Desertification Hazard Zonation in Central Iraq Using Multi-criteria Evaluation and GIS

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Abstract

Human communities all around the world are threatened by desertification, especially in arid and semiarid regions. Many factors affect the severity of desertification in an area such as topography, local climate, and land use. This research develops a multi-criteria evaluation method based on the analytical hierarchy process and geographic information system for assessing the desertification hazard zonation in central Iraq. Six factors including aspect, slope, rainfall, temperature, land use, and wind speed were considered in this study. Eight experts were interviewed and questioned about the importance of each indicator, and the final weights were obtained. These weights were used in GIS to obtain the desertification hazard zonation map. The results showed that 3.89%, 7.25%, and 25.97% of the study area were classified as very high, high, and moderately affected by desertification, respectively. It was concluded that rainfall, slope direction (aspect), and land use were the most important factors affecting the desertification process in the study area.

Keywords GIS · Remote sensing · Desertification

Introduction

In recent years, there has been worldwide recognition of the problems associated with desertification. Thus far, a number of studies attempted to evaluate the impact of desertification on the human community. Desertification is a serious global challenge that affects arid, semiarid, and semi-humid areas as a result of several geological, climatic, biological, and humanistic factors (Becerril-Piña et al. 2015; Belaroui et al. 2014; Wikle 2016). It impacts human communities; therefore, its control and reduction have been key projects in national and international organizations. In particular, the assessment of desertification hazards through zonation mapping is an important research area (Farajzadeh and Egbal 2007; Ladisa et al. 2012). In the Middle East, including Iraq, the livelihoods of farmers' families in arid and semiarid regions are threatened by growing drought, as a result, the human community, agricultural areas, and livestock have been influenced seriously (Alary et al. 2016). The United Nations Convention to Combat

Desertification defines 'desertification' as the degradation of land in arid, semiarid and arid, sub-wet areas due to various factors, including climate change and human actions (Ajaj et al. 2017). In recent years, combating and reducing desertification has been one of the most significant schemes in national and international associations. Humans have influenced the surface processes of the atmosphere in the environment by reducing vegetation through decrease in soil cultivation and deforestation. By reducing vegetation, the surface thickness changes, it affects wind speeds and also reduces soil moisture. Low vegetation and low soil moisture increase the amount of soil erosion and atmospheric dust. The dust of the atmosphere affects the surface temperature and provides a drop of rainfall. Droughts, as well as high population growth and uncontrollable land management, are the direct causes of desertification. Dust is mainly produced by airborne salt particles that affect the surface of the soil and release fine particles in the air (Okin et al. 2006). Dust can be transported around the world from dry and semi-dry places. Atmospheric dust or aerosols affect the regional climate through the effects of dust on light scattering and light absorption. Dust affects the properties of clouds and atmospheric chemicals. Desert dust can play a major role in maritime conception (Dansie et al. 2017). Clearing vegetation cover or allocating spaces for construction at the borders of

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municipalities and within towns lead to soil erosion and expose urban inhabitants to atmospheric dust (Katebi et al. 2018).

Different methods are presented for assessing the hazard zonation due to desertification such as Wang et al. (2008), which presented a regional pattern for environmental vulnerability assessment in Tibetan plateau by the means of multiple criteria evaluation and GIS method. The results showed that the Multi-criteria evaluation approach is of utmost importance for a desertification hazard to reflect the complexity of this phenomenon. These criteria are the altitude, slope, rainfall, wind, accumulated temperature, soil type, and vegetation cover. Shoba and Ramakrishnan (2016) used a geostatistical model with four factors (i.e., temperature, wind, rainfall, and human-induced) for assessing land degradation and desertification. On the other hand, several methods have been proposed to assess the desertification hazard and evaluate the desertification sensitivity degree (Canora et al. 2015; Gao et al. 2016; Lahlaoi et al. 2017; Rampone and Valente 2018; Salunkhe et al. 2018; 任 2016). Methods such as those based on wind erosion process, desertification risk index, and expert-based decision making considering multiple external factors are the most common in the literature. Afifi and Gad (2011) utilized the FAO_UNEP model in zoning and subjective assessment of territories defenseless to water and twist disintegration on the northern shoreline of Egypt.

Jianga et al. (2019) monitored the long desertification manner and assessed the related role of its effects. Based on the AHP analysis, it was focused on the spatiotemporal of the desertification, using four indicators between the years 1982 and 2012. The following analyzes focused on identifying the relative consequence of several factors that cause desertification in different ecosystems.

Desertification is a major environmental dilemma that leads to deterioration of environmental services and human activities, resulting in dust storms, erosion, and low vegetation cover (D'Odorico et al. 2013; Wang et al. 2017; Davi et al. 2015; Li et al. 2015). Currently, many studies that monitor the desertification and evaluate its contributing factors are either different or related to local and global scales (Wang et al. 2017; Zhou et al. 2015; Guli et al. 2015). Turan et al. (2019) illustrated the most important indices that are commonly used in soil degradation, especially Desertification Soil Quality Index (SQI). They discussed nine soil parameters in Turkey's desertification model (DTM), using the analysis of multi-criteria decisions in a Fuzzy environment connected to GIS and several models.

More than 40% of the global land surface is arid and semiarid environments. The countries located in these areas are directly threatened by desertification depending on the natural temperature regime of the region. It is because wind erosion has greater intensity in these regions, which leads to land degradation. There are many factors that affect the degree of wind erosion and thereby desertification including wind severity and duration, physical and chemical characteristics of the soil, topography of the region and vegetation condition (Meng et al. 2018). As a result, desertification sensitivity can be assessed by analyzing the response of the environment or part of it to a change in one or more external factors.

Several methods have been proposed to assess the desertification hazard and evaluate the desertification sensitivity degree (Canora et al. 2015; Gao et al. 2016; Lahlaoi et al. 2017; Rampone and Valente 2018; Salunkhe et al. 2018; 任 2016). Methods such as those based on wind erosion process, desertification risk index, and expert-based decision making considering multiple external factors are the most common in the literature. The first two methods highly depend on reliable data on the location, magnitude, and cost of the land degradation problem in individual countries. The most common methods in this category are the Mediterranean Desertification and Land-Use model (MEDALUS) (Lahlaoi et al. 2017), the PSR model (Pressure-State-Response) (Men and Liu 2018), ICD3 and MICD4. The latter method requires data regarding the external factors, which can be prepared in GIS at a low cost. Desertification events require a validation process to guarantee good results.

