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Evaluation of desertification hazard in the Jaz_Murian aquifer based on analysis of climate and groundwater criteria

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Key words: Desertification hazard, IMDPA Method, Groundwater Depletion, Geo-statistical analysis

Abstract

Desertification is a major concern of this century and occurs as a result of climatic and human induced factors. The current work aims to depict the desertification hazard map in the Jaz_Murian region using an Iranian Model of Desertification Potential Assessment (IMDPA) based on groundwater and climate criteria. For the evaluation of groundwater criterion, four indices included Electrical Conductive (Ec), Sodium Absorption Ratio (SAR), Chloride (CL), and groundwater depletion are usually used. As well as, two climatic (precipitation and aridity) indices were considered. As the groundwater quality data are collected in a much-dispersed network of wells, this problem is moderated by various geostatistical methods that have been developed to predict values at the unmeasured locations. This paper used Kriging's method to interpolate groundwater quality variables. In order to better understanding the groundwater level of Jaz_Murian aquifer, the groundwater hydrograph was generated. The results showed that the groundwater level depleted about 6.8 meter during the last 11 years. Moreover, evaluation of desertification based on climatic indices showed that the Jaz_Murian aquifer faces a critical desertification hazard. Results have shown that about 49% of the area fell into the moderate category and the rest (51%) fell into the high category for desertification hazard. Decrease in precipitation and severe utilization of groundwater particularly in the agricultural sector led to desertification that calls for urgent establishment of watershed management projects in this region.

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Introduction

Desertification is a major concern of this century and occurs as a result of climatic and human factors. Desertification can have a natural origin or can be induced by human activities (Bowyer *et al.* 2009; WER, 2009). Desertification is a complex process and many factors contribute to the occurrence of this phenomenon. For most scientists, desertification is known as a natural hazard capable of becoming a disaster (UN-ISDR 2004; Anagnostopoulos, 2006). In order to prevent disaster, the evaluation of desertification hazard is of great importance. In this regard, the use of Geographic Information Systems (GIS) is a tool used to gather large amounts of data coming from different sources such as maps or measurement stations and has become a successful tool in disaster management (Van Westen, 2002; Frantzova, 2010).

Desertification hazard assessment is an important component of environmental management at global and local scales in the world. Numerous methods exist to assess land degradation, among them, the most significant at the global level namely LADA (Land Degradation Assessment in Dry lands) (O.F. Nachtergaele and Licona-Manzur, 2008), GLASOD (Global Assessment of Soil Degradation) (Oldeman *et al.*, 1990) and FAO-UNEP (FAO, 1984) are prominent. One major effort carried out by the University of Tehran in 2005 to introduce a useful model for evaluation of desertification hazard in Iran entitled "Iranian Model of Desertification Potential Assessment (IMDPA)". The principal objective of the IMDPA project is to develop tools and methods to evaluate and quantify the severity of desertification potential. The IMDPA model is capable of generating a desertification map based on expert evaluation (Zehtabian *et al.*, 2014). Water and climate criteria are known as the major determinant factors in the IMDPA model.

Water deficiency is one of the main causes and/or consequences of desertification and certainly worsens the situation. The shortage is naturally more important in arid and semi-arid regions where water is the main limiting factor of land use performance in ecosystems (Batterbury and Warren, 2001).

In the last few decades, there has been a high demand for groundwater resources due to agricultural development activities and population growth in Iran, especially in the Jaz_Murian region. Monitoring of the quantity and quality of groundwater is one of the important factors in the evaluation of desertification potential in this region. Water resources are inextricably linked with climate. Climate affects desertification phenomenon through alteration of spatial and temporal patterns in precipitation, temperature, and winds etc. As well as, significant decrease in precipitation is expected in most subtropical land regions (WMO, 2007). Climate factor plays a key role in almost all the other desertification factors.

The main objective of this study was to assess desertification hazard with the IMDPA model in the Jaz_Murian region where suffering the scarcity of rainfall with long dry seasons, inappropriate human activity, high growth of population coupled with economic weakness and the lack of water availability, as one of the most critical areas prone to desertification. For this purpose, among the criteria normally used for the IMDPA model, water and climate criteria were selected and desertification hazard was measured based on six indices including water (Electrical Conductive (Ec), Sodium Absorption Ratio (SAR), Chloride (CL) and groundwater depletion) and climate (precipitation and aridity indices).

Materials and methods

Study Area

The study area is one of the main aquifers of the Jaz_Murian basin with an area of 5835 km^2 where is located at 27°26' 12″ to 28°15′ 21″ N and 57°25′ 00″ to 58°57' 16″ E in Kerman province, southeast of Iran (Fig. 1). According to the climatic data recorded at Shah_Abad station, from 2002 to 2013 the average precipitation is 113 mm/year (Fig. 2) with an average annual temperature approximately 26.5°C. Two main rivers crosscut the study area: Halil Roud from north-west of the Jaz Murian depression and Bam_Pur from north east. The major geological formation is high-level piedmont fan and valley terrace deposits and low-level piedmont fan and valley terrace deposits, and swamp and marsh and sand sheets.

