DESERTIFICATION ASSESSMENT USING THE ANALYTIC HIERARCHY PROCESS AND GIS IN SOUTHEAST IRAN

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ABSTRACT. Studying the factors influencing desertification progress of a region and its resulting zoning can be effective in helping to reduce the damage of this phenomenon. This study attempted to investigate the factors influencing desertification progress; hence, it proceeded to zone Sistan and Baluchestan Province using three analytic hierarchy processes, Expert Choice software and a geographic information system. First, factors affecting desertification progress were checked and they were then used to determine the most important aspects in order of priority as follows: climatic elements (temperature, evaporation, wind, precipitation and humidity), morphology (topography and slope) and human factors (land cover). Then, a zoning map of desertification-prone lands was prepared. The results showed that, in terms of hazard progress of these lands, there were five desertification hazard regions in Sistan and Baluchestan Province with an area of about 187 502 km^2 and high hazard regions covering approximately 29.2% of the province were located in the north of the province. High hazard regions with an approximate area of 3.20% of the total area of the province were mostly located in Saravan, Khash, and the surrounding areas; medium hazard regions with an approximate area of 19.6% were in Iranshahr and the southeastern part of the province; low hazard regions with an area of about 18.2% were in the southern parts of the province; and very low hazard regions with an approximate area of 12.7% were in Nikshahr and the southern parts of the province.

Key words: zoning, natural disaster, Sistan, Baluchestan, hazard

Introduction

Desertification has been considered by international organizations and societies as an environmental problem, as well as a human disaster. After the two challenges of climatic change and freshwater shortage, desertification is considered the third most important challenge of the international community in the twenty-first century (Ekhtesasi and Mohajer 1998).

At present, desertification is a problem for more than a hundred countries, including developing countries like Iran. This phenomenon consists of processes resulting from both natural factors and inappropriate behaviour of humans in nature.

According to one definition, desertification is reduced land capability due to one or a combination of various processes, such as wind and water erosion, vegetation destruction, destruction of water resources, soil salinization, and so on, which are intensified by environmental and human factors. In this regard, human factors play a fundamental role in emerging desertification and underlie the increased rate of desertification in different regions. Two-thirds of Iran is located in an arid or semi-arid zone, around 450 000 km^2 of which constitute deserts (Farahi and Mohammadi 2012). Drought is a normal recurrent feature of climate and causes a serious hydrological imbalance. It occurs in virtually all climatic zones, but its characteristics vary significantly from one region to another. Drought is a temporary aberration, which is due to low rainfall (Sharifikia 2013). Various geomorphological environments are also prone to substantial dust generation. Water plays a substantial role in the formation of mineral dust particles, even in arid zones (Varga 2012).

A natural disaster that causes a lot of damage every year, especially in the arid and desert regions of the world, is the sandstorm (Omidvar 2006). Wind erodes about 28% of the world's dry land (Webb *et al.* 2006). In addition, sand and dust storms, not only in Iran but also in other Asian, African and American countries, have caused multiple financial and human losses (Lin 2002). Among these, the storm of northern China in 1993 that killed 85 people and destroyed nearly 373 000 ha of agricultural crops (Youlin *et al.* 2001), and

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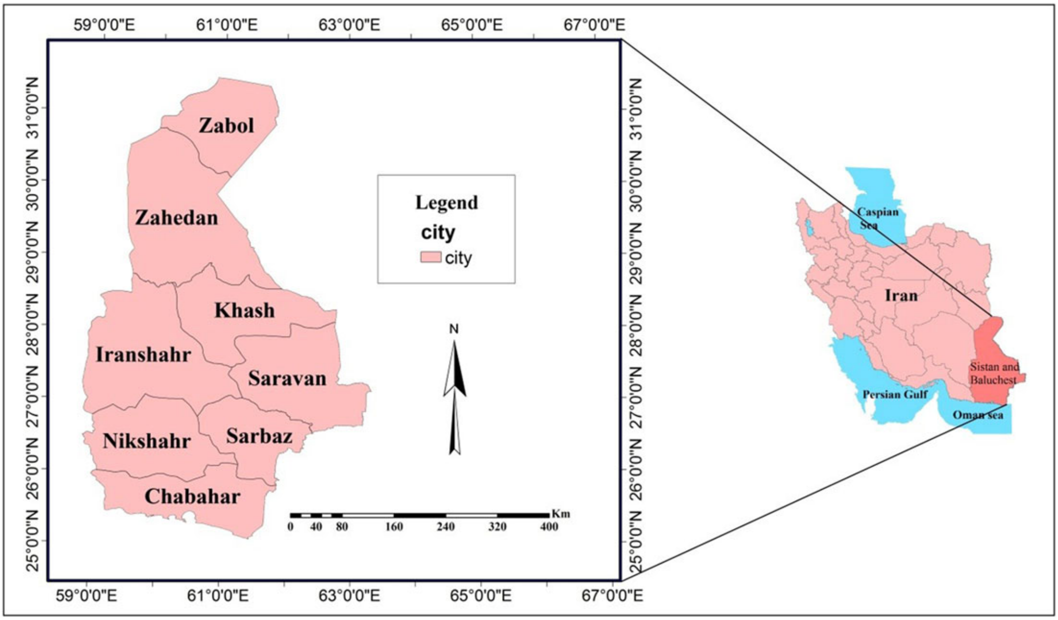

Fig. 1. Situation of the studied region.

Table 1. Preference values for paired comparisons.

Preferences (oral judgment)	Numerical value
Completely preferred or most desirable	9
Very strongly desirable or preferred	7
Strongly desirable or preferred	5
Slightly preferred or desirable	3
Preferred with less desirability or slightly less important	1
Preferences between the above intervals	2, 4, 6, 8

Source: Qodsipour (2008).

the displacement of at least 161 million tonnes of soil in Canada at a cost of US$249 million can be cited (Squires 2002). Sandstorms are included among the important atmospheric phenomena that have developed in many deserts and arid regions of the world and great attention has been paid to them in recent years (Wetphal 2006). These events cause great damage and loss every year worldwide (Youlin *et al.* 2001). Sometimes, the physical and financial damage, which is very difficult to avoid, requires more investment and allocation of resources. However, in many cases, in addition to compensation for the extensive financial loss, there are massive losses of life, since diseases, allergies etc. make up a large share of loss of human life (Miri 2005).

Iran is located on the dry desert belt of the world and two-thirds of its area is located in the arid territory (Maghsoudi 2006). Studies have shown that 14 provinces have been affected by wind erosion, with 229 174 ha ranked as the highest (Iranmanesh *et al.* 2005). Annual storms also cause great damage in this area.

The desertification phenomenon is more intensive in regions like Sistan and Baluchestan. Therefore, dealing with this phenomenon in all involved regions would be very effective and beneficial. Appropriate and efficient management solutions and methods could reduce the intensity of desertification and even prevent its spread.