Many methods by authors have been developed the mapping of desertification hazards. As well as, many researchers have attempted to address the challenges above by selecting a suitable algorithm to determine the sensitive areas to desertification for the study area. The task of making decisions on risk zone for desertification depending on a set of criteria the can be facilitated by integrating GIS and MCDM techniques. Six criteria with proper ranges were chosen based on literature reviews together with social and expert survey results. Suitable maps were created to show hazard zonation that meets all the requirements.

Changes in climate and human activity have led to increased surface temperature and reduced precipitation as a result, desertification increased in the study area. The data included huge GIS Layers in addition to landscapes and meteorological data. The main objective of this work was to identify the areas most exposed to desertification in Iraq and to quantify the contributing factors to desertification. The selection of criteria was specified by reviewing the literature and field experience on the identification of desertification hazard zoning. The total indicators for desertification hazard mapping were climate, geology, vegetation, agriculture, social and economic issues, urban and industrial development (technology), in addition to spatial factors, based on the literature and field experience, which are aspect, rainfall, slope, land cover and land use, temperature and wind speed (Akbari et al. 2016; Arami A et al. 2012; Becerril-Piña et al. 2015).

As aforementioned in the literature, there has been disagreement on the criteria and methods for specifying desertification hazards. This study provides an exciting opportunity to advance our knowledge of decision making about developing a multi-criteria evaluation method based on the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) for evaluating the desertification hazard zonation in central Iraq. This paper focuses on developing methods that link experts' knowledge and literature reviews with field surveys. The focus of the citizen's views and the general situation of Iraq is to develop a spatial model designed to categorize desertification based on geospatial analysis and remote sensing technology. It is hoped that this research will contribute to a deeper understanding of desertification

This study contributes to identifying areas liable to desertification, which is an important task before identifying mitigation and control measures. A desertification map which shows the level of hazard due to this phenomenon is prepared by a multi-criteria evaluation method using geographic information systems. It is expected to serve as a guide for planners to take action on how to reduce or avoid land degradation in the region.

Study Area

The study area is located between 44° and 46° latitudes and 32°–34° 30′ longitudes (Fig. 1). It covers a large part (30,545.25 km²) of Iraq including Diyala, Baghdad, Wasit, Al Anbar, Karbala, and Babylon provinces. The geography of Iraq is diverse and falls into five main regions: the desert (west of the Euphrates), Upper Mesopotamia (between the upper Tigris and Euphrates rivers), the northern highlands of Iraq, Lower Mesopotamia, and the alluvial plain extending from around Tikrit to the Persian Gulf. The mountains in the northeast are an extension of the alpine system that runs eastward from the Balkans through southern Turkey, northern Iraq, Iran, and Afghanistan, eventually reaching the Himalayas. The desert is in the southwest and central provinces along the borders with Saudi Arabia and Jordan—geographically belongs to the Arabian Peninsula.

Methodology

To establish desertification hazard zones and its subsequent mapping using decision-making methods first requires a set of indicators (external factors). The second step is to evaluate the importance of each factor compared to the remaining others—this is often done by experts. After that, the data are processed by multi-criteria evaluation methods such as AHP (Ishizaka 2019) to determine the importance weight of each factor involved in the process. Finally, the estimated weightages are used to combine the external factor in the form of rasters. The desertification is classified into nine distinct categories indicating slight, moderate, or severe sensitivity to degradation.

This section presents the data and methods used to generate the desertification hazard zones. In particular, it describes the desertification related factors, the application of the AHP method, and the hazard zonation mapping procedure in GIS.

Data

In this paper, we had many challenges for producing land use land cover through electing the suitable remote sensing data with the method; furthermore, we use the suitable software with the tool through accuracies and better computing performances for the required modeling. However, this study was proposed AHP method by several criteria that were used to investigate the desertification process in Iraq. Major desertification factors were determined by doing field surveys and digitizing by GIS. They are wind speed, DEM, slope, aspect, rainfall, temperature, and LULC. The next step downloads and prepares Landsat imagery and radar imagery for land use with a digital elevation model (DEM) for slope and aspect. Then, the prepared factor maps were converted to standard maps using fuzzy functions. After that, the weight for the factor was determined and the contribution AHP. Finally, the desertification areas in the study area were identified by using a multi-criteria evaluation method.

In this study, datasets from Landsat OLI (multispectral and thermal bands), MODIS, and Sentinel 1 SAR were used to prepare the desertification database. The Landsat OLI multispectral bands were used to create the land-use and land-cover map of the area using the random forest and neural network approaches. The thermal bands of the dataset were used to calculate the land surface temperature. The MODIS dataset was used to generate the average annual rainfall and wind speed thematic layers. The Sentinel 1 SAR was used to create the DEM, aspect, and slope. The description of these datasets is given in Table 1.

The Landsat OLi image with the Sentinel 1 SAR was preprocessed before using it for LULC mapping. This included radiometric calibration, geometric correction, atmospheric correction, and spatial subset. They helped to reduce the malfunction errors and reduce the noise from the images. It also helped to co-register the images correctly and remove the sunlight effects from the image. The digital numbers of the raw image were converted into radiance values (radiometric calibration) using the gain and offset values retrieved from the metadata file of the data. Second,

Fig. 1 Location of the study area
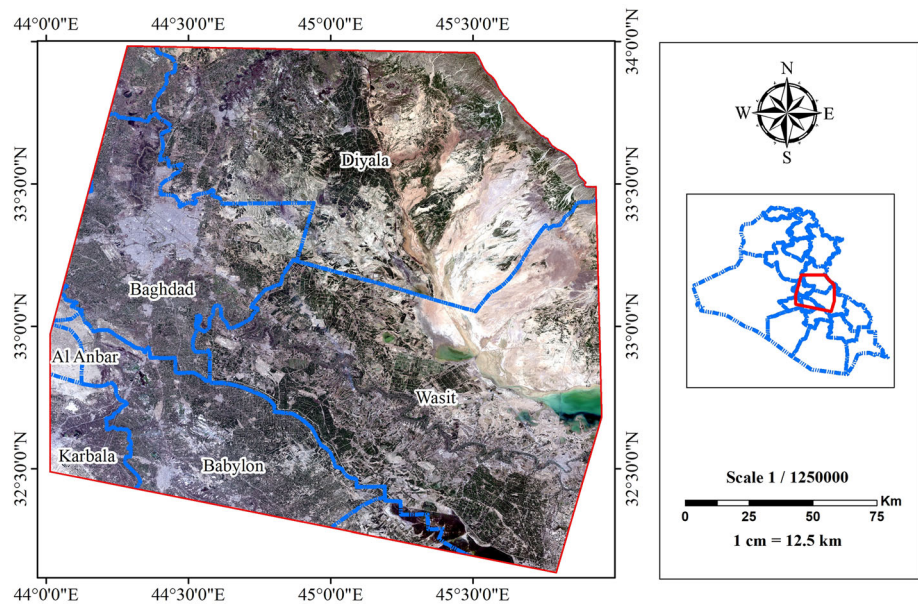
Table 1 Description of the datasets used in the current research

