the most effective factor in increasing groundwater degradation intensity of the studied region. In general, Table 4 introduces all indices influencing water resource deterioration.

Table 4. Geometric Average of the Quantitative Values of Water Resources Degradation Criterion

Order	Index	Value	Class
1	Groundwater table decrease	3.72	Very high
2	EC (µmhos/cm)	3.62	Very high
3	CL (Mgr/liter)	3.24	High
4	Water resources shortage	3.42	High
5	Water crisis index	3.71	Very high

3.1.2. Indices of water criterion

As soil is an essential factor in evaluating the environmental sensitivity of an ecosystem, especially in arid and semi-arid zones, the soil criteria was evaluated based upon depth, EC, texture, gravel percentage, slope, drainage and type of geologic formation, and sodium absorption ratio (SAR). Figure 3 presents maps of the soil quality indices.

After estimating the mean values of eight indices influencing soil quality, it was concluded that Type of geologic formation played the main role in the desertification of Kashan. In general, Table 5 presents results for all indices influencing climatic criterion.

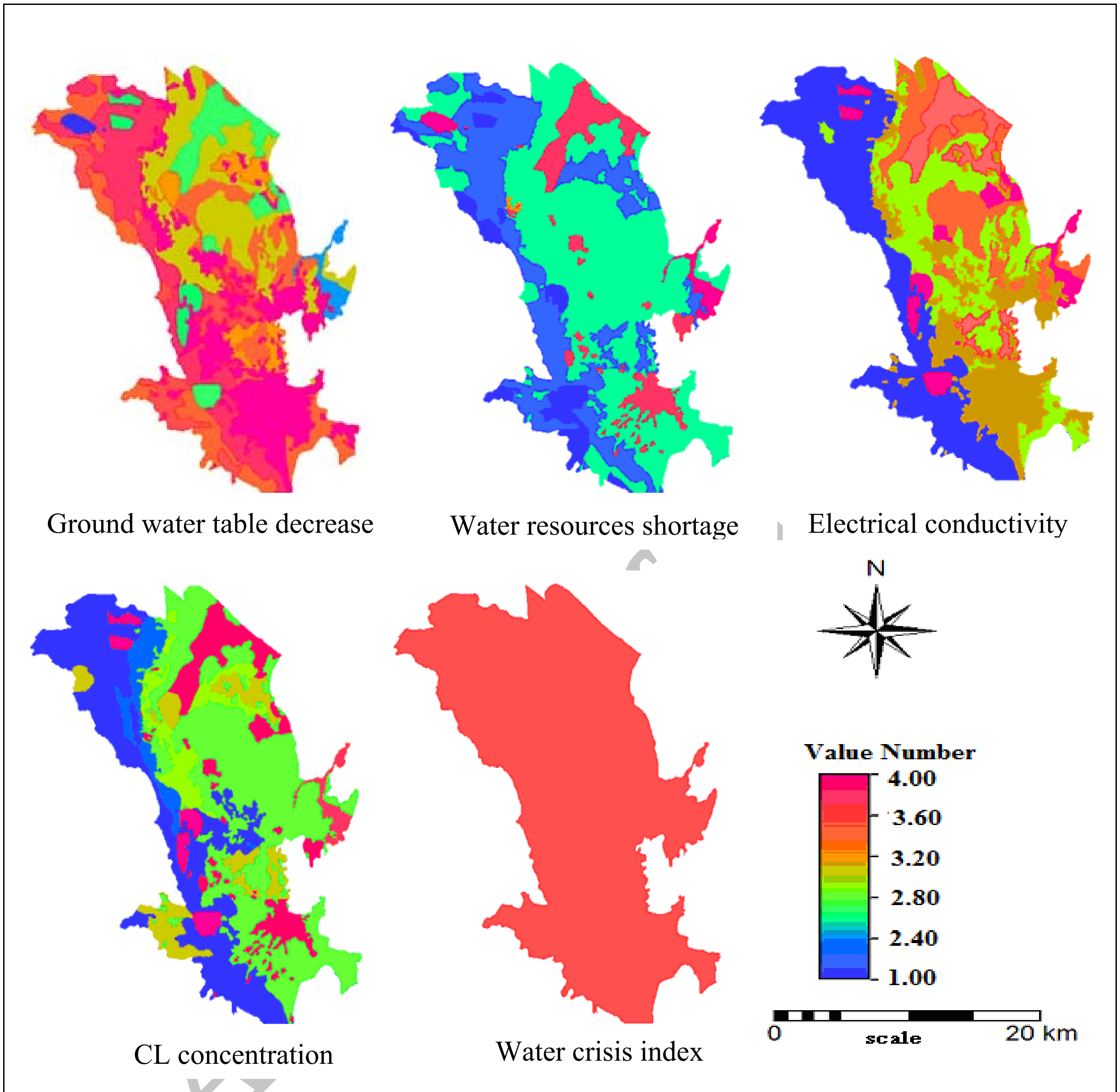

Fig. 2. Value Number Maps of Water Resource Indices

Table 5. Geometric Average of the Quantitative Values of Soil Degradation Index

Order	Index	Value	Class
1	Texture	1.47	Low
2	Percentage of underground gravel sand	1.36	Low
3	Depth (cm)	1.20	Low
4	Drainage	2.23	Medium
5	Slope	2.65	High
6	Type of geologic formation	2.85	Medium
7	Salinity (EC)	1.65	Medium
8	Alkalinity (SAR)	1.38	Low