Some studies have been performed on desertification, which include Harasheh and Tateishi[1] who conducted research in the western region of Asia to produce a desertification map. Accordingly, some processes such as destruction of vegetation, water and wind erosion, and soil salinization were considered the most important desertification processes. Wang *et al.* (2006) investigated the changes of seven parameters of climatic and human factors during a 50-year period to determine the key aspects of desertification in China. The results showed that both climatic factors and

[1] http://www.gisdevelopment.net/aars/acrs

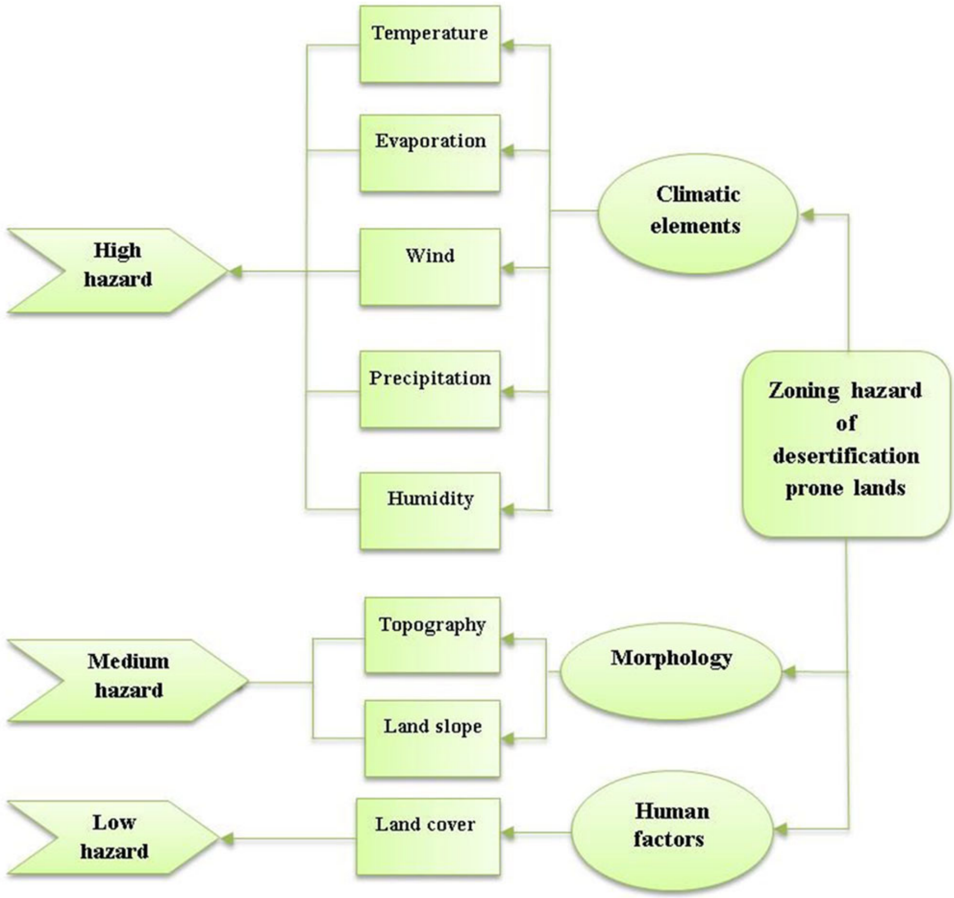

Fig. 2. Decision-making hierarchy for zoning hazard progress of desertification-prone lands in Sistan and Baluchestan Province.

human activities are involved in the process of desertification. According to James and Reynolds (2013), desertification, mainly due to adverse human activities such as excessive agriculture, fuel collection, irregular grazing of domestic livestock, deforestation and irrigation methods, often causes weather deterioration and finally dryness. Agostino Ferrara *et al.* (2012) evaluated the operation and costs of assessing a key index system by monitoring the vulnerability of desertification in the Mediterranean region. Final output of the environmental sustainability index method was the synchronization of four indices of weather, soil, vegetation and land management based on 14 primary variables. Jafari *et al.* (2011) studied the effect of soil properties on the desertification Sagzisangfarsh of Isfahan and determined the soil index score of the studied region based on Iranian Model of Desertification Potential Assessment (IMDPA). In this model, desertification potential classes were low, average, high and very high and there was no very low level. Type and intensity of desertification in Bari Province, Italy was examined by the Medalus model. In this study, six indices of soil, climate, vegetation, land use, quality management and human force index were considered and finally a desertification map of the region was drawn using the geometric mean of the mentioned indices (Ladisa *et al.* 2002).

Rafiq and Tahiz (1983) prepared a set of desertification maps for the Takhal Desert region on a scale of 1:1 000 000 using satellite images from 1972 and 1980. They observed that vegetation was extensively destroyed during this period. Land cultivation, excessive grazing and bush removal were mentioned as the main reasons

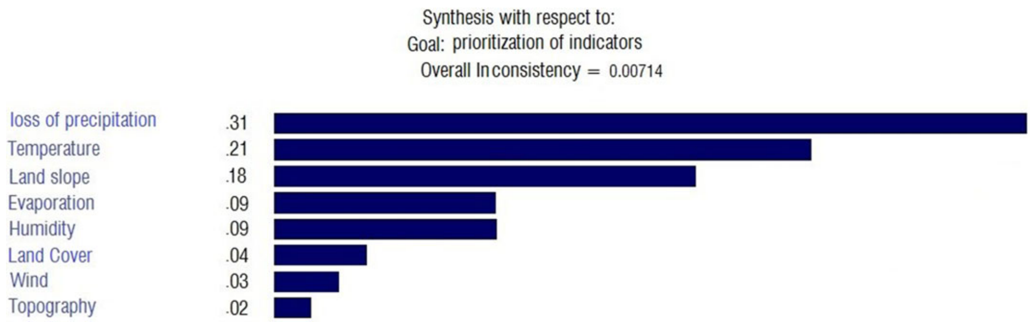

Fig. 3. Determining effective criteria for hazard progress zoning of desertification-prone lands in Sistan and Baluchestan Province.

Table 2. Binary comparison of effective factors in hazard progress of desertification-prone lands in Sistan and Baluchestan Province.

Factors	Precipitation	Temperature	Land slope	Evaporation	Humidity	Land cover	Wind	Topography
Precipitation	1	2	2	3	5	5	9	9
Temperature	0.5	1	1	3	3	7	5	9
Land slope	0.5	1	1	3	2	3	5	9
Evaporation	0.3	0.3	0.3	1	1	3	3	7
Humidity	0.2	0.3	0.5	1	1	3	3	7
Land cover	0.2	0.1	0.3	0.3	0.3	1	1	3
Wind	0.1	0.2	0.2	0.3	0.3	1	1	2
Topography	0.1	0.1	0.1	0.1	0.1	0.3	0.5	1

Table 3. Calculating weight of factors effective in hazard progress of desertification-prone lands in Sistan and Baluchestan Province.