Parameter	Landsat OLI	MODIS	Sentinel-1
Acquisition date	2019-03-05	2019-03-09	2019-03-13
Cloud cover (%)	2.3%	18%	5%
Spatial resolution (m)	30	250	10
Usage	LULC, surface temperature	Rainfall, wind speed	DEM, aspect, slope, LULC

the radiance values were normalized and converted into surface reflectance. This step was crucial as it helped to remove the variations due to atmospheric conditions and the bi-directional reflectance distribution function (BRDF). After that, the images were geometrically corrected and co-registered to ensure coincidence with each other and the ground-truth data, which were collected from Google Earth. Finally, the QUAC atmospheric correction algorithm was used to convert the radiance to reflectance and retrieve the spectral reflectance of the image. Finally, the images were subset to cover only the area of interest.

Desertification Related Factors

For desertification hazard mapping, a total of six factors have been prepared including land use and land cover (LULC), aspect, slope, rainfall, surface temperature, and wind speed. These factors were prepared in GIS as thematic maps at 30-m spatial resolution. The data that had lower spatial resolution were resampled at this resolution to achieve consistency in the spatial dimension of the layers.

In this paper, was used the Sentinel-1 to generate the digital elevation model (DEM). Two SAR images

(Sentinel-1) from somewhat separate viewing angles are recognized as an interferometric pair, and their interferometric fringes may be applied to create Digital Elevation Maps (DEMs) using SNAP software. The interferometric fringes imagery is determined as the phase of the SAR interferogram, which is the complex imagery produced by cross-multiplying the two SAR imageries. The relationship between the phase difference and ground elevation is normally explained by means of the monochromatic method (Pratti et al. 1990; Rocca et al. 1996).

The description of each factor is given in the following subsections:

1. *Land use and land cover* this thematic layer was created by a supervised classification method using the random forest and neural network algorithms. The training areas were determined according to field studies and acceptable Kappa coefficients. The results of the classification showed that the neural network method outperforms the random forest method, and thus, the former method was selected in this research. The area was classified into five distinct classes, namely building, water, agriculture, bare land, and wetland, as shown in Fig. 2.

2. *Aspect* Before producing the aspect factor, we have extracted the DEM from the Sentinel-1 which was used to produce the aspect. Aspect indicates the direction of the slope and is classified into ten classes (Fig. 2). The exposure to sunlight is impacted by the slope direction, and as a result, this factor plays an important role in soil erosion and soil moisture that have an effective impact on desertification.

3. *Slope* this thematic layer was derived from DEM which was derived from the Sentinel-1 SAR using the spatial analysis component of GIS. The area is almost flat with a maximum slope angle of about 52° (Fig. 2).

4. *Rainfall* the average annual rainfall was estimated from the MODIS datasets of the area. For this layer, we have used three data: first, the DEM to analyze the influence of topography on precipitation; second, the Moderate Resolution Imaging spectroradiometer EVI product; and third The Tropical Rainfall Measuring Mission (TRMM) which is a joint mission between NASA and the Japan Aerospace Exploration (JAXA) Agency to study rainfall. After that, the factors were prepared from theses data which are the DEM, aspect, slope, EVI and the data of rainfall from TRMM. Next, we used these factors as input to the regression model; in this case, the model is the random forest algorithm. All factors resampled to produce the rainfall layer map with spatial resolution 1 km. In this step, the GIS was used to prepare the factors and produce the rainfall map and the python software applied the regression random forest model to predict the monthly rainfall data with spatial resolution of 1 km on the study area. The produced rainfall raster was then interpolated into 30-m spatial resolution to be consistent with the other thematic layers. The minimum and maximum rainfall values of 21 and 203 mm/day were found for the area. The southeast (Wasit) and middle (Baghdad, Diyala) of the area witnessed more intense rainfall than other parts of the area.

5. *Temperature* the thermal band (10, 10.60–11.19) of the Landsat OLI image was used to calculate the land surface temperature. The brightness temperature was derived in three steps. First, the radiance values were converted into Top of Atmosphere Radiance. Then, the result was used to create the temperature raster in degrees kelvin. Finally, the temperature unit was converted from kelvin into Celsius. The average temperature of the area ranged from 7 to 40 degrees (Fig. 2). The hottest areas are found in the east region (Wasit province) and the west region (Al Anbar).

6. *Wind speed* wind information is critical for assessing the desertification hazard. In this study, the wind speed information was extracted from the MODIS dataset for the study area. The average wind speed was calculated from the monthly wind speed MODIS products. The produced raster was then interpolated to form the 30-m spatial resolution wind speed raster.

Analytical Hierarchy Process (AHP)

The AHP procedure involves four major steps (Saaty 1987): First, create the prototype in one step; second, change the context of the criteria, sub-criteria, and their significance by pairwise comparisons; and third, summarize the results of the assessment matrix; a detailed description of the AHP methodology can be found in Saaty and Vargas (2001). In recent years, AHP has been implemented in many applications (Zyoud and Fuchs-Hanusch 2017) and its methods have been further developed to overcome certain limitations, especially in spatial modeling, pairwise comparisons, and derivation methods, in addition to consistency, incomplete matrix, weight synthesis, sensitivity analysis, and group decisions (Sitorus et al. 2019; Altuzarra et al. 2010; Ishizaka and Labib 2011).