Poor rangelands and salty lands are the main land cover/land use types in the area. The dominant natural vegetation species are *Seidlitzia rosmarinus*, *Prosopis cineraria, Hamada salicornica, Ziziphus spinachristi, Stipagrostis plumose* and *Calligonum comosum*. The evidence of natural vegetation cover degradation is cleared due to over grazing, cultivation and woodcutting.

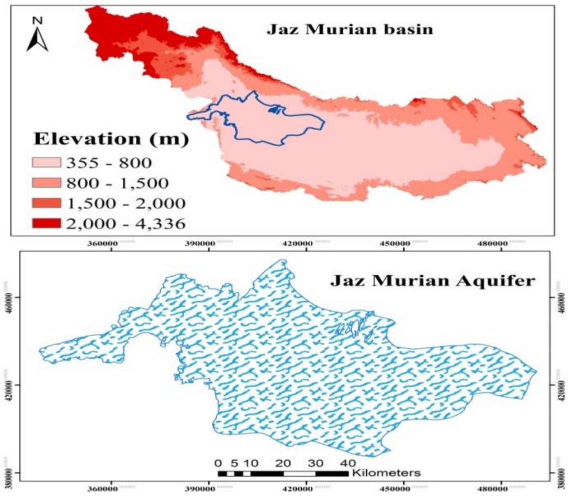


Fig. 1. Location of study area (Jaz_Murian aquifer) within the Jaz_Murian basin.

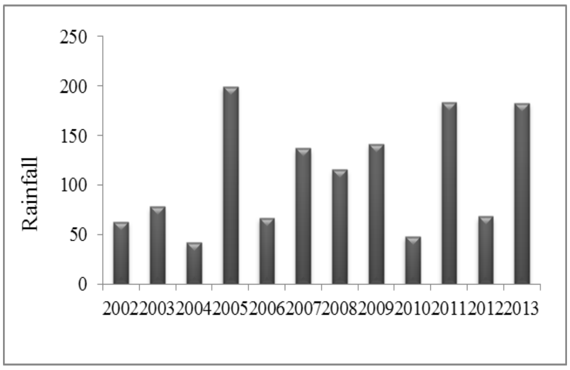


Fig. 2. Annual rainfall diagram of Jaz_Murian region from 2002 to 2013.

Ground-water Hydrograph

In subsurface hydrology, a Groundwater hydrograph is a record of the water level over time in wells screened across an aquifer (Mahdavi 2007). "Water-level measurements from observation wells are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge" (Taylor and Alley 2001).

In this study, analyses of selected data and information were used from the years 2002 to 2013 in order to establish the unit hydrograph drawing based on the Thiessen polygons method. Groundwater level was interpreted using water table data collected from 26 piezometer wells available in the Iranian Water Resources Management Corporation database. This database consists of wells, springs, aqueducts, and drain data of water resources in the Iran.

Interpolation method

Groundwater quality data is problematic. Because the information is recorded at very scattered monitoring wells, this problem is solved by various geostatistical methods that have been developed to predict values at unmeasured locations.

The geostatistical analyst provides two groups of interpolation techniques: deterministic (based on mathematical functions) and geostatistical (relies on both statistical models and mathematical methods). All methods rely on the similarity of nearby sample points to create (interpolates) the surface (Childs, 2004). One of the most important geostatistical methods of interpolation is Kriging that is derived from the regionalized variable theory (Oliver and Webster 1999).

In the Kriging method, predicted values are derived from the measure of relationships in samples using sophisticated weighted average technique (Childs, 2004).

In order to map the quality conditions of Jaz_Murian aquifer, this paper uses the Kriging method to interpolate ground water quality data such as: Ec, SAR, and Cl obtained from 65 monitoring wells in 2013 (to increase the accuracy of interpolation, some adjacent wells outside of the boundary were also considered) (Fig. 3). GIS 10.1 software was used for semivariogram estimations and final interpolations.

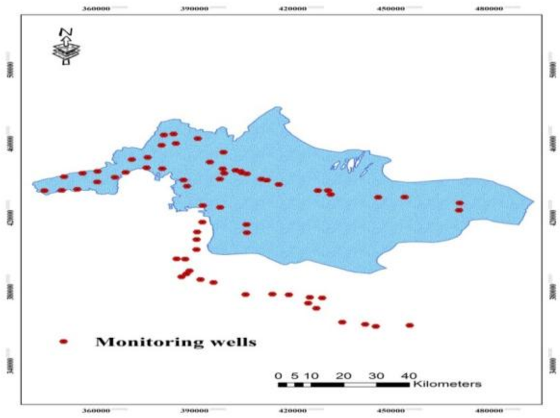


Fig. 3. Dispersion of monitoring wells which considered to interpolation of quality properties.

