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ORIGINAL RESEARCH PAPER

Desertification risk assessment and management program

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ABSTRACT: Risk assessment provides the possibility of planning and management to prevent and reduce the risk of desertification. The present study is aimed to assess the hazard and risk of desertification and to develop management programs in the semi-arid western regions of Golestan Province in Iran. Desertification rate was obtained using the Iranian model of desertification potential assessment. Since the rating system was considered for the indicators, data analyses were carried out according to the Mann-Whitney test. The risk of desertification was calculated based on hazard, elements at risk and vulnerability assessment maps. The intensity of desertification was estimated to be medium. Among the factors affecting desertification, agriculture by the weighted average of 3.22 had the highest effect, followed by soil, vegetation, water and wind erosion criteria by weighted averages of 2.45, 2.32, 2.15 and 1.6 respectively. Desertification risk assessment results also showed that about 78% of central and northern parts of the region, with the largest population and residential centers, surface and underground water resources, agriculture and horticulture, is confronted with a high to very high degree of risk. Management plans and control measures, based on risk values were presented in four activities (with two management priorities under critical and non-critical conditions). For the management program with the largest area. Control measures and strategies such as the establishment of halophytic and xerophytic plants, drainage networks, resilient facilities and infrastructure were proposed. Reducing the risk of desertification, could play a crucial role in the sustainable development of drylands and desert ecosystems.

KEYWORDS: *Criteria; Desertification; Golestan Province; Iranian model of desertification potential assessment (IMDPA); Risk assessment; Vulnerability*

NTRODUCTION

Arid regions of the world are constantly exposed to degradation and desertification for various reasons (Green facts, 2007).Desertification is the persistent degradation in arid ecosystems by climatic factors and human activities which crawls slowly due to land mismanagement (Millennium Ecosystem Assessment, 2005). Today, much of the concern related to desertification comes from the decline in the land productivity, especially in arid areas (UNCCD, 2006). According to available statistics, 10 to 20% (an area of 6 to 12 million kilometers) of the arid regions of the world suffers from some degree of damage (from low to very high), (Rubio and Recatala, 2005). Dry lands cover about 30% of the earth's surface and over 250 million persons are thought to be directly affected by the desertification process (Reynolds *et al.,* 2007). As a result, wide range of environmental, cultural, political and socio-economic impacts have emerged at local, national and global scales ICCD/COP, (2007). Nonetheless, still adequate information does not exist

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on the extent and severity of desertification in the world, (Lantieri, 2003). In addition to arid regions, desertification is also happening in other regions with different climates. According to statistics, 74% of arid regions in North America, 13 countries of the European Union members and 18 developed countries of the world are under the influence of desertification (Joint Research Center, 2008).

Despite of the importance of land degradation and desertification in arid regions of the world, there are few studies and assessments (Lal, 2008). Some of these models include the key and effective indicators to measure the type (natural/anthropogenic) and severity of risk (Nunez *et al*., 2009). Bouabid *et al.* (2010), prepared desertification sensitivity maps using Mediterranean Desertification and Land Use (MEDALUS) in the Souss Basin of Morocco. Their results showed that a large part of the field (72%), were highly vulnerable to desertification, with the southern part of the state as critical. Rasimet *et al.* (2010) used a dynamic version of the MEDALUS model for desertification assessment of West Nile in Egypt. Land use into various land use types often triggers degradation of the environment and led to a series of environmental problems such as soil and water erosion, wetland, desertification, land contamination. This alternation of land involves the process of biologically and technically reshaping, converting and managing land for socio-economic benefits (Xie *et al.,* 2007). This pressure on the environment and natural resources caused by human activities (Dai *et al.,* 2012). Afifi and Gad (2011) used FAO_UNEP model in zoning and qualitative evaluation of areas susceptible to water and wind erosion on the northern coast of Egypt. Their results showed that most of the region was affected by water and wind erosion in a moderate state. Iranian model of desertification potential assessment (IMDPA) has been successfully used in Iran. This is a comprehensive desertification model that developed by the Faculty of Natural Resources, University of Tehran, as the outcome of a project entitled Determination of Methodology of Desertification Criteria and Indices in Arid and Semi-Arid Regions of Iran. In total, 9 criteria and 130 indices were introduced in the form of quantitative and weighted values which would determine the desertification intensity under all cases. IMDPA is an Iranian model and is calibrated for different climatic regions; arid, semi-arid and desert environments (Ahmadi, 2004). Nikoo (2011) applied the IMDPA model to assess potential desertification, in a study to identify factors contributing to land degradation in Damghan, Iran. Results showed that the region was dominated by a high-intensity desertification. The most important factors in desertification were identified as soil surface cover deficiency, indiscriminate withdrawal of groundwater, unprincipled irrigation and agriculture. Khosravi *et al.* (2014) assessed the hazard of desertification in Kashan region and their analysis showed that water criterion is a major problem in the study area. Moreover, groundwater decrease and water crisis and depth of soil were the most and least effective factors, respectively. Risk-based management is an effective solution to tackle and reduce the risk of natural disasters (and in particular desertification) (Messner and Mayer, 2005), uncertainty management and minimization of potential vulnerability (UNISDR, 2013). Danfeng *et al.* (2006) by modeling risk index (RI), evaluated the possibility of understanding the causes of desertification in space-time dimensions in Minqin district, China's Gansu province. Ladisa *et al.* (2012), to evaluate the risk of desertification in the region of Apulia (southeast Italy), used new environmental indicators and socio-economic parameters. Data analysis was carried out in GIS environment and at two regional and local scales. The results of their study showed that the factors contributing to desertification can be easily identified at various spatial scales in affected areas. Becerril-Pina *et al.* (2015) used the Desertification Trend Risk Index (DTRI), that integration of a set of indices,(four desertification factors ; vegetation, soil, climate and anthropic disruptors).Their results showed that anthropic activities such as changes in land use and deforestation are the primary driving forces in the desertification process in the region. Based on the results of this study, the use of the DTRI is recommended as a low-cost and easily applied tool to assess and monitor desertification. In another study, Silakhori *et al.* (2014), to assess the risk of desertification in Sabzevar, prepared risk maps by combining risk intensity, frequency and degree of vulnerability of the elements. Their analysis revealed that most of the regions could be accounted for high-risk classes (46.77%). Arami *et al.* (2013) has used IMDPA model to risk assess the desertification hazard in Aq-band area in Golestan province. Their analysis showed that 30.03% of the study area could be classified as high and very high. Momenzadeh *et al.*