AHP is a very well-known tool for calculating the required weight-related indicators. All the parameters/indicators that are essential in the selection are examined one by one in a pairwise comparison matrix illustrated by the consistency ratio to test the consistency of the obtained scores by the experts' survey. Thus, the correlation between consistency records in the Consistency Index (CI) and the Random Index (RI) list is generalized. There are many methods for breaking down complex decision processes into decision analysis. These methods include dividing individual tasks into smaller and more logical zones, reviewing each piece, and coordinating the components in an intelligent process to show a clear layout (Malczewski 1997, 1999; Vogel 2008). Multiple Criteria Decision Making (MCDM) is a process which allows you to summarize and consider various (usually controversial) standards for identifying choices to assist decision making (Zopounidis 1999; Comino et al. 2014). Mulliner et al. (2013) have shown that MCDM is well suited to meet a variety of qualitative and quantitative criteria that can be integrated into a single evaluation process. This technique also includes comparisons to obtain the relative matrix. The main idea behind AHP is to test together using a homogeneous ratio matrix (Yuen 2014). AHP is important and highly involved in the management of interconnected decision-making tasks as it focuses on general thought and implementation (Deng et al. 2014). The consistency list of a haphazardly delivered corresponding reciprocal matrix is known as the random index (RI). Normal RI values for the order matrices were computed from 1 to 15 with a sample size of 100 (Brent et al. 2007). The final ratio to be calculated is CR (consistency ratio). If the CR is less than 0.1,
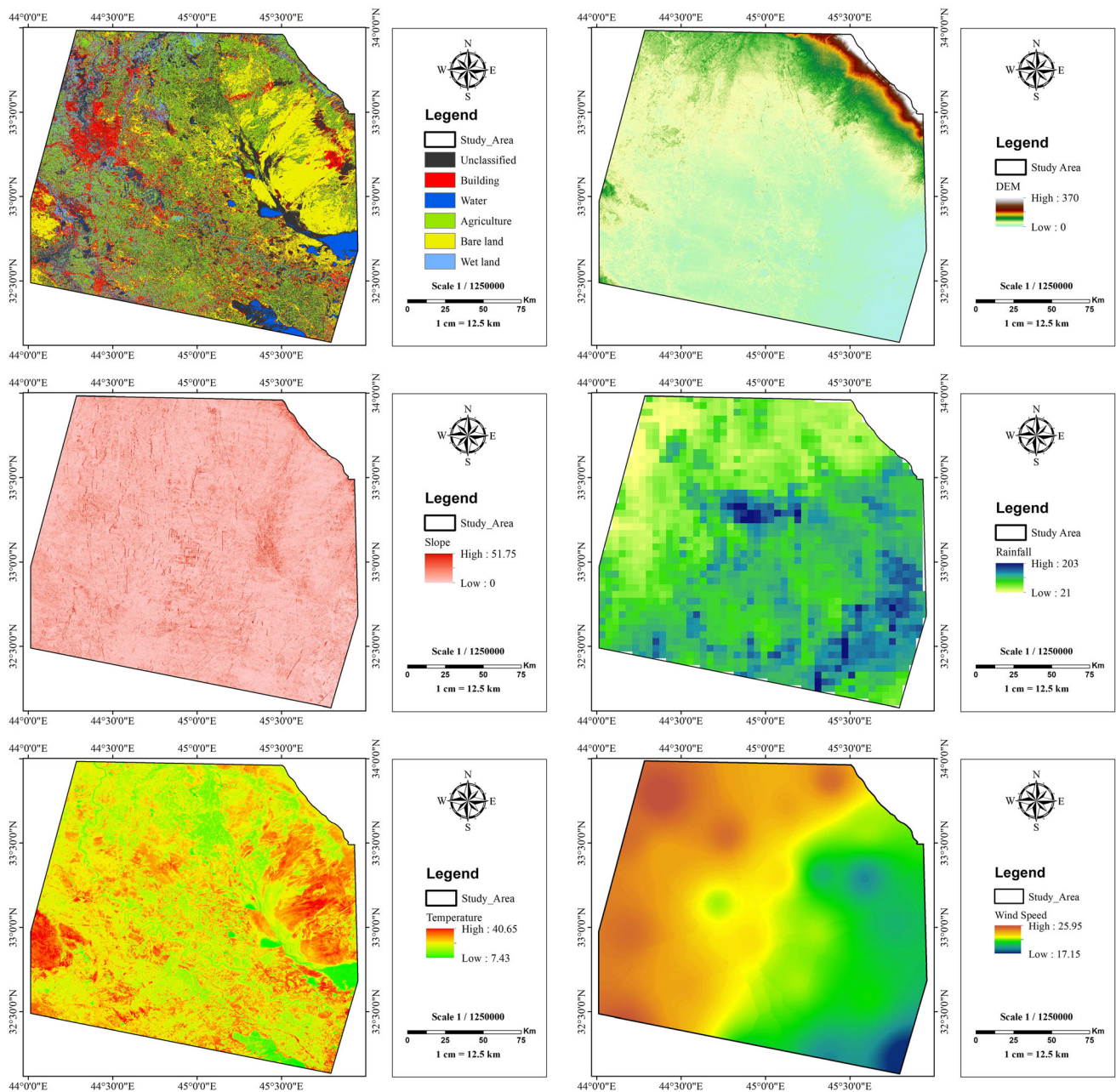
Fig. 2 Desertification-related factors in the form of thematic GIS layers

the judgments are reliable and the weights can be used (Deng 1999; Khatwani and Kar 2016).

The AHP method in this research involved (1) a qualitative and quantitative analysis of the expert decisions on the importance of desertification indicators and (2) a geometric mean of the decisions made for each indicator. After establishing the pairwise comparison matrix for each decision alternative to each indication, the normalized matrix and the preference vector were obtained. Then, the overall value for each decision alternative was calculated.

Finally, the rank of alternatives was calculated according to the value acquired in the previous step.

The scale range 1–9 is assumed sufficiently representing human beings' perception. The reason why the AHP method limits the ratio-scale 1–9 is according to the research conducted by a psychologist, which shows that human beings cannot simultaneously compare more than seven objects, either it increases or decreases two objects. In such a condition, human beings will lose their consistency in making the comparison. Given that decision-makers cannot make a perfectly consistent decision, an

inconsistency ratio is then acquired to calculate the consistency of the data provided by the experts. Inconsistency measurement is an important element in the AHP process. The higher the consistency ratio, the assessment result becomes more inconsistent.

Desertification Hazard Zonation Mapping

Once the importance of each desertification indicator was obtained by the AHP method, they were combined together to form the desertification hazard zones. This was achieved by the spatial analysis process, namely weighted sum in GIS. Each factor was multiplied by its own weight, and then all the factors were summed up to create an intermediate raster that combines all the factors along with their importance weights. After that, the raster was reclassified into nine classes using the Natural Break classification method in GIS indicating the sensitivity of the pixels to desertification. For further simplification of the produced map, it was reclassified into five classes using the same method. This new classification system allows easy interpretation and fast access to information regarding the most hazardous zones in the region. The five classes' means not sensitive, low, moderate, high, very highly sensitive to desertification .