Iranian Model of Desertification Potential Assessment (IMDPA)

The Iranian Model of Desertification Potential Assessment (IMDPA) was presented by the University of Tehran in 2005, as the result of a project entitled "Determination methodology of desertification criteria and indices in arid and semi-arid regions of Iran" (Shakerian *et al.*, 2011).

Desertification is a compound phenomenon and occurs because of many factors such as climate, soil, vegetation cover, water, erosion, agriculture, geology & geomorphology, socio & economic, urban development & technogenic.

The IMDPA model classifies these factors in four groups, weather group (includes climate and water criteria), land group (geology & geomorphology, soil and erosion criteria), vegetation and ground group (vegetation and agriculture criteria), and human group (socio & economic, urban development & technogenic criteria). Each criterion includes some indices (Tahmoures, 2013). The goal of this research is to evaluate the desertification hazard according to weather group factors.

For assessment of desertification hazard, the value of each index (Fig. 4) was weighted based on manual of model (Table 1) and combined with each other in GIS 10.1 software by calculating geometric mean of indices according to the following equation (Zehtabian *et al.*, 2014):

$$Qi = \sqrt[n]{q_1 \times q_2 \times q_n}$$

Table 1. Classification of water and climate criteria in order to desertification assessment.

criteria	Index	Score and Classification			
		1-1.5 (Low)	1.51-2.5 (Moderate)	2.51-3.5 (High)	3.51 – 4 (Severe)
Water	Groundwater depletion (cm/year)	<20	20-30	30-50	50<
	Ec (µmhos/cm)	<750	750-2250	2250-5000	>5000
	SAR	<18	18-26	26-32	>32
	Cl (mg/lit)	<500	500-1500	1500-3000	>3000
Climate	Precipitation(mm)	>280	150-280	75-150	<75
	Aridity index (P/PET)	>0.45	0.2-0.45	0.05-0.2	<0.05

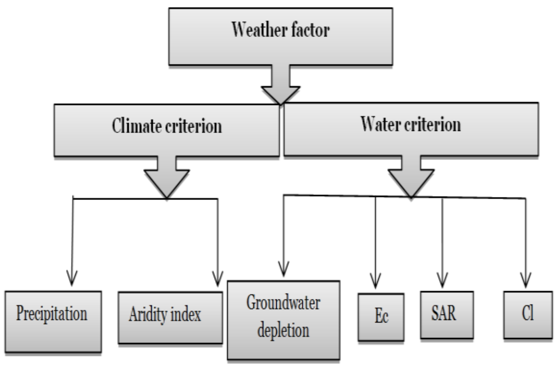


Fig. 4. Selected indices in IMDPA model in order to assess desertification.

Where Qi: is value of criterion and q: is score of index. The score of each index was weighted from 1 to 4, respectively, for low and severe desertification hazard. Finally, the desertification map of Jaz_Murian region was extracted using geometric average of all criteria.

Results and discussion

Groundwater Hydrograph

Groundwater level was interpreted using water-level data collected from 26 piezometer wells. The results of unit hydrograph drawing based on the Thiessen method (Fig. 5) indicated a decreasing trend in groundwater level in Jaz_Murian aquifer showing that it has decreased about 6.8 meters during 11 years, on average declining approximately 0.6 meter per year (Fig. 6), which is caused especially due to agricultural activities. In addition, a moderate rise centered in 2005 and a higher rise in 2011 is evident because of increase in precipitation in 2005 and 2011 years (Fig. 2).

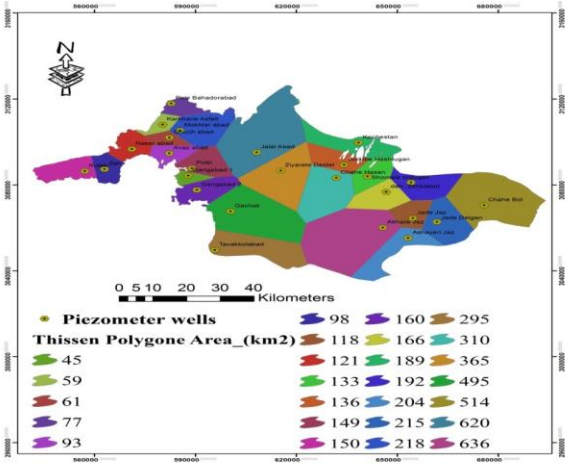


Fig. 5. Effective area of each piezometer well in Jaz Murian aquifer using the Thiesse method.

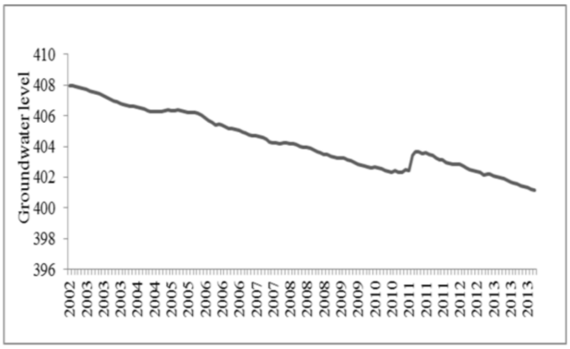


Fig. 6. The Groundwater Hydrograph of Jaz_Murian region.