(2014) provided the vulnerability map in Fadisheh Neishabour in Khorasan Province of Iran. Their results indicated that a large share of region were at the high risk of desertification. The European Union promoted a soil thematic strategy, which identified the following threats to soil functions: erosion, organic matter decline, loss of biodiversity, compaction, sealing, point or diffused Contamination, pollution and salinization (Salvati *et al.,* 2007).These strategies include a combination of land management, water and living resources of the ecosystems with optimal utilization and maintenance of a sustainable ecosystem quality (UNEP, 2004). The Millennium Ecosystem Assessment (2005) defines the sustainable management of ecosystems as an effective way to tackle and prevent desertification process, both at a local level and globally.

The aim of this study was to assess the severity and risk of desertification in semi-desert areas West of Golestan Province, and to provide management plans to mitigate the effects of the risk of desertification. Intensity and risk maps of desertification could provide means of efficient and appropriate risk management and the development of early-warning systems to reduce the effects of land degradation and desertification. Abbasabadi *et al.* (1999), in their quantitative assessment of desertification in Aq-Qala-Gomishan plain in Golestan Province, came to the conclusion that processes such as waterlogging, salinization, vegetation degradation and soil erosion are the important causes of desertification. Sabeti *et al.* (2007), on investigating the mechanism of wind erosion and its effect on the risk of desertification in the northern plains of Aq-Qala found that 58.45% of the area fell into high risk class of wind erosion with the largest area in the very high risk class of desertification. Afkhami Ardeshir *et al.* (2007) evaluated the effect of land use changes in the development of desertification in Aq-Qala - InchehBorun region. Their results showed significant land-use changes during the last 50 years. Ownegh (2009), using the analytic hierarchy process and a subjective model, assessed the risk severity and corresponding management plants in Gorgan plain where the classes of desertification increases from the forest covered areas in the south to the lowland steppes in the north. Honardoust *et al.* (2011), by assessing the severity and risk of desertification in the northern part of Gorgan showed that more than 52% of the area was affected by severe desertification by the dominant roles of soil and waterlogging factors.

This study has been performed in Golestan Province of Iran in 2016. The reason for choosing the Gorgan to study has been ongoing development desertification conditions in recent years. This has led to land degradation, intensification of natural hazard, reduction of land production, poverty expansion and immigration.

MATERIALS AND METHODS

Study area

The study area encloses an area of about 5101 km^2, in the western part of Golestan Province (approximately one quarter of the total area of the Province) and the northern part of Iran. This area lies between 53 51 14 to 54 51 46E and 36 37 57 to 37 27 24N.

Features such as proximity to the Karakum Desert of Turkmenistan, steep environmental and geomorphological gradients (located in between the forest and the sea), typical facies, hills and sandy zones, playas and low salt pans, fine saline evaporative sea sediments, high water table and sharp capillary fluctuations, rapid changes in land use and development of mechanized agriculture have given the area a total desert outfit with high desertification rate (Topographic analysis report. 2013).

Table 1 provides topographic and climatic conditions and Fig. 1 illustrates the location of the study area in Iran's Golestan Province.