Evaluation items	Weights
Precipitation	0.31
Temperature	0.21
Land slope	0.18
Evaporation	0.09
Humidity	0.09
Land cover	0.04
Wind	0.03
Topography	0.02

for desertification in this region (Kharin and Orlovsky 1986). In a study investigating the present condition of desertification, vegetation destruction was considered the main cause and the most severe cases were observed in the areas surrounding villages and livestock watering wells. Zhu *et al.* (1988) prepared maps of desertification changes in China during the previous 100 years (covering an area of 162 000 km^2). They concluded that the scope of desertification exceeded 50 000 km^2 during this period, which was caused by not observing cultivation patterns (23.3%), inefficient use of water resources (8.6%) and consequently soil progression (5.5%). Szaboles (1989) reported that, after Soviet Union countries, India, China and Pakistan, Iran has the highest rate of saline lands in Asia. This study was concerned with the geologic and geomorphologic features, human intervention and its impact, along with their interaction. The locations most vulnerable to flooding were recorded. *Geographic information system* (*GIS*) processing was used to present the results. The relief of the region, the geologic and geomorphologic conditions. The stream flow features, the drying up of wetlands and lagoons, the elimination of vegetation cover, the urbanization of streams and the deficient draining networks are the main causes of flooding in the study area (Skilodimou *et al.* 2003).

Zehtabian *et al.* (2006) attempted to evaluate the desertification capability of lands in Mahan Region, Kerman, Iran using Iranian Classification of Desertification (ICD) and Food and Agriculture Organization-United Nations Environment Programme (FAO-UNEP) analytical methods. Based on the results, the most effective process in the desertification of this region was water erosion. Kashaki *et al.* (2006) prepared a map of the desert areas of Khorasan Province based on climatic parameters and use of a GIS and concluded that desertification processes were active in this region. Zehtabian *et al.* (2003) determined the intensity of wind erosion in Kashan Region using a

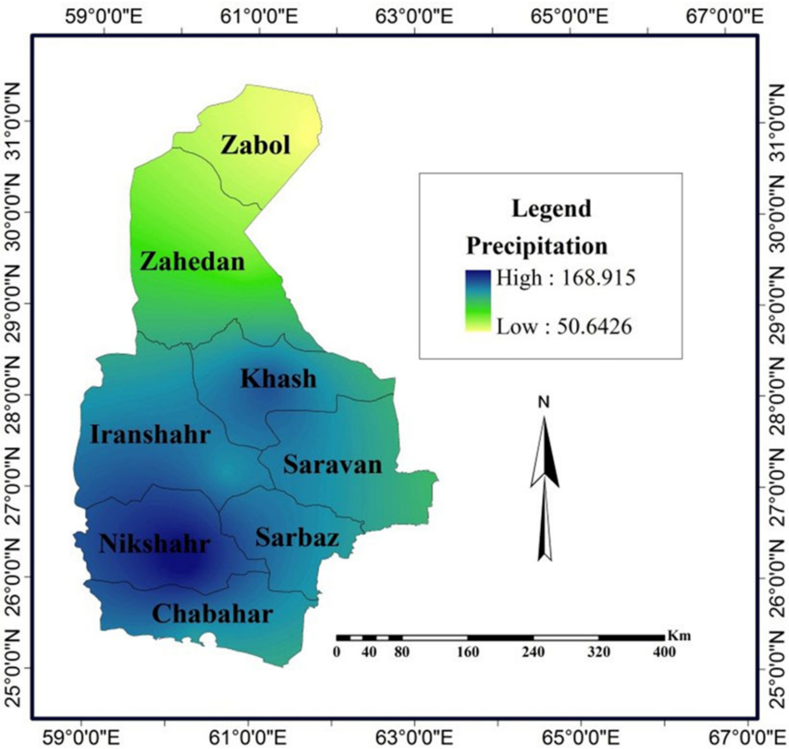

Fig. 4. Zoning annual precipitation of the province.

desertification model. They concluded that, out of the entire area studied which was 616 km^2, about 118.2 km^2 was ranked as very severe. Hosseini *et al.* (2004) developed a method to identify and classify desert regions considering Tehran's climatology. The results showed that specifications of the region inside and outside the desert and the non-desert strip were distinctively separable. Azimpour *et al.* (2009) evaluated the results of an *analytical hierarchy process* (*AHP*) model for landslide hazard zoning of Ahar Chai Drainage Basin. They showed that geological and human factors had the maximum and minimum weights in this regard, respectively. Factors such as lithology, slope, fault, direction of slope, height, distance to river, type of use and distance to roads were the most important elements of landslide, respectively. Ranjbar and Roqani (2009) performed landslide hazard zoning of Ardal city using AHP. They demonstrated that, in this city, slope was the most important factor affecting landslide and lithology was considered the second most important factor.

In this research, attempts were made to investigate the factors affecting desertification progress in the region and its resulting zoning, which can be used to reduce hazards resulting from this phenomenon. By investigating factors affecting desertification progress, Sistan and Baluchestan Province was zoned using AHP, Expert Choice software and GIS. The most important factors in order of priority included climatic elements (temperature, evaporation, wind, precipitation, humidity), morphology (topography and slope) and human factors (land cover). Finally, according to the information obtained, a zoning map of desertification-prone lands was prepared.

Study area

Sistan and Baluchestan Province with an area of 187 502 km^2 and geographical coordinates of 25° 3′ to 31° 28′ N and 58° 47′ to 63° 19′ E is located in the southeast of Iran. This vast province has 900 km and 300 km common borders with Pakistan and Afghanistan, respectively. In the south, it has a water border of approximate length 270 km with the Sea of Oman. It is surrounded by Khorasan Province with a border length of 190 km in the

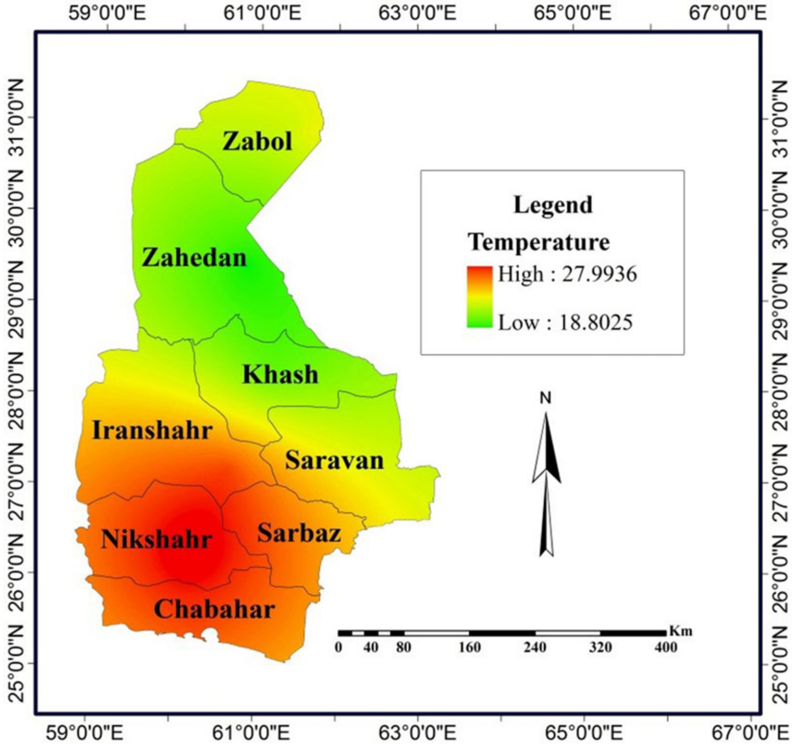

Fig. 5. Zoning annual temperature of the province.

north and northwest, and Kerman Province with a border length of 580 km and Hormozgan Province with a border length of 165 km in the west.