Validation

The desertification map was created from remote sensing images and the factors of desertification. The accuracy of these maps is based on the collection of truth data, which were collected by field survey. This step is considered to be very important. Two types of accuracies in this step were used: first one for the AHP methods based on CR. In this study, we applied the AHP two times, one was the average method and the other one was geometric mean method, respectively, the methods that have less CR will be taken to the next step to produce the desertification map. The second type of validation was based on the desertification map and truth data from the field based on the RMSE test. Then, the specified method, which achieved good accuracy, will be used for mapping of desertification hazard.

Results and Discussion

This section presents and discusses the main results of the AHP application to desertification hazard zonation mapping in central Iraq. The comparison between the geometric mean and average methods of indicator importance calculation is also presented in this section.

Applications of AHP

Table 2 shows the pairwise comparison matrix obtained from eight experts for each desertification indicator. Each expert evaluated the importance of the indicators (aspect, rainfall, slope, LULC, temperature, and wind speed) by comparing them with each other. The importance value of 0–9 was given to each indicator when compared with another indicator. As a result, the importance of an indicator is calculated against the remaining indicators.

The produced desertification hazard map indicates that 3.98% of the area is under very high sensitivity to desertification (Figs. 3a and b). The remaining area is under high sensitivity by 7.25% and moderate sensitivity by 25.97%. The most hazardous areas are found to be in the middle and south parts of the study area. In general, the map shows that the north part of the area is less sensitive to desertification since the experts have given high weightages to rainfall, aspect, and LULC indicators. To reduce the sensitivity to desertification in very high and high hazardous areas, increasing green spaces can play an important role. Urban areas should be planted by trees, and green spaces should be considered in future urban developments.

Looking at the correlation between the severity of desertification and the indicators, one can observe that bare lands need to be developed and converted into built-ups. This can radically reduce the hazard and improve the economy of the nation. As the correlation between the rainfall and the severity of desertification is high, this would require effective urban and resource management in the north part of the study area. Local climate should also be considered an important element to improve the vulnerability of these areas to desertification. Places, where air rises more frequently, get more rain, and it rains more heavily when the updraft is stronger. Therefore, efforts should be made by the local authorities and the government to improve the local climate system in the study area, especially in the north.

In this study, the consistency ratio is less than 0.1 (0.0685), so the paired comparison of desertification indicators has good stability. Figure 3b shows the desertification hazard zonation map produced by the proposed model. The hazard is classified into three distinct classes (moderate, high, and very high) based on the natural break method (Fig. 4).

Results of AHP with Average and Geometric Mean Methods

Table 3 shows the normalized matrix and the importance of each indicator calculated by the average method. On this basis, rainfall is the most important indicator in the

Table 2 The pairwise comparison matrix for each decision alternative to each indication

	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
1	Aspect	1	0.14	4	0.16	3	0.5
	Rainfall		1	3	2	8	5
	Slope			1	0.25	0.5	0.33
	LULC				1	6	5
	Temperature					1	2
	Wind speed						1
2	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
	Aspect	1	0.2	3	0.5	4	4
	Rainfall		1	6	2	5	5
	Slope			1	0.14	0.16	0.25
	LULC				1	5	3
	Temperature					1	2
	Wind speed						1
3	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
	Aspect	1	0.33	0.14	0.16	0.14	2
	Rainfall		1	0.33	0.33	1	2
	Slope			1	0.5	0.33	3
	LULC				1	2	4
	Temperature					1	5
	Wind speed						1
4	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
	Aspect	1	7	3	5	8	9
	Rainfall		1	4	6	8	9
	Slope			1	5	5	6
	LULC				1	4	6
	Temperature					1	7
	Wind speed						1
5	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
	Aspect	1	0.33	2	0.25	3	2
	Rainfall		1	6	3	5	4
	Slope			1	0.125	0.25	0.33
	LULC				1	4	4
	Temperature					1	3
	Wind speed						1
6	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
	Aspect	1	6	4	5	8	8
	Rainfall		1	4	6	7	8
	Slope			1	5	7	7
	LULC				1	4	7
	Temperature					1	6
	Wind speed						1

Table 2 (continued)

	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
7	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
	Aspect	1	0.33	2	0.5	0.25	0.2
	Rainfall		1	0.5	0.33	0.5	0.33
	Slope			1	0.5	0.2	0.16
	LULC				1	0.5	0.33
	Temperature					1	3
	Wind speed						1
8	Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed
	Aspect	1	0.25	2	0.2	2	2
	Rainfall		1	8	4	6	6
	Slope			1	0.14	0.2	0.33
	LULC				1	4	3
	Temperature					1	2
	Wind speed						1

desertification of the study area. The second important indicator is aspect with 27.90% importance value. LULC has an importance value of 16.01% slightly greater than the slope (11.99%). The temperature and wind speed obtained the lowest importance values of 8.32% and 4.93%, respectively.

On the other hand, calculating the importance of the indicators by the geometric mean resulted in a different scenario (Table 4). The highest importance value remained for the rainfall indicator (31.59%). However, the second important indicator was found to be LULC (23.20%). The aspect was the third important indicator by an importance value of 16.23%. Both temperature and wind speed were also found to be the lowest important indicators (12.52% and 7.67%, respectively). The results of this study showed that the geometric mean method results in a different importance calculation of the indicator compared to the average method. Based on the estimated consistency ratio for each method, the geometric mean was observed to be best for the environment of the study area. The results suggested that the rainfall, aspect, and LULC are the three most critical factors that impact the severity of desertification in the study area.

Validation of Results

In this paper, we combined the opinions of experts in two ways: (i) average method and (ii) geometric mean method. The results of the above-mentioned ways are shown in Sect. 4.2. The validation is based on the consistency ratio (CR); the higher the value, the more inconsistent the judgments. The acceptable consistency ratio is less than or equal to 10 percent. In this study, the consistency ratio is less than 0.1 (0.00685), so the paired comparison of desertification indicators has good stability. Also, we did more validation on the second type of validation based on the desertification prediction with collection data of desertification from the field, where the equation of RMSE was used. Also, the geometric mean method achieved higher accuracy of 0.60, while the average method achieved 0.77. Finally, after the proposed method achieved good accuracy, we will produce the risk desertification map.