Research methodology

The flow diagram of the proposed research is provided in Fig. 2.

Assessment of the severity of desertification

To assess the degree of desertification, IMDPA model as the geometric mean of nine criteria including climate, geology, vegetation, agriculture, water, soil,

Table 1: Topographic and climatic characteristics of the study area

Height of sea level			The weighted average slope (%)	The average annual rainfall (mm)	The annual average temperature (mm)	Type climate (drought index transo)
Minimum height (m)	Maximum height (m)	The weighted average height (m)				
-32	3088	254	9.5	501.95	17.87	Arid

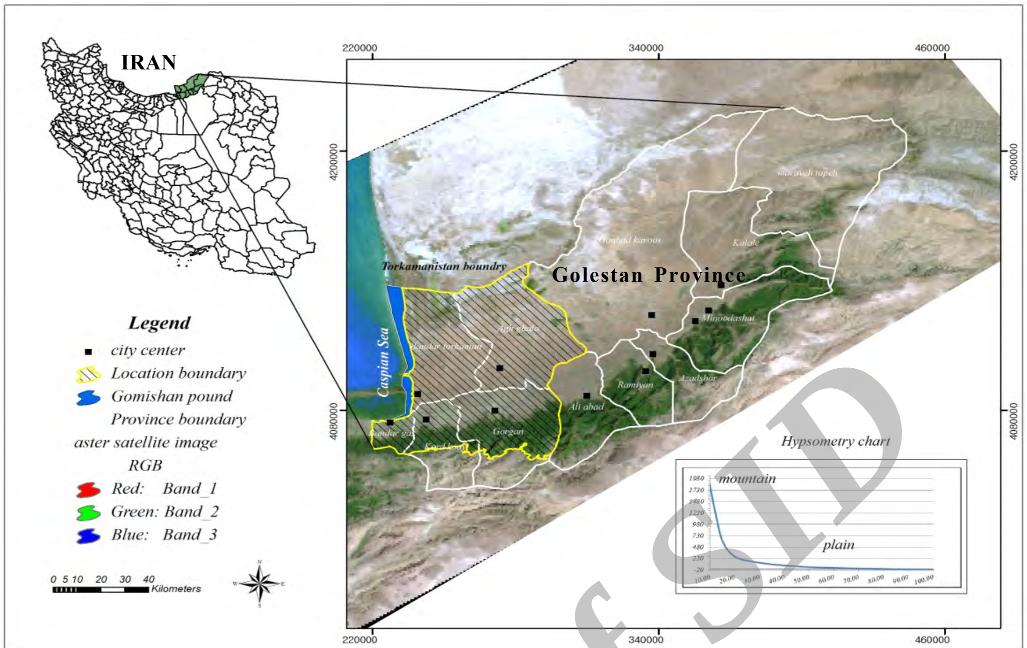

Fig. 2: Geographical location of the study area in Golestan Province, Iran

Table 2: Scoring scheme for each index in the IMDPA model (Arami, 2012)

Classes of elements	Qualitative classes	Range of class
I	Very low	0 – 1.5
II	low	1.6 – 2.5
III	medium	2.6 – 3.5
IV	high	3.6 - 4

erosion, social and economic issues, urban and industrial development (technology) was used. Scoring for the criteria and indicators was carried out in geo-bio-facies. To each indicator in each work unit, a weight between 0 and 4 was given. Eventually, desertification was classified into four classes of severity including little, moderate, severe and very severe. In this way, each criterion was calculated from the geometric mean of their indices, according to Eq. 1 (Khosravi, 2012).

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

Where Index-x is the criterion of interest, layer denotes the indicators under each criterion, and N represents the number of indicators in each criterion. Table 2 shows scoring scheme for each index in the IMDPA model.

It should be mentioned that for scoring each index (36 indices) in the 9 criteria of the IMDPA model, a separate table was prepared similar to Table 2. Scorings were carried out according to expert judgments (being familiar to the region) using available or prepared maps and statistics.

The geometric mean of the nine criteria under the IMDPA Model produced the final desertification severity map as indicated in Eq. 2.

$$DM= (Q_C.Q_V.Q_S.Q_G.Q_A.Q_E.Q_W.Q_{(S-E)}.Q_T)^{\wedge 1/9} \quad (2)$$

QC: climate quality criteria, Qv: cover quality criterion, Qs: soil quality criterion, QG: Geology and geomorphology quality criterion QA: Agricultural quality criterion, QE: Erosion status criterion, QW: Water quality criterion, Q (S-E): Socio-economic criterion QT: Urban and Industrial Development criterion, DM: desertification map.

Compliance of model output with ground truth

Due to ranking scheme used as the data scoring system, accuracy of results was determined according to Mann-Whitney test and in the Minitab 17 software environment.