Interpolation

Before using the interpolation methods to produce quality maps of groundwater in Jaz_Murian aquifer, it is necessary to explore the distribution of data to select an appropriate method for the interpolation technique. For this purpose, log transformation was applied to the skewed data; this transformation makes the data distribution closer to normal. In (Fig. 7) the distribution is bell-shaped, so, this distribution is close to normal because the mean and median values are close.

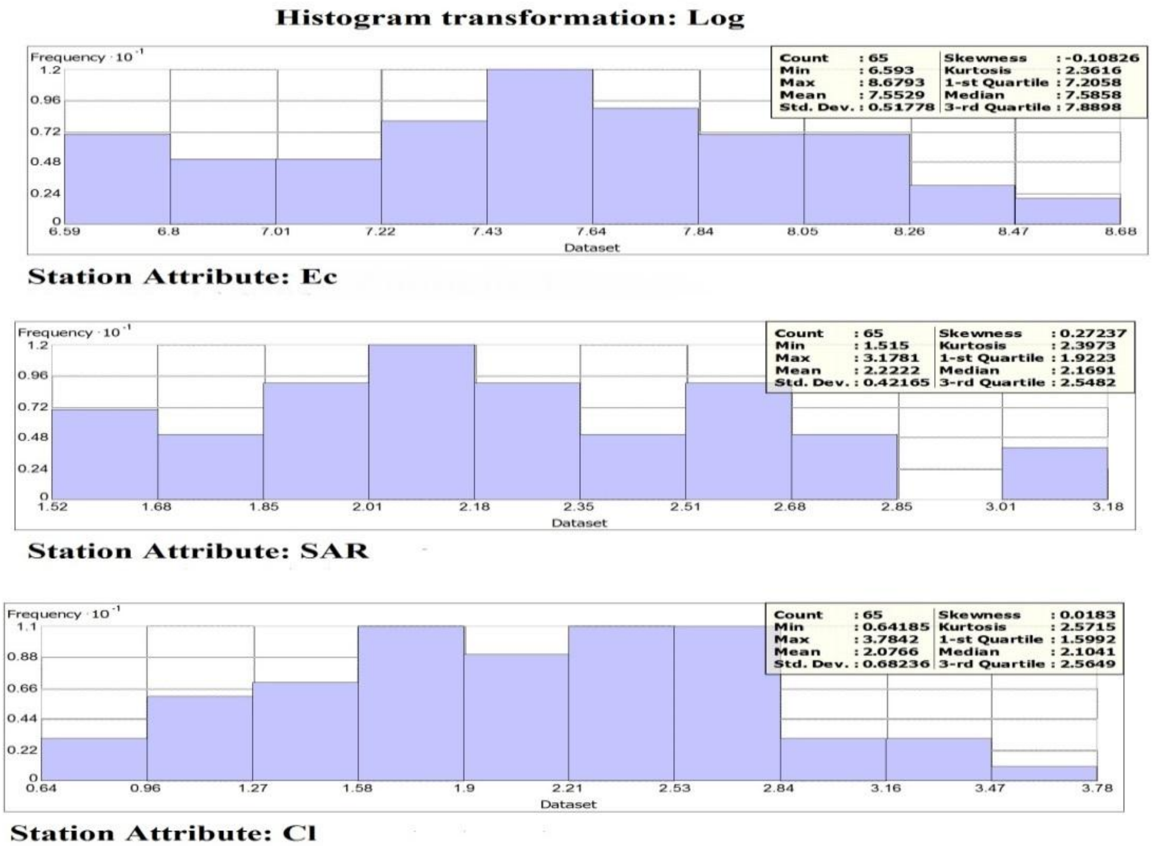


Fig. 7. Log transformation is applied to normal distribution.