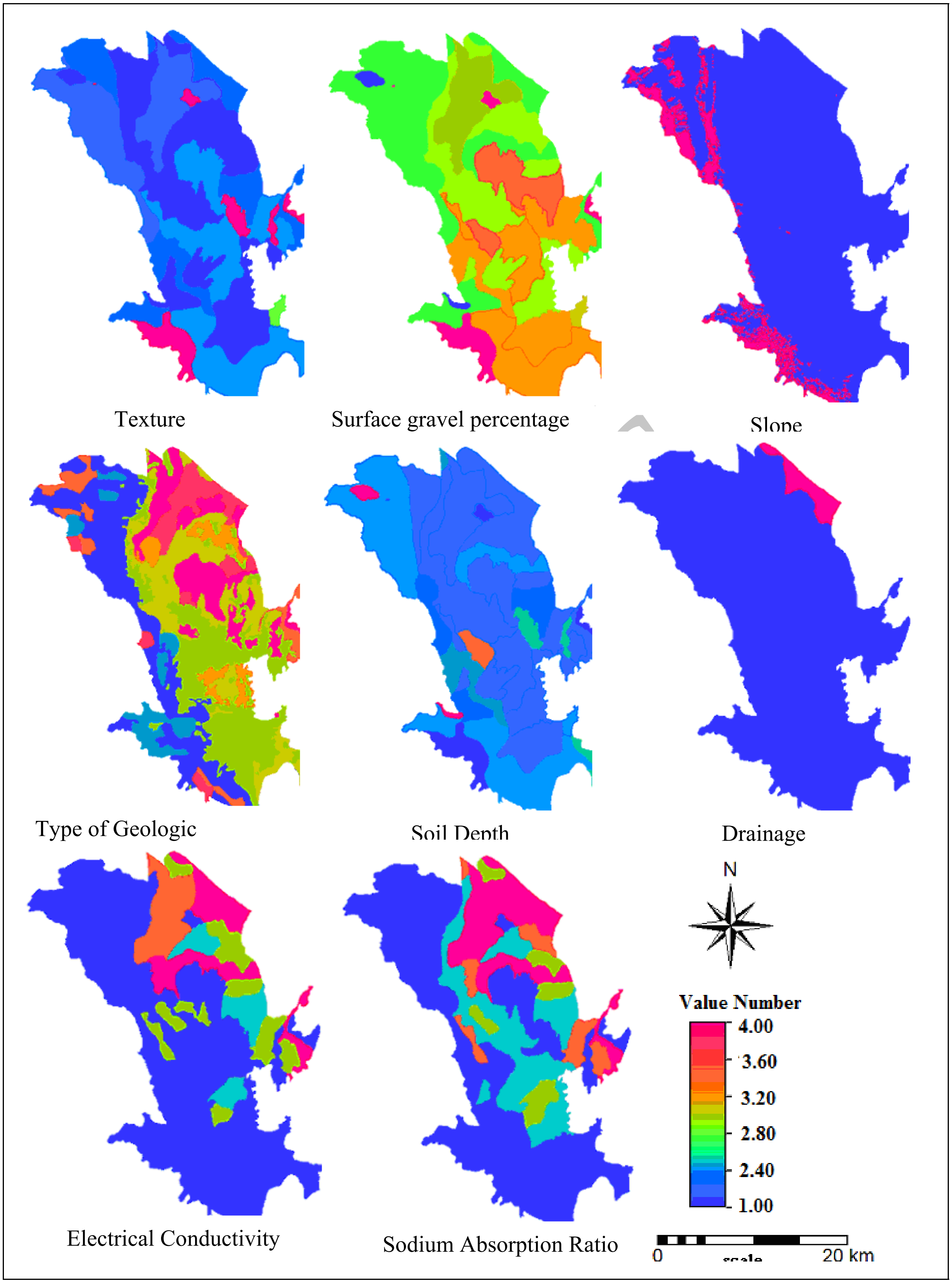

Fig. 3. Value Number Maps of Soil Indices

3.2. Analysis of criteria

Analysis of the studied criteria from the Kashan region showed that water resources degradation criterion with a geometric average of 3.59 shows very high class, while soil with a weighted average of 2.12 stands in medium class.

4. Conclusion and Discussion

Desertification is widespread in the arid regions of the world. In Iran where more than 85% of its 164.8 million ha is occupied by arid, semi-arid, and hyper-arid regions with 34 million ha of desert, a major part of the country is susceptible to desertification. Although the government has introduced many projects to combat desertification in recent years, it seems that they are not adequate due to the country's extensive arid region. This problem needs more attention and effective cooperation in the national as well as the international scene over the long term.