Significance of the criteria was established according to the pair wise X^2 test.

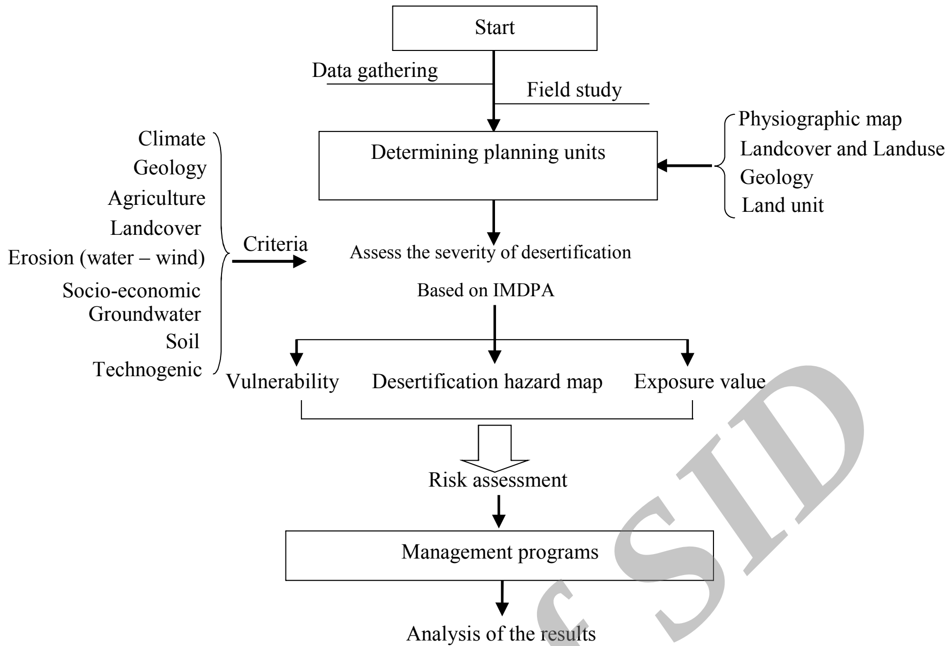

Fig. 2: The flow diagram of the proposed research

Table 3: Classes of elements at risk in the study area (Ownegh, 2009)

No.	Classes of elements	Qualitative classes	No. of elements
1	I	Very low	2?
2	II	Low	3
3	III	Medium	4
4	IV	High	5
5	V	Very high	6

Assessment of desertification Risk

Desertification risk was calculated using Eq.1. Given the risk formula, a combination of desertification severity map, elements at risk and vulnerability, provides an opportunity for the risk assessment. Eq. 3 specifies the risk equation (Ammann, 2016)

$$Risk = H * E * V \quad (3)$$

In the above equation, H indicates the severity and persistence of the risk of desertification which has been achieved on the basis of risk assessment models. E represents elements at risk and contains all the biological elements (demographic, residential, forest and pasture land, agricultural land, physical infrastructure, social and welfare elements, Mines and Water Resources). V is the vulnerability level a function of stability (resilience) and instability (vulnerability).

Elements at risk's map

Using land use and topography maps as well as cataloging the elements at risk (agricultural land, rangelands, forest, residential areas, facilities, roads, population, wells and springs) per unit of risk map, elements of interest were identified and classified according to Table 3 (Ownegh, 2009).

Elements' vulnerability map

In order to assess the vulnerability of elements, the presence of risk and the socio-ecological conditions of each of the elements have to be identified. Vulnerability is a function of resilience and sensitivity of the elements at risk. Elements that are at a higher risk classes will be more vulnerable. Table 4 provides the scores for the characteristics of the elements at risk, and Table 5 provides the elements' vulnerability values.

Table 4: Characteristics of the elements at risk (Arami, 2012)

Elements	Factor
Forest and Rangelands	With the increase in vegetation cover and risk importance, rises by a factor of 2
Agricultural Lands	In case of the presence of more vulnerable plants and bigger risk, increases by a factor of 3.
Wells and springs	For larger risk values, increases by a factor of 2.
Residency	For larger risk values, increases by a factor of 3
Roads and infrastructures	For larger risk values, increases by a factor of 2.
Mines	For larger risk values, increases by a factor of 2.

Table 5: Class and vulnerability value of elements at risk (Arami, 2012)

Vulnerability class	Qualitative classes	Vulnerability value
I	Very low	<7
II	low	7-15
III	medium	15-35
IV	high	35-45
V	Very high	> 45

Table 6: Classes and qualitative categorization of risk value in the study area (Nazarinezhad, 2010)

Risk class	Qualitative classes	Vulnerability value
1	Very low	0-10
2	Low	10-25
3	Medium	25-40
4	Very high	> 40

Risk assessment of desertification

After the calculation of the risk (using the IMDPA model), mapping important elements at risk of desertification and preparing vulnerability maps, desertification risk assessment was conducted. By risk mapping, prioritization of management plans to combat and reduce desertification processes was determined (Nazarinezhad, 2010). Table 6 shows the classes and qualitative categorization of risk value in each work unit.