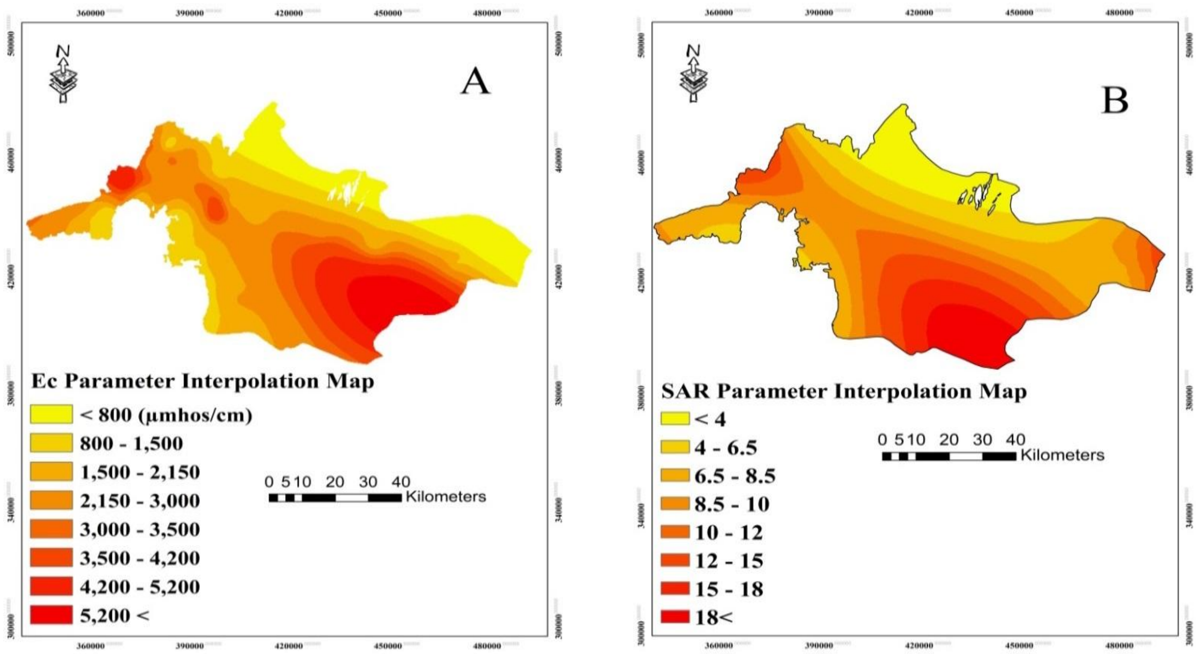
In this study, the simple Kriging method is chosen as an appropriate interpolation method because it can be used to predict values at unmeasured locations, and assess the uncertainty associated with a predicted value at the unmeasured locations (Childs, 2004). Geostatistics provides descriptive tools such as semivariograms to characterize the spatial pattern of a variable such as water attributes.

In order to apply simple Kriging to a data set, it is necessary to model the semivariogram/variogram. Based on Root Mean Square Standardized (RMSS) and Mean standardized (MS) indicators, the Gaussian semivariogram showed better accuracy than other methods; therefore, it was selected as the most appropriate semivariogram for interpolation (Kriging) (Table 2). Fig. 8 shows the maps of Ec, SAR, and Cl estimates obtained by the simple Kriging interpolation method.

Table 2. Results of geostatistical analysis of water quality parameters.

variable	Method type	Nugget	Partial Sill	Range	Mean standardized (MS)	Root Mean Square Standardized (RMSS)
Ec	Circular	0	0.2	6597	-0.041	1.03
	Spherical	0.11	0.099	8312	-0.024	0.967
	Exponential	0.014	0.23	10066	-0.011	0.969
	Gaussian*	0.02	0.21	6597	-0.026	0.963
	Stable	0.006	0.22	6597	-0.02609	0.968
SAR	Circular	0.097	0.053	14915	-0.036	1.23
	Spherical	0.096	0.051	14915	-0.038	1.25
	Exponential	0.092	0.052	14915	-0.048	1.27
	Gaussian*	0.1	0.051	14915	-0.03	1.22
	Stable	0.103	0.051	14915	-0.033	1.22
CL	Circular	0.06	0.312	6864	-0.033	1.003
	Spherical	0.059	0.319	7679	-0.033	1.003
	Exponential	0.006	0.406	9739	-0.016	0.95
	Gaussian*	0.11	0.271	6641	-0.029	0.99
	Stable	0.11	0.27	6641	-0.0291	0.998

*= The selected method for interpolation technique.



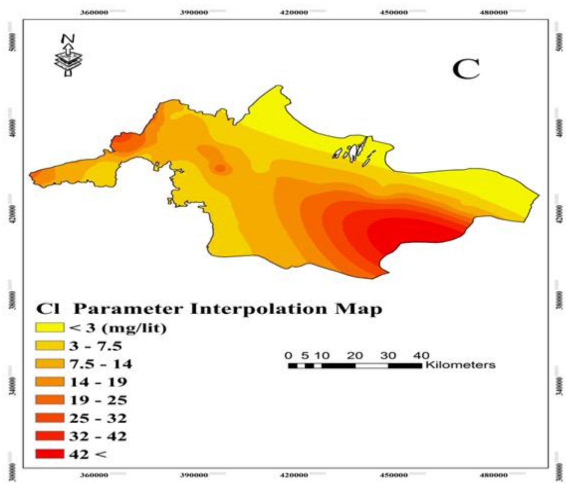


Fig. 8. Groundwater quality parameters maps resulting from Kriging interpolation method: A: Ec interpolation Map, B: SAR interpolation map, C: Cl interpolation map.