Considering its geographical situation, Sistan and Baluchestan Province is influenced by various atmospheric conditions like wind flows from the Indian subcontinent and consequently monsoons from the Indian Ocean on the one hand, and high pressure from middle latitudes on the other. In addition, extreme heat is the most observable climatic phenomenon of this region. In general, Sistan and Baluchestan Province has a dry and desert climate.

Methods

The purpose of the research was to zone hazard progress of desertification-prone lands using AHP and Expert Choice software in a GIS environment. Zoning hazard progress refers to defining the regions in which desertification has been exacerbated as a result of factors such as climatic elements, as well as morphologic and human factors, and led to more expansion of desert areas. In the 1977 Nairobi Conference on Desertification, development of desert conditions was defined as the trend causing loss of biological production, reduction of biomass, decreased capacity for plant resources, and reduction in agricultural production or destruction of the human environment.[2]

In this study, GIS was used for zoning, which involved data entry, data analysis and generating data layers. AHP was used to increase accuracy in zoning the hazard progress of desertification-prone lands and its validity was assessed using Expert Choice software. Then, the priority of the factors and elements was determined. This method was based on the analysis of complex issues and creating a hierarchy (Chen 2001). The main advantage of AHP is that it analyses a challenging and complicated problem and creates a hierarchy (Shaw and Wheeler 1985) by weighing the factors in a logical way to identify their role according to priority (Ahmadi 2003). AHP is a flexible, powerful and simple method for making decisions in situations where there are opposing

[2]UNEP, http://www.sdnpbd.org/sdi/international_days/wed/2006/ UNEP

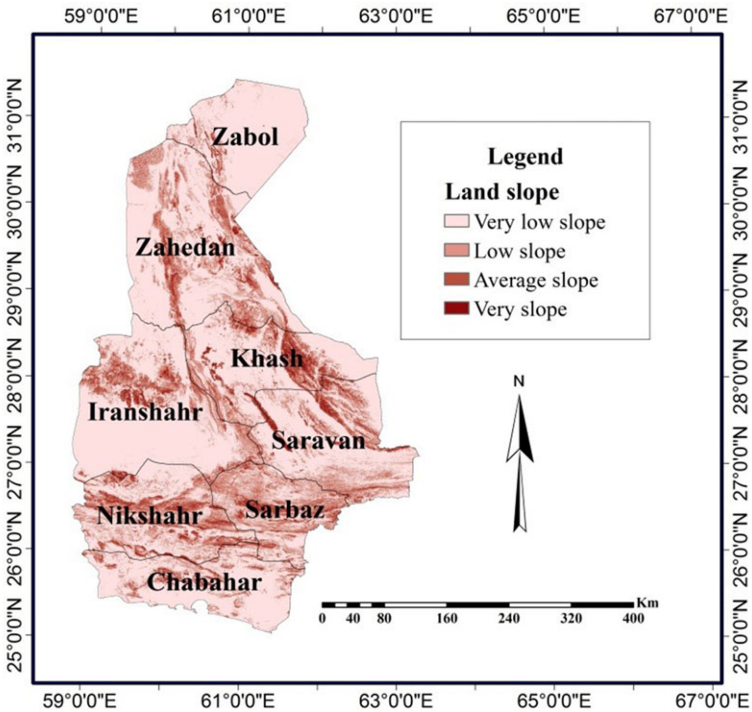

Fig. 6. Zoning very slope of the province.

decision-making criteria that challenge selection between choices (Zebardast 2001). This process involves different options in decision-making and provides the possibility for sensitivity analysis of criteria and subcriteria. Additionally, it is founded on paired comparison, which facilitates judgments and calculations. It also shows the compatibility and incompatibility of decisions, which is one of the major advantages of this technique in multi-criteria decision-making (Ghodsipour 2012). This technique consists of three major steps: generating a binary comparison matrix; calculating weights of criteria; and compatibility. Moreover, if the calculated consistency ratio is equal to or less than 0.1, the consistency of the comparison matrix is acceptable; otherwise, our judgments are inconsistent and the entry of the ratios should be revised (Nikmardan 2007). Expert Choice software is used for performing AHP and paired comparisons, as well as making and generating decisions. AHP aims to determine the effective factors and elements, and perform paired comparisons between the elements. Extracting and determining weight is an important step for extracting decision-making criteria. The weight obtained for each criterion is stated as a number, which indicates the relative importance of that criterion with respect to other criteria in specific conditions. Weights are usually normalized in a way that their sum equals 1 (Bahador 2007).

Discussion

By determining a set of criteria for evaluating decision-making options, it is necessary to demonstrate each layer as a map layer in the GIS-based database (Parhizkar and Ghafari 2006). In order for an attribute to be applicable, it is necessary to have a specified scale. Thus, criteria maps can be classified, according to measurement scales, into quantitative and qualitative ones.

Using the AHP model and Expert Choice software in GIS for studying Sistan and Baluchestan Province required going through the following steps:

1. Identifying effective factors for the progress of lands prone to desertification in the province: in this step, based on the comparative studies, works of other researchers and effective factors for land-cover changes (such as slope,