Risk management policies and programs desertification

Spatial units, according to the scale of the proposed maps, can be the basis of evaluation of terrestrial phenomena in the models. In this regard, the selection of geometric cells as management units for medium and large scale criteria maps on the scales of 1: 50,000 and 1: 25,000, could be effective in geographic information systems. Table 7 details the standard maps in terms of scale, size and dimensions of the map.

Plans and management solutions to tackle desertification for sustainable development and improving environmental conditions were proposed and mapped according to the risk score in the natural areas; in four desertification risk management plans (Table 8).

RESULTS AND DISCUSSION

By combining physiographic maps (elevation, slope and slope directions) along with vegetation, geology, land use and capability, about 80 work units (with spatial distribution) were established in the study area. Based on the geometric mean of the indices of desertification in the IMDPA model, weighted average of desertification severity was obtained 1.28, which represents a moderate class.

In the weighted averages of 2.45, 2.15 and 1.6.The results of the studies are consistent with the findings of Honardoust *et al.* (2011), Abbas Abadi *et al.* (1999) and Sabeti *et al.* (2010). Table 9 provides the criteria's significant values based on pair wise comparisons in chi-square test. The frequency percentages of desertification severity classes are presented in Table 10.

As it is shown earlier, scoring was performed according to the IMDPA mode, geometric average of the three climatic criteria (precipitation, aridity and drought persistence) was 1.38 which falls into the Low to negligible class according to Table 2.

Table 7: Standard maps in terms of scale, size and dimensions

Map scale	Area		Geographic dimensions
	Area Km^2	Surface as Km^2	
100000	2400 - 2800	46 * 55	0.5 x 0.5 degrees
50000	600 - 700	23 * 27	15 x 15 minutes
25000	150 - 175	12 * 14	7.5 x 7.5 minutes

Table 8: A guide to setting priorities in management plans
(Adopted from Ownegh, 2009 with a slight modification based on the UNEP's strategy)

Risk class	Management plan	Proposed actions	Management priority	Management plan's class
I	No action	No management plan proposed	uncritical condition	0
II	Sustaining status quo	Prevention of land-use changes, vegetation removal and grazing control	uncritical condition	I
III	Risk avoidance	II-a: using appropriate methods to maintain the stability of ecosystems II-b: cultivation of salt resistant crops - targeted cultivation of crops	Critical condition	II
IV	Control measures	III-a: increase in vegetation, especially resistant plants to drought and salinity III-b: mechanical operation, construction of Open Drains III-c constructing facilities and infrastructure more resilient (resistant to earthquakes, floods, and etc)	Critical condition	III

Table 9: Pairwise comparisons among criteria in chi-square test

Criteria	Climate	Geology	vegetation	Agriculture	Erosion water	Erosion wind	Socio-economic	soil	groundwater	Technogenic
Climate	0	0.308	0.000**	0.000**	0.004**	0.367	0.017*	0.000**	0.376	0.192
Geology	-	0	0.014*	0.000**	0.058	0.906	0.169	0.004**	0.057	0.020*
Vegetation	-	-	0	0.007**	0.570	0.010**	0.276	0.674	0.000**	0.000**
Agriculture	-	-	-	0	0.000**	0.000**	0.000**	0.022*	0.000**	0.000**
Erosion water	-	-	-	-	0	0.044*	0.603	0.322	0.000**	0.000**
Erosion wind	-	-	-	-	-	0	0.135	0.003**	0.074	0.027*
Socio-economic	-	-	-	-	-	-	0	0.131	0.000**	0.000**
Soil	-	-	-	-	-	-	-	0	0.000**	0.000**
Groundwater	-	-	-	-	-	-	-	-	0	0.670
Technogenic	-	-	-	-	-	-	-	-	-	0

** Difference in area between classes is significant at 1% (p value=0.01)
* Difference in area between classes is significant at 5% (p value=0.05)

Table 11 states that the weighted average values of the criteria and desertification classes. Fig. 3 shows a map of desertification hazard in the study area.

Based on the values of Table 11 and Fig. 3, areas with low to negligible severity is found mostly in the southern and eastern parts of the region while moderate severity class covers northern to the southern parts along with a geo-ecological gradient. In order to verify the IMDPA desertification classes with ground truth, the Mann-Whitney test was used. The results showed no significant difference between the model's output and the ground truth at the level of 5% (P-value = 0.169). In order to estimate the risk of desertification, a map concerning the elements-at-risk of desertification was prepared. Table 12 offers the percentage distribution of each of the elements in the 5 classes, and Fig. 4 shows the map of the elements-at-risk classes in the study area.