We used a regional model by modifying the IMDPA model whereby desertification parameters were collected in the study area using GIS. The two composite criteria, each consisting of several indices, were analyzed. The water resources degradation map (Fig. 4) is classified into two classes of high and very high, but the soil map is classified into two classes of low and medium (Fig. 5).

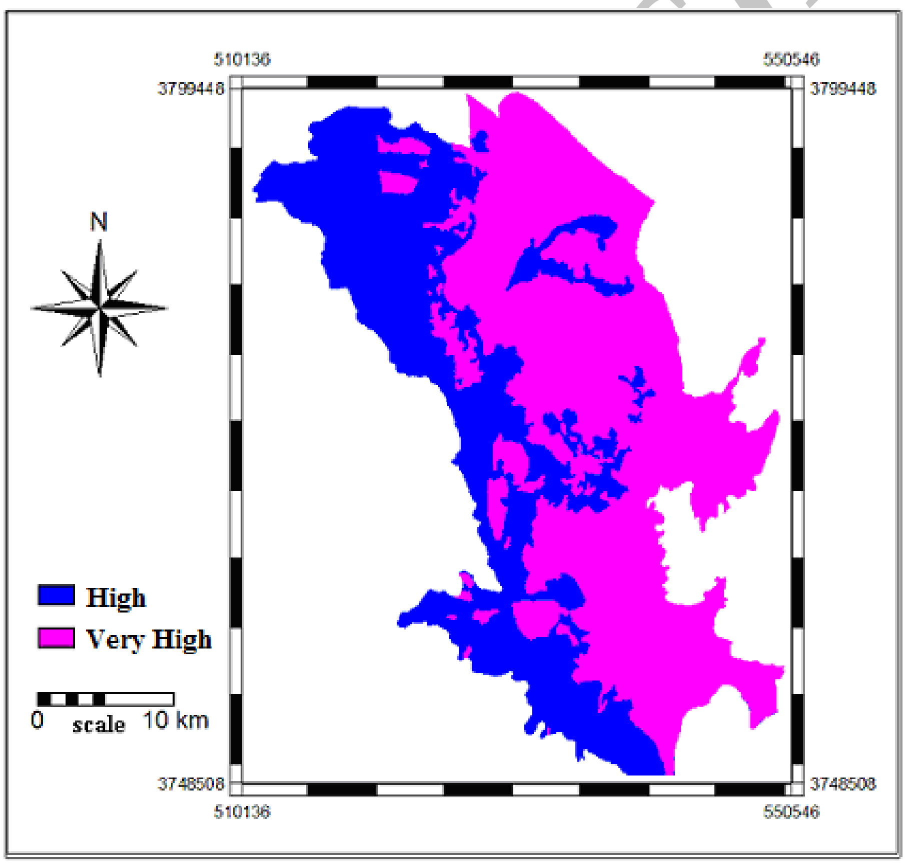

Fig. 4. Map of Desertification Conditions Based on Water Resources Criterion

The present study, based on the geometric average of quantitative indices in Kashan, showed that among 43 indices and sub-indices, the two indices of groundwater decrease and water crisis index had the most significant effect with values of 3.72; the two other indices of depth and drainage had the lowest effect with values of 1.20 and 1.36, respectively.