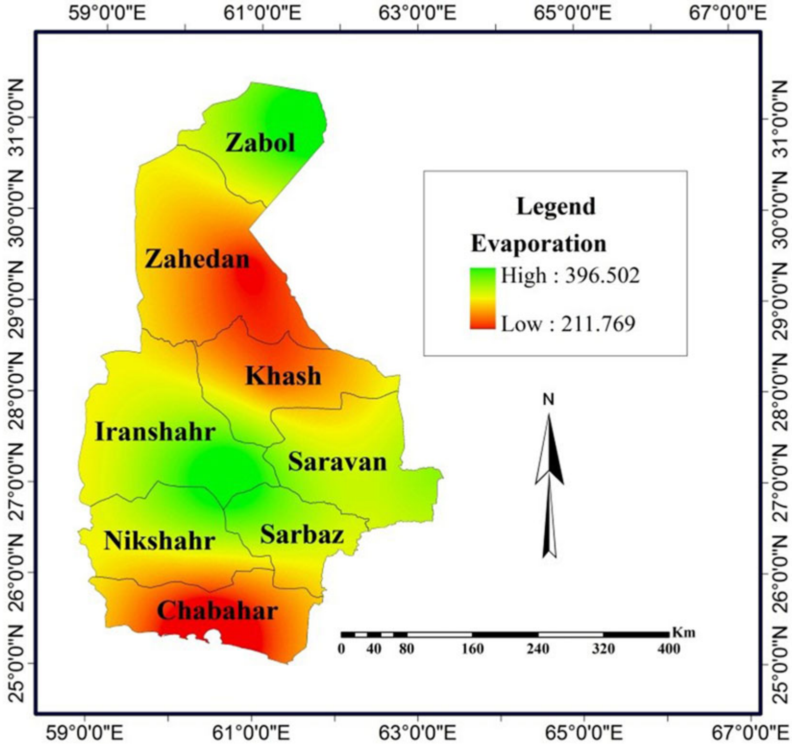

Fig. 7. Zoning annual evaporation in the province.

topography, land cover, temperature, rainfall, etc.) were generally investigated. Then, after classifying these factors, three levels of the involved morphologic, climatic, and human factors were identified and used to classify effective elements.

2. Prioritizing effective elements: since there are different effectiveness rates for the studied factors in the investigation of lands prone to desertification, it is necessary to correctly prioritize these elements. To pass through this step and find the importance degree of the elements, a part of the work was performed by field studies, questionnaires and the input of experts, and another part was done using paired comparison of the elements in the AHP model. In the AHP decision-making model, quantitative criteria include discrete or continuous factors with their preferences and are presented in Table 1, along with the qualitative criteria. Finally, as mentioned by Foreman, a decision-making system should be capable of formulating an issue. This method considers different options, including quantitative or qualitative as well as discrete or continuous, makes their combination feasible, and then formulates them (Qodsipour 2008).
3. Preparing digital layers required for zoning and combination in the Raster Calculator: after recognizing effective factors using Arc GIS software, the required layers were prepared. Considering the prioritization performed in the previous section, among the effective factors, eight layers in three general parts were finally prepared as follows:
   a. Climatic factors: to prepare the existing layers, meteorological data of the stations of the province were gathered and entered into Arc GIS software after standardization. Five layers were prepared as follows: total annual precipitation; mean temperature; total annual evaporation; mean relative humidity; and mean wind speed.
   b. Morphology: two topographic layers and slope direction were prepared for the province in order to provide layers relating to the morphology of this province using a *digital elevation model* (*DEM*).

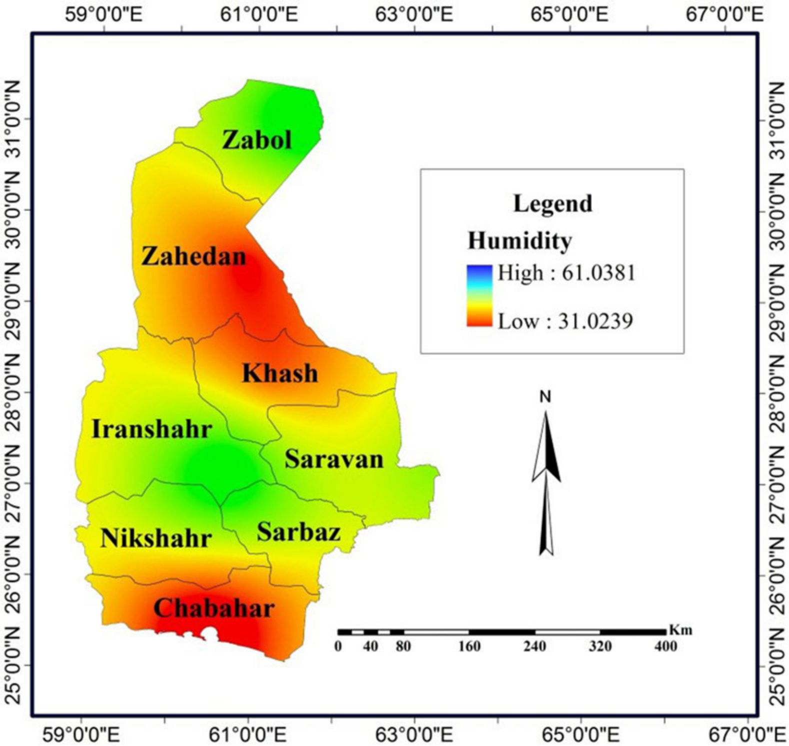

Fig. 8. Zoning annual humidity in the province.

c. Human factors: among the effective human factors which can be related to the progress of lands prone to desertification in the province is land cover. The land cover layer of the province was obtained using the land capability maps of this province and land cover in Arc GIS software.

In the next step, after providing all the layers effective in the progress of desertification-prone lands, the weight of each layer was determined based on the AHP method and considering their importance. Maximum weight belonged to the layer which played the most important role in the progress of desertification-prone lands in the province (Tables 2 and 3). Weight value of the layers varied from 1 to 9, 1 for the weak factor and 9 for the most effective factor (Varnes 1984). After weighing and finalizing the data layers, vector layers were converted into Raster ones in Arc GIS software. Finally, using the relative weights of the layers according to the Raster Calculator, a progress hazard zone of lands prone to desertification in Sistan and Baluchestan Province was prepared in five groups of regions classified as very high, high, moderate, low, and very low.

The method based on binary criteria was proposed by Saaty (1977) in the context of an AHP. In this method, binary comparison is performed to generate a ratio matrix. Binary comparisons are considered the input and relative weights are produced as the output. In the hierarchical method, first, the complex issue of the progress of desertification-prone lands is hierarchically analysed to produce components which are considered at four levels as follows (Fig. 2):

1. First level: the general purpose of a hierarchy which provides the zoning map for hazard progress of desertification-prone lands at the highest level.
2. Second level: includes determination of components and major effective constituents in the progress of desertification-prone lands which is divided into three parts (morphology, climatic elements and human factors).
3. Third level: in this part, components of the second level are divided into smaller