Based on the values of Table 12 and Fig. 4, the most important ecological, biological, physical and socio - economic elements at risk of desertification are concentrated in the central part of the area (extensive residential areas – population centers, agricultural lands, wells, springs and means of communication). In these areas, the harmful effects of desertification, due to the severity of drought and land mismanagement, can cause considerable damage. Resilience and vulnerability of elements against environmental conditions are other important parameters considered in the risk assessment, since elements are at higher risk classes will be more environmentally vulnerable and accompanied by economic and social consequences. Table 13 offers percentage distribution of vulnerability classes and Fig. 5 indicates the vulnerability of elements at risk. Given Table 13, classes with low and medium vulnerability obtained the highest

Table 10: The weighted average values of the criteria and classes of desertification intensity severity

No.	Criteria		Index	Index value	Corresponding desertification class	Criteria value	Corresponding desertification class
1	Climate		amount of annual rainfall	1.5	Low to negligible	1.38	Low to negligible
			Dryness Index	1.77	Medium		
			Drought Persistence	1	Low to negligible		
2	Geology		Stone sensitivity	2.44	Medium	1.63	Medium
			Slope	1.63	Medium		
			Land-use	1.37	Low to negligible		
3	Vegetation cover		Vegetation cover	2.14	Medium	2.32	Medium
			Vegetation utilization	2.15	Medium		
			Vegetation regeneration	2.80	Severe		
4	Agriculture		Cultivation pattern	2.99	Severe	3.22	Severe
			Crop performance	3.80	Very severe		
			Utilization of inputs	3.04	Severe		
5	Erosion	water	Type and density	2.20	Medium	2.15	Severe
			Land use	2.06	Medium		
			Canopy density	2.25	Medium		
		wind	emergence of facies	2.18	Medium	1.6	Severe
			vegetation percentage	2.25	Medium		
			dust index	0.75	Low to negligible		
6	Socio-economic		population	1.91	Medium	2	Severe
			Poverty and economy	2.97	Severe		
			Institutional factors	2.06	Medium		
			Participation and communities	1.98	Severe		
7	Soil		Ec	2.23	Medium	2.45	Severe
			drainage	2.70	Severe		
8	Groundwater		Ec	2.90	Severe	1.18	Low to negligible
			SAR	0.76	Low to negligible		
			Cl	0.75	Low to negligible		
9	Urban-industrial development		Orchard land conversion	0.75	Low to negligible	1.09	Low to negligible
			Rangeland conversion	0.75	Low to negligible		
			Road and mine density	0.86	Low to negligible		
			Per capita green spaces	2.9	Severe		

Table 11: Weighted average of desertification severity classes

Desertification severity class	Code	Range of class	Area (m^2)	Area (ha)	Relative frequency
Low to negligible	1	0-1.5	2994746601.83	299474.66	59.03
Medium	2	1.6-2.5	2078842488.54	207884.25	40.97

frequency values in the order of 47.23 and 33.71. According to Fig. 5 and distribution of elements at risk in the central part of the region, the spatial distribution of environmental vulnerability of biological, physical and infrastructural facilities in this region had greater extent than in other sectors.

According to Eq. 1, the product of desertification severity, elements at risk and vulnerability was considered as the risk which is the base map for management. Table 14 shows the relative frequency of risk classes and Fig. 7 shows a map of the risk of desertification in the study area.

According to Table 14, most of the area could be grouped under the high risk of desertification and land degradation. This means that changing and intensifying the climate and Technogenic conditions with improper land management and physical development regardless of the circumstances of ecosystem sustainability (development without compliance with the land-use upstream documents) can bring a harsh condition. Unfortunately, many of these conditions occur in internal arid and semi ecosystems of Iran's (Silakhori *et al.* (2014) and Momenzadeh *et al.* (2014)).

But in the semi-desert areas (western province), for various reasons, including steep environmental and geomorphological gradients (being located in between the forest and the sea), existence of hills and sandy zones, playas and salt pans, fine sediments, saline and evaporative sediments of the Caspian sea, activity of wind erosion, high water table