Precipitation and Aridity Index

This study was undertaken to analyze precipitation and aridity index (AI), utilizing the ratio of precipitation (P) over potential evapotranspiration (PET) at six synoptic stations (Jiroftsilu, Eslamabad, Kahnuj, Ghale-Gang, Jiroftmiyandeh, and Jabalbarez) located in Jaz_Murian region during a 20-year period (1993-2013).

The precipitation map was prepared using precipitation gradient equation (y=-0.273x + 1405.9, r2=0. 98) and Digital Elevation Model (DEM) through correlation between altitude and rainfall (Fig. 9).

There is a significant correlation between aridity and desertification. Increasing aridity because of global warming can be a real hazard, with the threat of desertification (Hrnjak, 2013). Several numerical indices have been proposed to quantify the degree of dryness of a climate at a region. Aridity Index (AI) was defined as the ratio of the annual precipitation and PET totals (UNEP 1992). The Transeau (1905) Aridity Index can successfully be used to determine the aridity index from available meteorological data (Fig. 10).

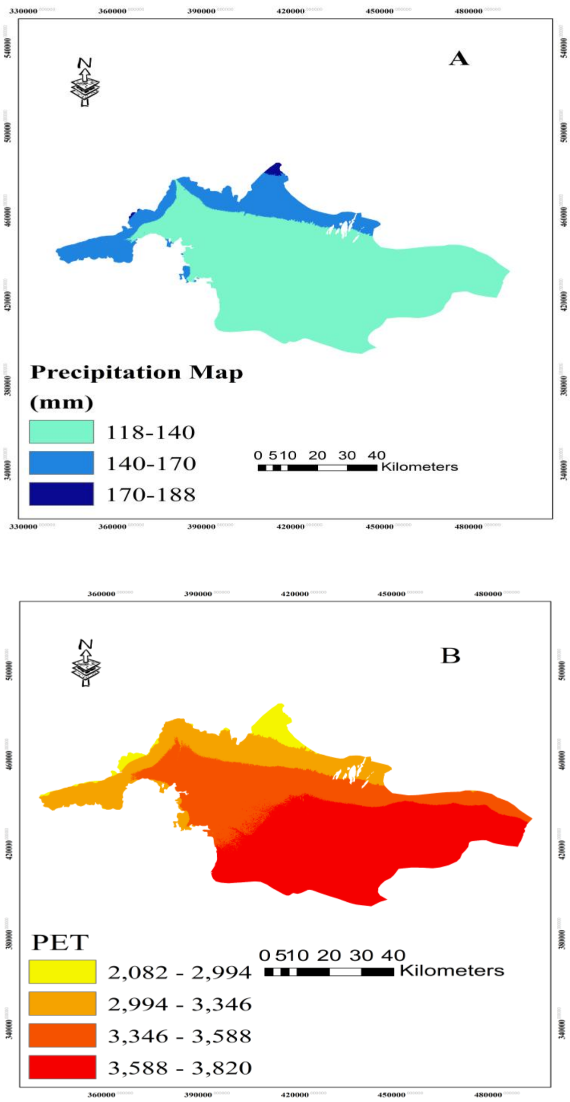


Fig. 9. Precipitation map (A) and PET map (B) in the Jaz_Murian aquifer.

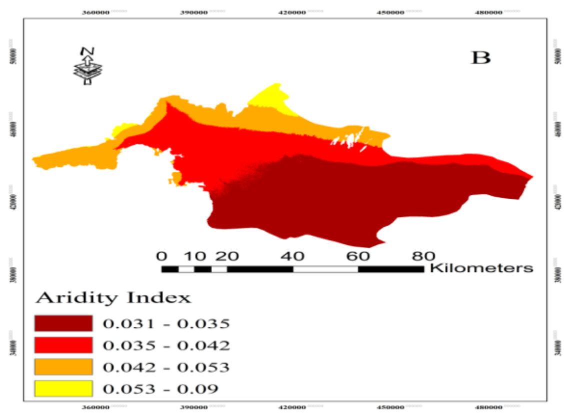


Fig. 10. Aridity Index map based on Transeau Index in the study area.

Desertification Hazard Assessment

To assess desertification hazard, water and climate criteria were determined based on IMDPA methodology for up to 5835 km^2 in the Jaz_Murian aquifer. According to Fig. 4, the unit hydrograph showed a decreasing trend in the Jaz_Murian aquifer, approximately 0.6 meter per year, which indicates degradation in the groundwater resources in this region. Regarding Table 2, the desertification hazard maps based on groundwater depletion index were produced and classified for Jaz_Murian region in severe classes of desertification (Fig. 11).

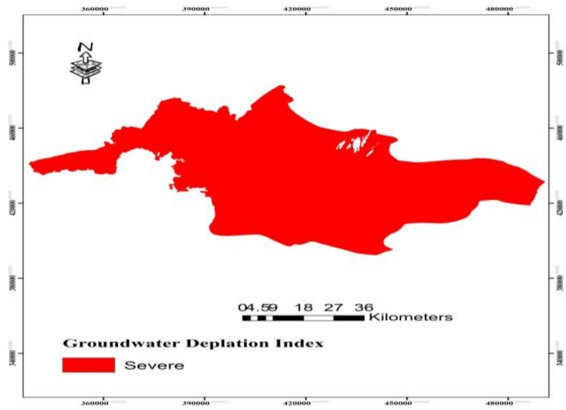


Fig. 11. Desertification hazard classification related to groundwater depletion index.