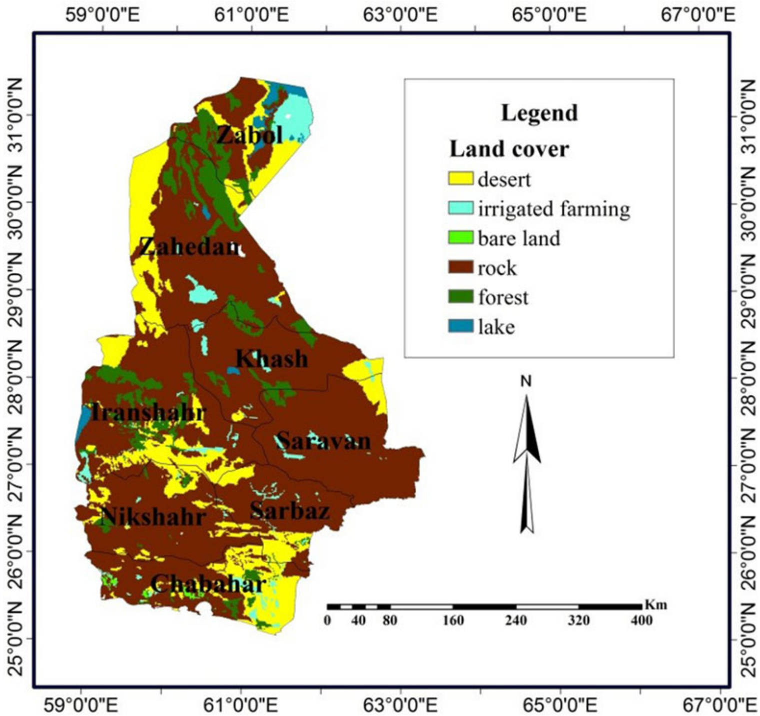

Fig. 9. Land cover in the province (Natural Resource Office, Sistan and Baluchestan Province).

components such as temperature, evaporation, topography, land cover, etc. to provide the possibility of spatial modelling and prepare the zoning map.

4. Fourth level: at this level, considering the weight obtained for the effective factors and elements using the AHP method, three classes of very high, moderate and low hazard are determined.

Calculating weight of criteria using the hierarchical method

After weighing the criteria and subcriteria using Expert Choice software with a consistency ratio of 0.007, the comparison matrix was considered acceptable. The obtained weights indicated the relative importance of precipitation compared with other criteria in the present research. In addition, topography had a minimum effect in this regard (Fig. 3).

The weight of each criterion indicates the importance level of each factor relative to others; the sum of all these factors should be 100%.

For binary comparison of factors and determining their priority, first, the factors were compared with each other and then the values related to each column of the comparison matrix were added in pairs (Table 2). In the next step, the weight of each factor was obtained. Accordingly, the factor with a higher numerical average and higher value that had a higher effect than other effective factors in desertification was introduced (Table 3).

In Table 2, for example, elements 1 and 8 of the matrix (first row and eighth column) show the priority of precipitation over topography; that is, the importance ratio of precipitation to topography in Sistan and Baluchestan Province was 9. Then, the weight of each factor was calculated using the AHP model and Expert Choice software and similar results were found, which demonstrated that these two methods were complementary (Table 3).

Therefore, each factor with a higher numerical average had a higher value and was introduced as the factor with a higher effect in terms of the progress of desertification-prone lands. As can be observed, precipitation and temperature had maximum and topography had minimum influence on the studied region.

Data layers considered for providing the final zoning map for the hazard progress of

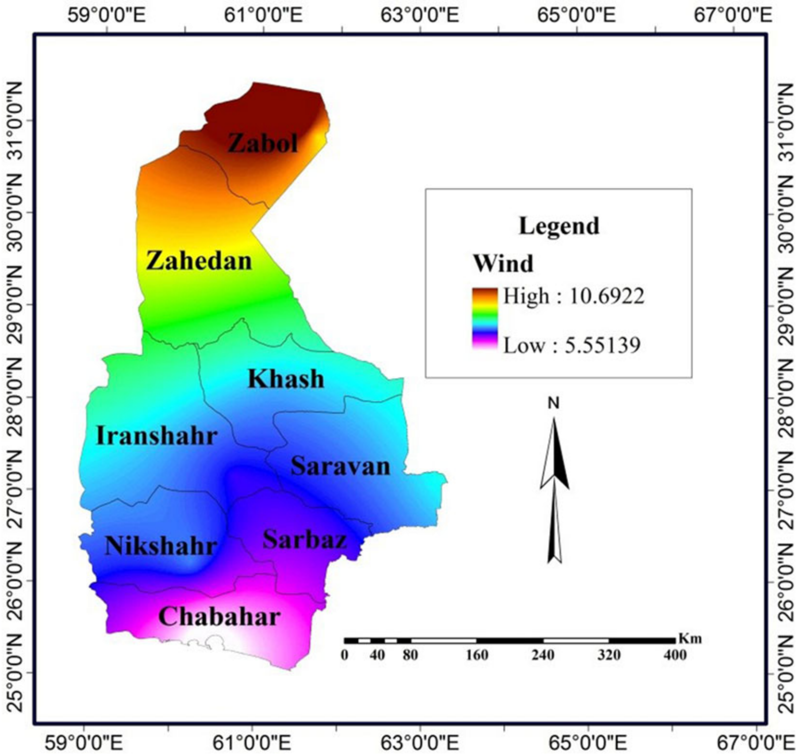

Fig. 10. Zoning annual wind of the province.

desertification-prone lands were prepared using land cover maps, DEM, and temperature, wind, precipitation and humidity data in Arc GIS software (Figs 4–11).

Analysing layers effective in progress of desertification-prone lands

1. Total annual precipitation: maximum and minimum annual precipitation were in the southern and northern parts of the province in Zabol and Zahak stations, respectively. The amount of precipitation increased from north to south.
2. Mean annual temperature: maximum and minimum temperatures were in southern and central parts of the province in Iranshahr, Nikshahr, Kenarak and Chabahar, and also Zahedan and Khash stations, respectively.
3. Relative humidity percentage: rate of relative humidity was reduced from the south to the north of the province. Maximum humidity was observed in Kenarak and Chabahar stations and total scope of humidity in the province varied from 31% to 61%.
4. Annual evaporation: maximum and minimum rates of annual evaporation were found in Zabol, Zahak and Iranshahr, along with Zahedan, Khash, Kenarak and Chabahar stations, respectively.
5. Mean wind speed: wind speed was decreased from north to south of the province and Zabol station with a mean speed of 10.9 m s^{-1} had the maximum wind speed.
6. Slope: minimum slopes were observed in the northern parts of the province, including Zabol and Zahak, and central parts such as Iranshahr. The maximum slopes were around Khash and Bazman Heights. In sum, slope increased with the increasing height.
7. Topography: topographically, Mount Taftan determines the general process of topography in the province. The maximum height in the province belonged to Mount Taftan, which was 4070 m, and the minimum heights were in the southern plains of the province, which were about 7 m above sea level. Overall, the heights of the province were from north-west to south-east.