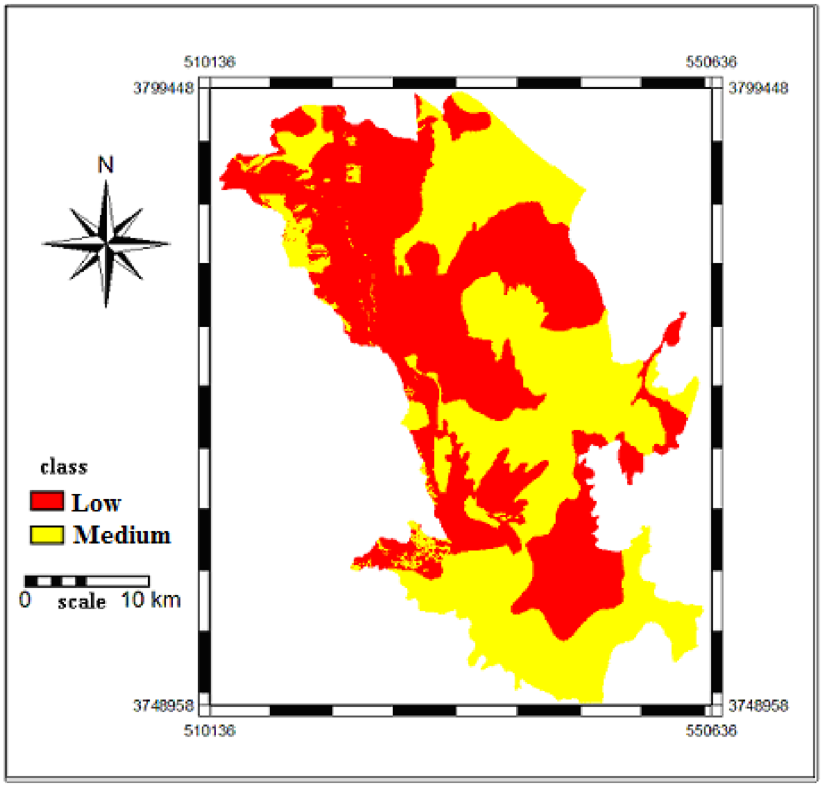

Fig. 5. Map of Desertification Conditions Based on Soil Criterion

Initial results provided by this study for determining effective indices and criteria on desertification showed that anthropogenic factors play significant roles in desertification. As an example, the most important factor in desertification in the Kashan region is water resource degradation. This is mainly because of better access to groundwater resources, intensive population, and numerous wells in plain areas. Other effective factors are surface water harvesting projects to supply water demands for domestic, industrial, and agricultural uses.

Groundwater depletion caused by increased exploitation and salt/fresh waters imbalance has decreased water quality for different uses. These factors in addition to the misuse of resources have increased soil degradation while decreasing production and biomass.

The results of this research confirm the results of Jafari (2000) and Khosravi (2005). Using the UNEP-FAO model, Jafari showed in the Kashan area that, between wind erosion and groundwater degradation, the second criteria are the important ones. Khosravi's results using the IMDPA model indicated that among the 7 criteria of climate, vegetation cover, water, wind erosion, water erosion, soil, and agriculture, water resources degradation criteria is the major problem which showed a very high class, while climate quantity criterion stood in second order of desertification factors.

The results of the present research can be used in future management for obtaining sustainable development, so that the marginal ecosystems and investment in arid and semi-arid regions will be protected. Moreover, they will help the managers of desert lands achieve better and more suitable results and avoid wasting investments.

It can be concluded that the assessment of desertification sensitivity is rather important to planning sustainable development in highly potential desert areas such as the Kashan region. The obtained information is essential to improving the employment of natural resources. The merely quantitative aspect of desertification sensitivity demonstrates a clearer image of the risk state; thus, reliable priority actions can be planned. Remote sensing and thematic maps may supply valuable information concerning the soil quality at the general scale. However, for more detailed scales, conventional field observation would be essential.

One of the disadvantages of the proposed procedure is the difficulty of measuring all effective factors because of limiting parameters such as costs, intensive field work, and deficiency of necessary data and information. All indices play major roles in the desertification process. Since the number of indices in the current study has been reduced, consequently, the efficiency of the model has decreased and more studies are needed to find solutions for overcoming this problem.

The application of desertification models needs continuous data updating to better determine trend and intensity of desertification in order to recommend preventive measures. It can be recommended that mathematical modeling should be developed for the operational monitoring of different elements contributing to desertification sensitivity. Multiscale mapping of IMDPA are needed to point out the risk magnitude and causes of degradation in problematic areas.

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