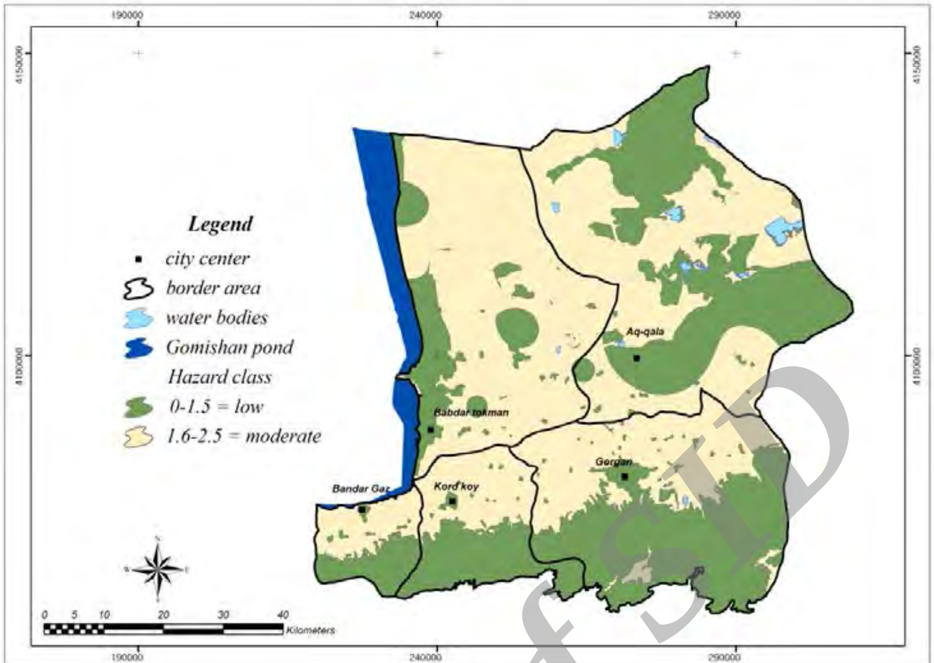

Fig. 3: Desertification hazard map of the study area

Table 12: Frequency distribution of the percentage of each element at risk in the study area

Qualitative range of the vulnerability of elements at risk	Element class	Number of elements	Area (m^2)	Area (ha)	Relative frequency
Very rare	I	<2	401318450.00	40131.85	7.91
Rare	II	3	1050658096.00	105065.81	20.71
Occasional	III	4	698284159.00	69828.42	13.76
Frequent	IV	5	1506647255.37	150664.73	29.70
Very frequent	V	6	1416681130.00	141668.11	27.92

and capillary action, and drastic changes in land-use, the effects of environmental degradation could rise remarkably. The results of the studies of Afkhami Ardeshir *et al.* (2007), Ownegh (2009) and Honardoust *et al.* (2011) are consistence with the results of this study.According to Fig. 6, except for parts of forest lands in the southern part, other land received a relatively high risk of desertification and land degradation.

Programs and management strategies in the study area

Management of natural areas, residential and agricultural lands and providing appropriate plans to reduce and counteract the negative effects of risk, becomes operational and practical by the assessment and calculation of desertification risk. Table 15 provides details of the appropriate management plans and strategies based on the proven models by other researchers in the region (Ownegh, 2009), as well as UNEP's proposed strategy for the sustainable development of ecosystems.

Based on Fig. 7, management plans in the southern part of the region included maintaining the status quo and preventing forest and pasture land use change to other land uses such as agriculture and residential. On the other hand, for the central and hill slopes, a range of control and prevention measures were suggested. For major parts of central and northern regions, risk avoidance plans by creating the right conditions for a controlled and targeted agricultural, cultivation of drought tolerant species along with the maintenances of ecosystem stability are highly recommended. Fig. 7 shows a map of the management plan.

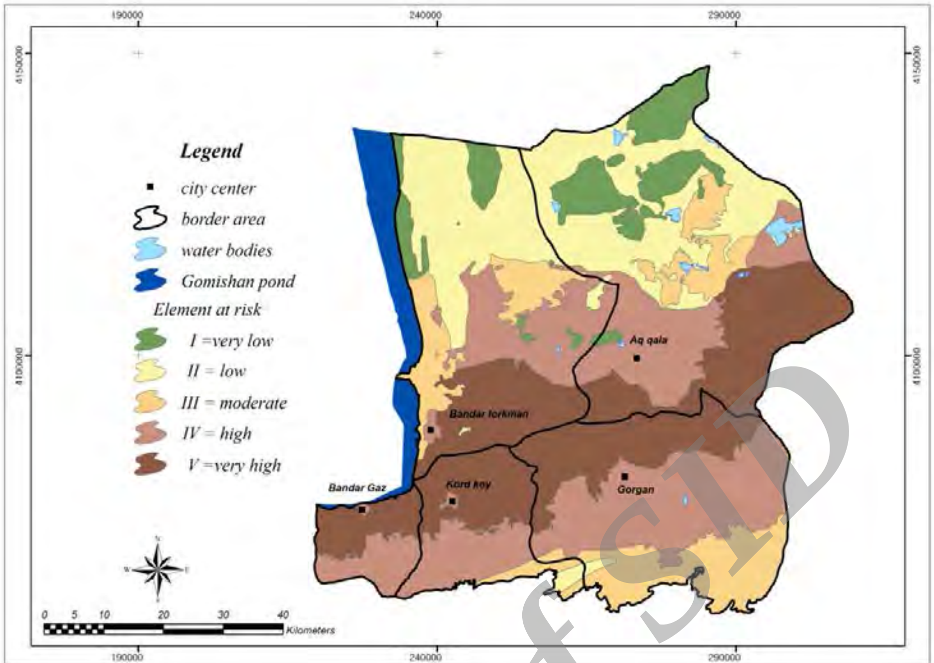

Fig. 4: The class map of the elements at risk in the study area

Table 13: Frequency distribution of the percentage of each element at risk in the study area