Conclusion

Desertification threatens many places around the globe, and Iraq is no exception. In addition, because there are no proper urban planning and management, the severity of
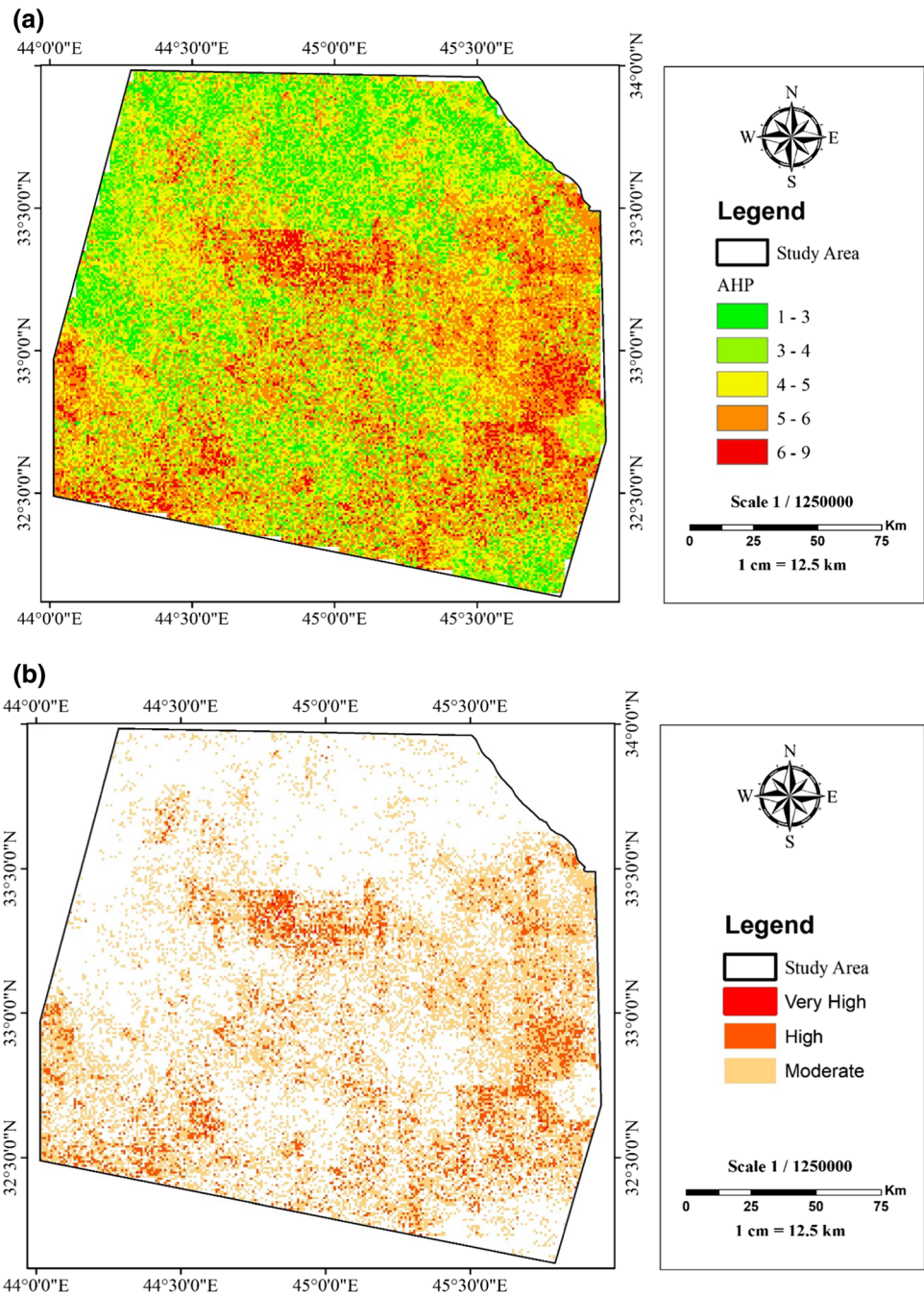
such hazards is high in this nation. There are many ways to study and model the severity of desertification. This research focused on AHP method comparing the geometric and average means for calculating the importance of the desertification indicators. It is important to accurately model the importance of the indicators regarding their impacts on desertification hazards in the study area. This will help to narrow down the focus of future plans to certain indicators. As a result, improvements could be made to reduce the severity of the hazard in the areas under the desertification threat.

Future works should focus on a more detailed assessment considering the vegetation cover, water resources, and local climate in the assessment of desertification

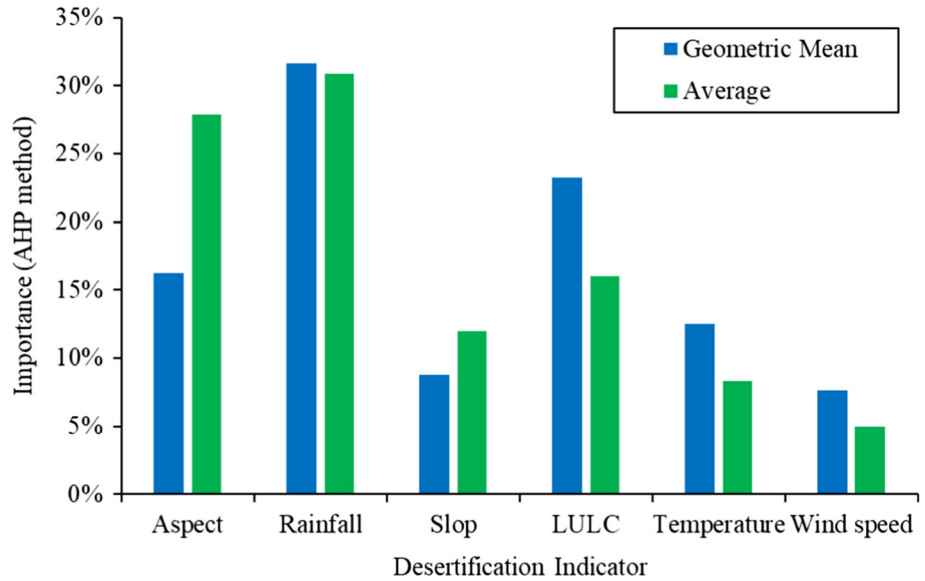**Fig. 4** Importance of each desertification indicator as calculated using the AHP method

Table 3 The normalized matrix and the importance of each indication (average method)

Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed	Importance (%)
Aspect	0.31	0.48	0.27	0.20	0.23	0.18	27.90
Rainfall	0.17	0.26	0.43	0.40	0.33	0.25	30.83
Slope	0.12	0.07	0.11	0.20	0.11	0.11	11.99
LULC	0.21	0.09	0.07	0.13	0.24	0.21	16.01
Temperature	0.09	0.05	0.06	0.04	0.07	0.19	8.32
Wind speed	0.09	0.05	0.05	0.03	0.02	0.05	4.93

Table 4 The normalized matrix and the importance of each indication (geometric mean method)

Criteria	Aspect	Rainfall	Slope	LULC	Temperature	Wind speed	Importance (%)
Aspect	0.16	0.19	0.18	0.12	0.18	0.14	16.23
Rainfall	0.29	0.33	0.25	0.42	0.35	0.26	31.59
Slope	0.09	0.13	0.09	0.11	0.05	0.06	8.79
LULC	0.30	0.17	0.19	0.22	0.29	0.23	23.20
Temperature	0.09	0.09	0.17	0.07	0.10	0.24	12.52
Wind speed	0.08	0.09	0.12	0.07	0.03	0.07	7.67

hazards. Other methods such as fuzzy AHP or automated (non-expert-based methods) may also be suitable to study desertification hazards in the study area.

References

Afifi, A. A., & Gad, A. (2011). Assessment and mapping areas affected by soil erosion and desertification in the north costal part of Egypt. *International Journal of Water Resources and Arid Environments, 1,* 83–91.

Ajaj, Q. M., Pradhan, B., Noori, A. M., & Jebur, M. N. (2017). Spatial monitoring of desertification extent in Western Iraq using Landsat images and GIS. *Land Degradation and Development, 28,* 2418–2431.

Akbari, M., Ownegh, M., Asgari, H. R., Sadoddin, A., & Khosravi, H. H. (2016). Desertification risk assessment and management program. *Global Journal of Environmental Science and Management, 2*(4), 365–380. https://doi.org/10.22034/GJESM.2016.02.04.006.

Alary, V., Messad, S., Daoud, I., Aboul-Naga, A., Osman, M. A., Bonnet, P., et al. (2016). Social network and vulnerability: a clear link in Bedouin Society (Egypt). *Human Ecology, 44,* 81–90.

Altuzarra, A., Moreno-Jiménez, J. M., & Salvador, M. (2010). Consensus building in AHP-group decision making: A bayesian approach. *Operations Research, 58*(6), 1755–1773.

Arami A H, Ownegh M, Sheikh B, Honardoust F. (2012). Tehran, International Research Center for desert Tehran University, Iran.

Becerril-Piña, R., Mastachi-Loza, C. A., González-Sosa, E., Díaz-Delgado, C., & Bâ, K. M. (2015). Assessing desertification risk in the semi-arid highlands of central Mexico. *Journal of Arid Environments, 120,* 4–13. https://doi.org/10.1016/j.jaridenv.2015.04.006.

Belaroui, K., Djediai, H., & Megdad, H. (2014). The influence of soil, hydrology, vegetation, and climate on desertification in El-Bayadh region (Algeria). *Desalination and Water Treatment, 52*(10–12), 2144–2150. https://doi.org/10.1080/19443994.2013.782571.

Brent, A. C., Rogers, D. E., Ramabitsa-Siimane, T. S., & Rohwer, M. B. (2007). Application of the analytical hierarchy process to establish health care waste management systems that minimise infection risks in developing countries. *European Journal of Operational Research, 181,* 403–424.

Canora, F., D'Angella, A., & Aiello, A. (2015). Quantitative assessment of the sensitivity to desertification in the Bradano River basin (Basilicata, southern Italy). *Journal of Maps, 11*(5), 745–759. https://doi.org/10.1080/17445647.2014.980857.

Comino, E., Bottero, M., Pomarico, S., & Rosso, M. (2014). Exploring the environmental value of ecosystem services for a river basin through spatial multi-criteria analysis. *Land Use Policy, 36,* 381–395.

D'Odorico, P., Bhattachan, A., Davis, K. F., Ravi, S., & Runyan, C. W. (2013). Global desertification: Drivers and feedbacks. *Advances in Water Resources, 51,* 326–344.

Dansie, A. P., Wiggs, G. F. S., & Thomas, D. S. G. (2017). Iron and nutrient content in wind-erodible sediment in the ephemeral river valleys of Namibia. *Geomorphology, 290,* 335–346.

Davi, N. K., D'Arrigo, R., Jacoby, G. C., Cook, E. R., Anchukaitis, K. J., Nachin, B., et al. (2015). A long-term context (931–2005 C. E.) for rapid warming over Central Asia. *Quaternary Science Reviews, 121,* 89–97.

Turan, I. D., Dengizb, O., & Özkanc, B. (2019). Spatial assessment and mapping of soil quality index for desertification in the semi-arid terrestrial ecosystem using MCDM in interval type-2 fuzzy environment. *Computers and Electronics in Agriculture, 164,* 104933.

Deng, H. (1999). Multi-criteria analysis with fuzzy pairwise comparisons. *International Journal of Approximate Reasoning, 21,* 215–231.

Deng, X., Hu, Y., Deng, Y., & Mahadevan, S. (2014). Supplier selection using AHP methodology extended by D numbers. *Expert Systems with Applications, 41,* 156–167.

Farajzadeh, M., & Egbal, M. N. (2007). Evaluation of MEDALUS model for desertification hazard zonation using GIS; study area: Iyzad Khast plain. *Iran. Pakistan Journal of Biological Sciences, 10*(16), 2622–2630.

Sitorus, F., Cilliers, J. J., & Brito-Parada, P. R. (2019). Multi-criteria decision making for the choice problem in mining and mineral processing: Applications and trends. *Expert Systems with Applications, 121*(2019), 393–417.

Gao, Z., Sun, B., Li, Z., Barrio, G. del, & Li, X. (2016). Desertification monitoring and assessment: A new remote sensing method. In *2016 IEEE international geoscience and remote sensing symposium (IGARSS)* (pp. 3810–3813). IEEE. https://doi.org/10.1109/igarss.2016.7729988.

Guli, J., Liang, S., Yi, Q., & Liu, J. (2015). Vegetation dynamics and responses to recent climate change in Xinjiang using leaf area index as an indicator. *Ecological Indicators, 58,* 64–76.

Ishizaka, A. (2019). Analytic hierarchy process and its extensions. In M. Doumpos, J. R. Figueira, S. Greco, & C. Zopounidis (Eds.), *New perspectives in multiple criteria decision making: Innovative applications and case studies* (pp. 81–93). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-11482-4_2.