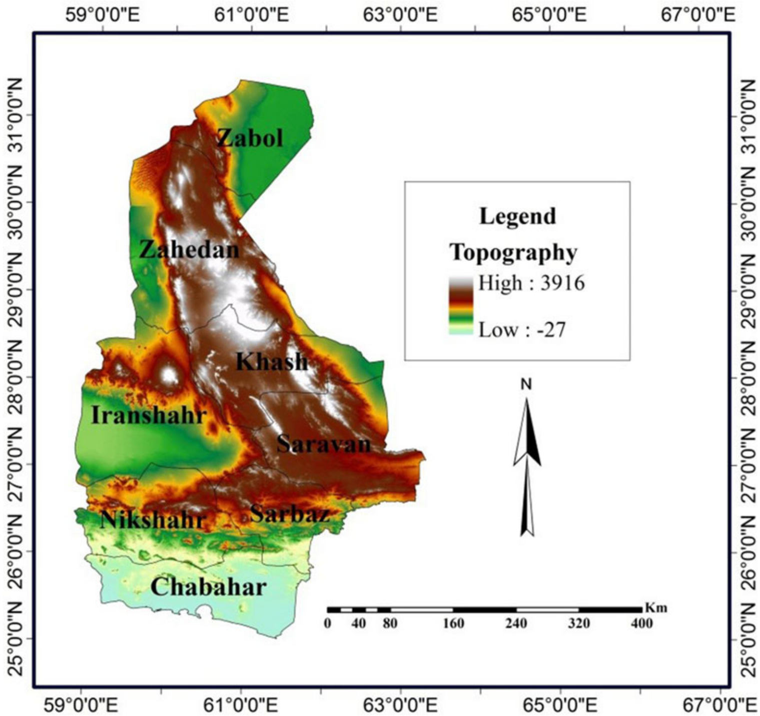

Fig. 11. Topographic map of the province (Natural Resource Office, Sistan and Baluchestan Province).

8. Land cover: from a land cover viewpoint, most parts of the province were rocky and farming was very limited; dryland agriculture was only common in some parts of the north and south, and irrigation agriculture was observed in the regions with sufficient water resources. Other land covers of the province such as meadows and desert constituted sparse parts of the province.

Finally, a zoning map of hazard progress of desertification-prone lands was prepared using the most effective layers in the progress of desertification-prone lands and their relative weights (Fig. 12).

As determined by the final zoning map of the hazard progress of desertification-prone lands in Sistan and Baluchestan Province, the hazard level considerably decreased from north to south, and the very high hazard regions were more extended than low-hazard regions.

Conclusion

One of the most important measures in environmental planning is the evaluation and investigation of the effectiveness rate of environmental hazards in a region. Zoning a region against environmental hazards facilitates the possibility of planning. Progress of desertification-prone lands is linked to many complex natural and human factors.

The desertification phenomenon leads to the development of active deserts. In addition, the dominance of difficult climatic conditions in different regions along with severe erosive winds seriously threaten environmental situations in all cities of the province. It seems that AHP is the most logical method for identifying the effective factors. This method not only determines the effect degree of each factor, but also hierarchically illustrates the relationship and coordination between effective factors in the progress of desertification-prone lands. Among the given weights, climatic elements with 0.76 and human factors with 0.04 had maximum and minimum weights, respectively. Factors such as precipitation, temperature, land slope, evaporation, relative humidity, land cover, wind and topography were the most effective factors in zoning the hazard progress of desertification-prone lands, respectively. Using the prepared maps and combining them with each other, landslide-prone areas of the province were identified. The

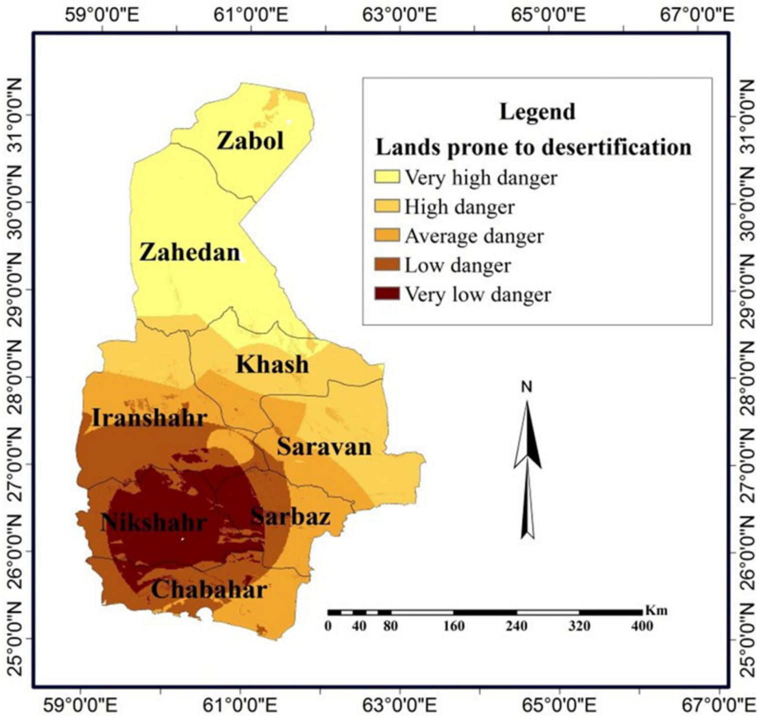

Fig. 12. Zoning of hazard progress of desertification-prone lands in Sistan and Baluchestan Province.

results showed five regions with a desertification hazard in Sistan and Baluchestan Province covering an area of around 187 502 km^2 as follows: very high hazard regions with an area of about 29.2% of the province were in the northern parts; high hazard regions with the area of about 20.3% were mostly in Khash, Saravan and the surrounding areas; medium hazard regions with an area of about 19.6% were in Iranshahr and south-eastern parts; low hazard regions with an area of about 18.2% were in southern parts; and very low hazard regions with an area of about 12.7% were located in the southern parts and Nikshahr. As was determined, more than half of the province was located in medium and high hazard regions. Thus, to deal with the hazards which affect the lives of people, forward planning and increasing attention of the authorities are necessary.

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References

Ahmadi, H., Feiznia, S., ShariatJafari, M. and Esmaeili, A., 2003. Hazard zoning of mass movement using two methods of multivariate regression (MR) and analytic hierarchy process (AHP) in GarmiChah Basin. *Iranian Journal of Natural Resources*, 56, 323–335.

Azimpour, A., Sadough, H., Dalal Oqli, A. Servati, M.R., 2009. Evaluating results of AHP model in landslide hazard zoning (Ahar Chai Drainage Basin). *Journal of Geographical Space, Islamic Azad University, Ahar Branch*, 26, 71–87.

Bahador, M., 2007. *Design models of locating of urban parking using AHP method combined with GIS analysis*. MS thesis, Faculty of Civil Engineering, University of Science and Technology, Iran.

Chen, W., 2001. Implementing an hierarchy process by fuzzy integral. *International Journal of Fuzzy System*, 3, 493–502.

Ekhtesasi, M.R. and Mohajer, S., 1998. Classification and desertification intensity of lands in Iran. In: *Proceedings of Conference on Desertification and its Different Methods*. Forest and Pasture Research Institute, 121–134.

Farahi, M. and Mohammadi, M., 2012. Grain size distribution and composition of modern wind Sands, Tasouki-Rigchah area, Sistan, Iran. *Scholarly Journal of Agricultural Science*, 2 (6), 111–114.