Electrical Conductivity, Sodium Absorption Ratio, and Cl concentration are the major factors of water quality degradation in Iran. Fig. (8) shows the situation of these indices in the Jaz_Murian aquifer. Based on Electrical Conductivity Index (Ec), the Jaz_Murian aquifer classified in low, moderate, high and severe classes of desertification hazard. According to SAR and Cl indices, the region is classified in two (low and moderate) and one (low) classes of desertification, respectively (Fig. 12).

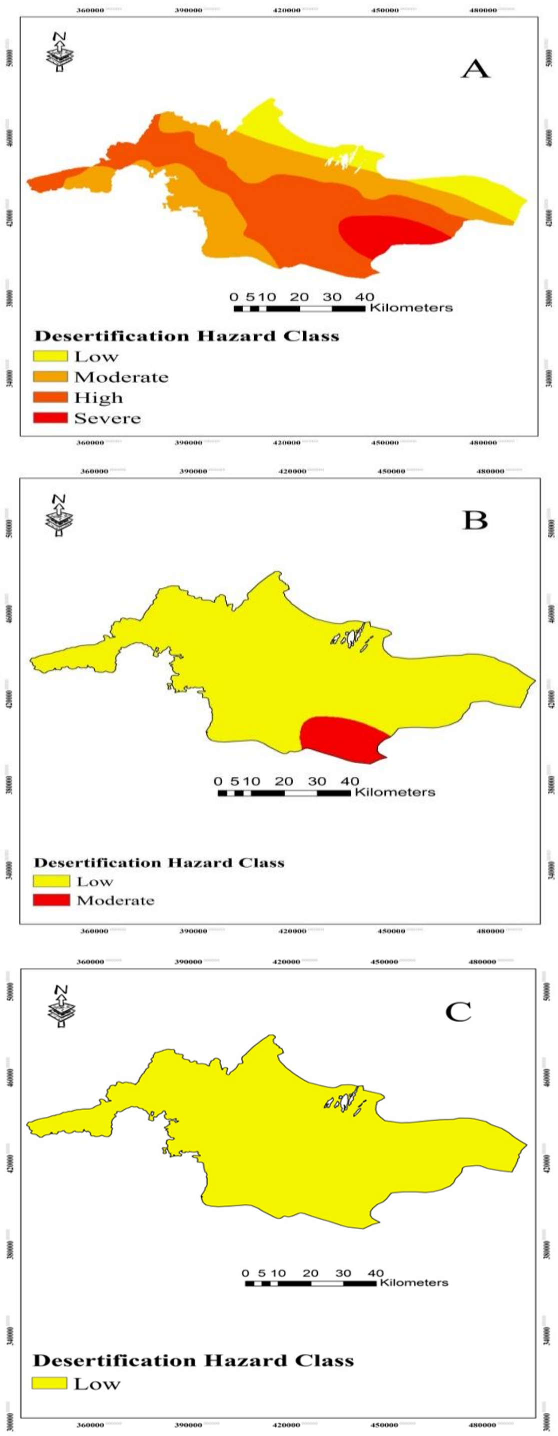


Fig. 12. Desertification hazard map related to Electrical Conductivity Index (A), Sodium Absorption Ratio Index (B) and Cl Concentration Index (C).