Ishizaka, A., & Labib, A. (2011). Review of the main developments in the analytic hierarchy process. *Expert Systems with Applications.* https://doi.org/10.1016/j.eswa.2011.04.143.

Jianga, L., Guli, Jiapaera, Baoa, A., Kurbana, A., Hao, Guoa, Zhenga, G., et al. (2019). Monitoring the long-term desertification process and assessing the relative roles of its drivers in Central Asia. *Ecological Indicators, 104,* 195–208.

Katebi, H., Fahmi, A., Kafil, H. S., & Bonab, M. H. (2018). Stabilization of calcareous sand dunes using phosphoric acid mulching liquid. *Journal of Arid Environments, 148,* 34–44.

Khatwani, G., & Kar, A. K. (2016). Improving the cosine consistency index for the analytic hierarchy process for solving multi-criteria decision making problem. *Applied Computing, and Informatics.* https://doi.org/10.1016/j.aci.2016.05.001.

Ladisa, G., Todorovic, M., & Liuzzi, G. T. (2012). A GIS-based approach for desertification risk assessment in Apulia region, SE Italy. *Physics and Chemistry of the Earth.*

Lahlaoi, H., Rhinane, H., Hilali, A., Lahssini, S., & Moukrim, S. (2017). Desertification assessment using MEDALUS model in watershed oued el maleh, morocco. *Geosciences, 7*(3), 50. https://doi.org/10.3390/geosciences7030050.

Li, Z., Chen, Y., Li, W., Deng, H., & Fang, G. (2015). Potential impacts of climate change on vegetation dynamics in Central Asia. *Journal of Geophysical Research: Atmospheres, 120,* 2045–2057.

Malczewski, J. (1997). Propogation of errors in multi-criteria location analysis: A case study. In G. Fandel, & T. Gal, (Eds.), *Multiple Criteria Decision Making* (pp. 154–155). Berlin: Springer.

Malczewski, J. (1999). *GIS and multi-criteria decision analysis.* New York, Chichester, Weinheim: John Wiley & Sons.

Men, B., & Liu, H. (2018). Water resource system vulnerability assessment of the Heihe River Basin based on pressure-state-response (PSR) model under the changing environment. *Water Science and Technology: Water Supply.* https://doi.org/10.2166/ws.2018.017.

Meng, Z., Dang, X., Gao, Y., Ren, X., Ding, Y., & Wang, M. (2018). Interactive effects of wind speed, vegetation coverage and soil moisture in controlling wind erosion in a temperate desert steppe, Inner Mongolia of China. *Journal of Arid Land, 10*(4), 534–547. https://doi.org/10.1007/s40333-018-0059-1.

Mulliner, E., Smallbone, K., & Maliene, V. (2013). An assessment of sustainable housing affordability using a multiple criteria decision-making method. *Omega, 41,* 270–279.

Okin, G. S., Gillette, D. A., & Herrick, J. E. (2006). Multi-scale controls on and consequences of aeolian processes in landscape change in arid and semi-arid environments. *Journal of Arid Environments, 65,* 253–275.

Pratti, C., Rocca, F., Monti Guarnieri, A., & Damonti, B. (1990). Seismic migration for SAR focusing: interferometrical applications. *IEEE Transactions on OARS, 28*(4), 627–640.

Rampone, S., & Valente, A. (2018). Assessment of desertification vulnerability using soft computing methods. *Journal of Ambient Intelligence and Humanized Computing.* https://doi.org/10.1007/s12652-018-0720-8.

Rocca, F., Prati, C., & Monti Guarnieri, A. (1996). Possibilities and limits of SAR interferometry. In *Proceedings of AGARD* (pp. 2.1–2.13). Tolouse.

Saaty, R. W. (1987). The AHP and how it is used. *Mathematical Modelling, 9*(3–5), 161–176.

Saaty, T. L., & Vargas, L. G. (2001). *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process.* Berlin: Springer.

Salunkhe, S. S., Bera, A. K., Rao, S. S., Venkataraman, V. R., Raj, U., & Murthy, Y. V. N. K. (2018). Evaluation of indicators for desertification risk assessment in part of Thar Desert Region of Rajasthan using geospatial techniques. *Journal of Earth System*

Science, 127(8), 116. https://doi.org/10.1007/s12040-018-1016-2.

Shoba, P., & Ramakrishnan, S. (2016). Modeling the contributing factors of desertification and evaluating their relationships to the soil degradation process through geomatic techniques. *Solid Earth, 7,* 341–354.

Vogel, R. (2008). *A Software framework for GIS-based multiple criteria evaluation of land suitability*. 11th AGILE International Conference on Geographic Information Science. University of Girona: Spain.

Wang, X., Hua, T., Lang, L., & Ma, W. (2017). Spatial differences of aeolian desertification responses to climate in arid Asia. *Global and Planetary Change, 148,* 22–28.

Wang, X. D., Zhong, X. H., Liu, S. Z., Liu, J. G., Wang, Z. Y., & Li, M. H. (2008). Regional assessment of environmental vulnerability in the Tibetan Plateau: Development and application of a new method. *Journal of Arid Environments, 72,* 1929–1939.

Wikle, T. A. (2016). Arid climates and desertification. In D. Richardson, N. Castree, M. F. Goodchild, A. Kobayashi, W. Liu, & R. A. Marston (Eds.), *International encyclopedia of geography: people, the earth, environment, and technology* (pp. 1–10). Oxford: Wiley. https://doi.org/10.1002/9781118786352.wbieg0243.

Yuen, K. F. (2014). The Primitive Cognitive Network Process in healthcare and medical decision making. Comparisons with the analytic hierarchy process. *Applied Soft Computing, 14,* 109–119.

Zhou, W., Gang, C., Zhou, F., Li, J., Dong, X., & Zhao, C. (2015). Quantitative assessment of the individual contribution of climate and human factors to desertification in northwest China using net primary productivity as an indicator. *Ecological Indicators, 48,* 560–569.

Zopounidis, C. (1999). Multi criteria decision aid in financial management. *European Journal of Operational Research, 119,* 404–415.

Zyoud, S. H., & Fuchs-Hanusch, D. (2017). A bibliometric-based survey on AHP and TOPSIS techniques. *Expert Systems with Applications, 78,* 158–181. https://doi.org/10.1016/j.eswa.2017.02.016.

任静. (2016). Evaluation of the degree of desertification degradation based on analytic hierarchy process. *International Journal of Ecosystem*, *05*(03), 49–56. https://doi.org/10.12677/IJE.2016.53006.