Ferrara, A., Salvatib, L., Saterianoc, A. and Nole, A., 2012. Performance evaluation and cost assessment of key indicator system to monitor desertification vulnerability. *Journal of Ecological Indicators*, 23, 123–129. doi:10.1016/j.ecolind.2012.03.015

Ghodsipour, S.H., 2012. *AHP*. Amirkabir University Press, Iran.

Hosseini, M., Karami, S.A. and Khosrowshahi, M., 2004. Developing a method for identifying and separating deserts from climatic viewpoint; Case study of Tehran. *Iranian Journal of Desert and Grassland Research*, 1, 39–55.

Iranmanesh, F., Arabkhedri, M. and Akram, M., 2005. Investigation of dust origins and characteristics of their spreading in Sistan's storms, Iran region, using image processing. *Journal of Pajouhesh-va-Sazandegi*, 67, 25–33.

Jafari, M., ZareChahouki, M.A., Ahmadi, H. and Abbasi, H.R., 2011. Evaluation of the effects of soil properties on desertification (case study: Segzi Pediment of Isfahan, Iran). *Journal of Desert*, 1, 1–4.

James, F. Reynolds, 2013. Desertification. *Elsevier Inc.*, 479–494. doi:10.1016/B978-0-12-384719-5.00289-6

Kashaki, M.T., Ghafourian, R. and Khosrowshahi, M., 2006. Preparing desert area map of Khorasan Province based on climatic parameters and using GIS. *Iranian Journal of Desert and Grassland Research*, 12, 1–19.

Kharin, N. and Orlovsky, N., 1986. Current situation and prediction of desertification in dry regions of Soviet Union. *Journal of Desert Fundamental Issues*, 5, 58–68. [In Russian]

Ladisa, G., Todofvica, M. and Trisorio-Liuzzi, G., 2002. Characterization of area sensitive to desertification in southern Italy. In: *Proceedings of the 2nd Conference on New Trend in Water and Environmental Engineering for Safety and Life, Eco-compatible Solution for Aquatic Environment*. Capri, Italy, 2–14.

Lin, G., 2002. Dust bowl in the 1930s and sandstorms in 1999 in the USA. In: Y. Yang, V. Squires and Q. Lu (eds.) *Global Alarm: Dust and Sandstorms from the Worlds Dry lands*. United Nations, Publication, Beijing, 109–124 (In English and Chinese).

Maghsoudi, M., 2006. Assessment of effective factors on evolution of sand landforms (case study: sand landforms of Sirjan playa). *Journal of Geographical Research Quarterly*, 38, 149–160.

Miri, A., 2005. *The effect of progressives demanding effects of wind on Zabol*. MS thesis, Tehran University, Tehran, Iran.

Nikmardan, A., 2007. *Introducing Expert Choice Software*. Jihad-e Daneshgahi Office, Branch of Amirkabir University of Technology, Iran.

Omidvar, K., 2006. Synoptic analysis of sandstorms in the desert city of Yazd-Ardakan. *Geographical Research Quarterly*, 81, 43–58.

Parhizkar, A. and Ghafari G., 2006. *Geographic Information System and Multi-criteria Analysis*. Samt publication, Tehran.

Qodsipour, S.H., 2008. *Analytic Hierarchy Process (AHP)*, fifth edition. University of Sanati Amirkabir Publication, Tehran.

Rafiq, M. and Tahiz, M.A., 1983. *Provisional Metrology for Assessment and Mapping of Desertification*. FAO, Rome, 13–25.

Ranjbar, M. and Roqani, P., 2009. Landslide hazard zoning in Ardal city using AHP. *Quarterly Geographical Journal of Chashmandaz-e-zagros*, 1, 21–30.

Saaty, T., 1977. A scaling method for priorities in hierarchial structures. *Journal of Mathematical Psychology*, 15, 234–281. doi:10.1016/0022-2496(77)90033-5

Sharifikia, M., 2013. Environmental challenges and drought hazard assessment of Hamoun Desert Lake in Sistan region, Iran, based on the time series of satellite imagery. *Journal of Natural Hazards*, 65, 201–217.

Shaw, G. and Wheeler, D., 1985. *Statistical Techniques in Geographical Analysis*. John Wiley and Sons, Dublin, 114–131.

Skilodimou, H., Livaditis, G., Bathrellos, G. and Verikiou-Papaspiridak, E., 2003. Investigating the flooding events of the urban regions of Glyfada and Voula, Attica, Greece: a contribution to urban geomorphology. *Geografiska Annaler. Series A, Physical Geography*, 85, 197–204.

Squires, V., 2002. Dust and sand storms: An early warning of impending disaster. In: Yang Youlin, Squires, V. and Lu, Qi (eds.) *Global Alarm: Dust and Sand storms from the Worlds Dry lands*. United Nations, Beijing, 15–28.

Szaboles, I., 1989. *Salt-affected Soil. GRG (Geothermal Resource Group) Press Inc.*, Florida.

Varga, G., 2012. Spatio-temporal distribution of dust storms: a global coverage using NASA TOMS aerosol measurements. *Journal of Hungarian Geographical Bulletin*, 61 (4), 275–298.

Varnes, D.J., 1984. *Landslide Hazard Zoning: A Review of Principles and Practice*. United Nations Educational, Scientific and Cultural Organization. UNESCO, Paris, 5, 156–178.

Wang, X., Chen, F. and Donga, Z., 2006. The relative role of climatic and human factors in desertification in Semiarid China. *Journal of Global Environmental Change*, 16, 48–57. doi:10.1016/j.gloenvcha.2005.06.006

Webb, N., McGowan, H., Phinn, S. and McTainsh, G., 2006. AUSLEM (Australian Land Erodibility Model): a tool for identifying wind erosion hazard in Australia. *Journal of Geomorphology*, 78, 179–200. doi:10.1016/j.geomorph.2006.01.012

Wetphal, D., 2006. *Status and Future of Dust Storm Forecasting, Marine Meteorology Division*. Naval Research Laboratory, United States.

Youlin, Y., Squires, V. and Qi, L., 2001. *Global Alarm: Dust and Sandstorms from the World's Dry lands*, United Nations, Thailand, Bangkok.

Zebardast, E., 2001. Applying AHP in urban and regional planning. *Journal of Fine Arts*, 2, 25–33.

Zehtabian, G.R., Ahmadi, H., Ekhtesasi, M.R. and Jafari, R., 2003. Determining wind erosion intensity in Kashan Region using desertification model. *Journal of Iran Natural Resources*, 2, 145–158.

Zehtabian, G.R., Javadi, M., Ahmadi, H. and Azarnivand, H., 2006. Investigating effect of wind erosion on increasing desertification intensity and presenting a regional desertification model in Mahan Basin. *Journal of Research and Construction*, 3, 65–67.

Zhu, Z., Lin, S. and Di, X., 1988. Desertification and Rehabilitation in China. *Journal of Arid Environments*, 37(3), 419–432. doi:10.1006/jare.1997.0290

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