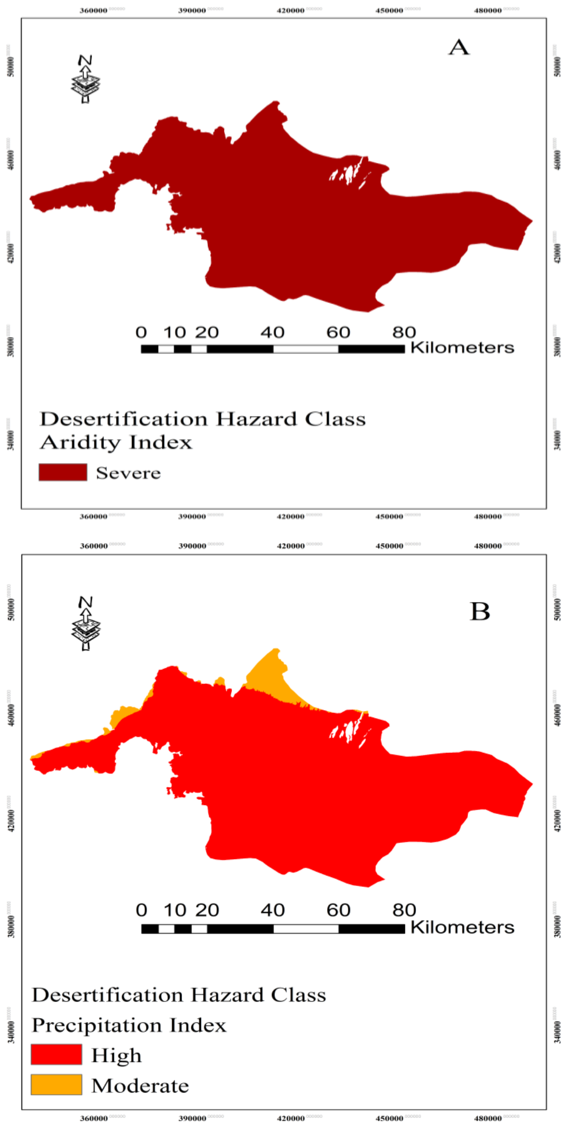


Fig. 13. Desertification hazard map related to climate indices: Aridity Index (A) and Precipitation Index (B).

Considering that climate is a major factor in the assessment of desertification hazard, especially in arid and semi-arid regions, the climate criterion was assessed based on precipitation and aridity indices. Fig. 13 shows desertification hazard maps of the climate indices. According to aridity index, the region was classified in the high and severe classes and based on precipitation index classified in high class of desertification.

Finally, the desertification hazard intensity of Jaz_Murian aquifer was obtained based on water and climate criteria by geometric average of scores of indices (Fig. 14). Table 3 shows the area of sensitivity classes to desertification hazard in the Jaz_Murian aquifer.

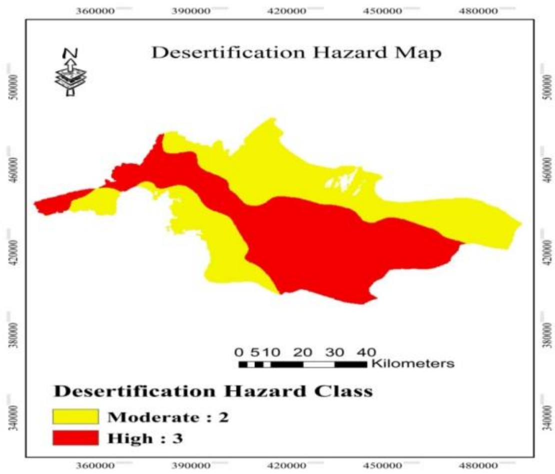


Fig. 14. Desertification hazard map based on water and climate criteria.

Table 3. Area of sensitivity to desertification hazard in Jaz_Murian region.

Desertification Hazard Class	Area(Km^2)	Area (%)
Moderate	2855.625	49
High	2976.9375	51

Discussion

Nowadays, desertification is known as a serious threat in arid and semiarid regions, which cover about 40% of the global land surface and are populated by approximately one billion humans (Verón *et al.*, 2006). As the Jaz_Murian region is located in an arid region and keeps pace with agricultural activities development and rising demand, so these factors decline water levels in the wells of the region because over exploitation and gradually make the situation prone to desertification. As a result, the average water table has dropped from 408 m to 401 m during the years from 2002 to 2013 with an annual rate of declining about 0.6 m. Excessive withdrawal of groundwater by pumping for irrigation and domestic use is the most significant human activity that affects the amount of groundwater in Jaz_Murian aquifer.

When the rate of groundwater discharge is greater than the rate of groundwater recharge, water level decreases. Moreover decrease in precipitation results in reduced recharge that has consequently strained groundwater resources resulting in lowering of the water table and deterioration of groundwater quality in the Jaz_Murian aquifer.

In the past years, rapid population growth has significantly increased demand on groundwater resources. Moreover, The overexploitation of wells can generate multiple cones of depression that result in "reduction in the amount of base flow to streams, alter the direction of ground water flow within an aquifer, and capture water from adjacent aquifers" (Taylor and Alley, 2001). Moreover, with the reduction in groundwater quantity, the quality of groundwater also declines. Gradually, this process will lead to socio-economic problems for farmers because agriculture is the only source of income and livelihood for the largest population that lives in the Jaz_Murian region. The results indicated that about 49 and 51 percentage of the area have fallen in moderate and high classes of desertification, respectively, that needs to introduce management strategies in order to combat to desertification.

Conclusion

Because a major threat is induced by human activities and especially overexploitation of water resources for agriculture, this result can be considered one of the major fields of intervention introducing a series of irrigation methods that reduce evapotranspiration.

As evapotranspiration is high in this region and farmers employ traditional irrigation methods (flood irrigation), therefore management strategies should emphasize on modification of irrigation methods and decreasing agricultural activities.

In addition, water plays a critical role in providing income and sustainable development for rural areas, so it can be concluded that evaluation of desertification hazard is important for future management to ensure sustainable development and devising sound combat strategies against desertification.

In addition to the technical methods for the control of this phenomenon, considering economic and social plans for reducing pressure on groundwater resources is necessary for this region.

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