Qualitative range of the vulnerability of elements at risk	Vulnerability Class	Vulnerability value	Area (m^2)	Area (ha)	Relative frequency
Very rare	I	< 7	389253904.00	38925.39	7.67
Rare	II	8-15	2396159591.00	239615.96	47.23
Occasional	III	16-35	1710272285.39	171027.23	33.71
Frequent	IV	36-45	577903307.00	57790.33	11.39

The proposed management programs

Table 15 proposed plans were presented in four groups, based on previous studies and UNEP's strategies. The analysis of the produced maps is as follows:

Maintaining the status quo (I)

This plan includes all operations to avoid changing land use, vegetation removal and grazing control in order to maintain the status quo. According to the management plans' map, the study area for this type of management was approximately 61779.46 ha (an area equivalent to 12.17%). As with the important elements at risk, 9.68 km main asphalted road and 234.27 km rural gravel roads and exist in the region. There is 338.78 km waterway to transfer water from upland watersheds to the lower elevations and plains. Important settlement areas include Karkandeh, Baghoo, Sarkalateh, Gaz Sharghi which divert flow of water from the river to irrigate citrus orchards and crops like soybeans, beans and herbs. Groundwater sources such as wells (342 shallow and deep wells), springs (967 springs with non-mineral quality) and Aqueduct (five permanent Aqueducts) also exist in this area that are used for irrigation in agriculture and fish farming. Due to the predominance of dense and semi dense forests, prevention programs for forest land use conversion to residential or agricultural areas, preventing land degradation flash floods, livestock grazing control and livestock removal from forest lands can be constructive.

Risk avoidance plans (II)

The plan consists of two management strategies such as using appropriate methods to maintain the stability of the ecosystem (IIa) and cultivation of salt tolerant crops - in addition to purposeful cultivation of crops (IIb).

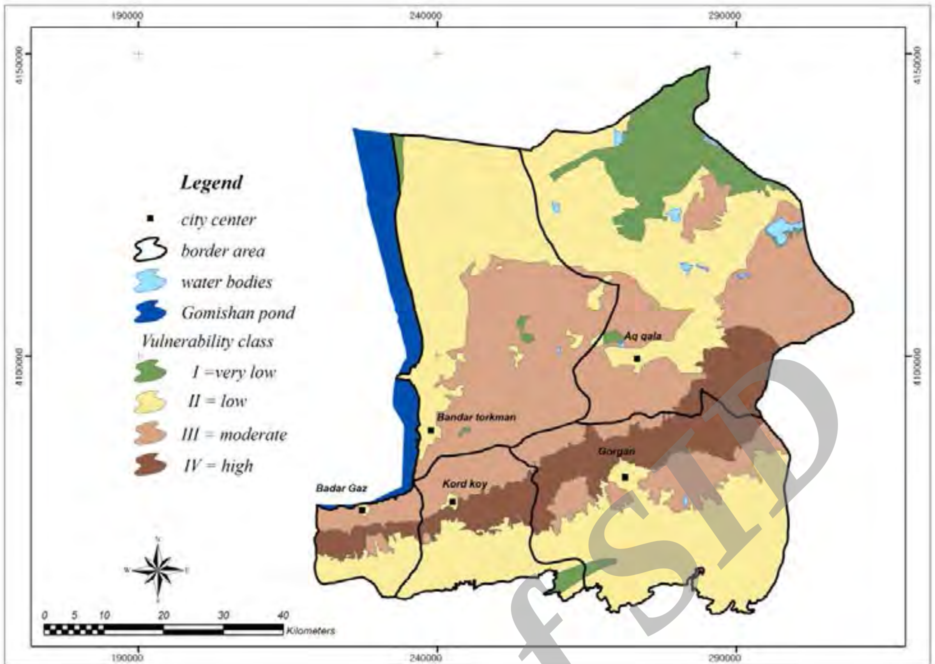

Fig. 5: Class map of the vulnerability of the elements at risk in the study area

Table 14: Frequency distribution percentage of the risk classes of desertification in the area under study

Qualitative range of the vulnerability of elements at risk	risk class	risk value	Area (m^2)	Area (ha)	Relative frequency
Very rare	I	< 10	957300293.83	95730.03	18.87
Rare	II	10-25	133815232.42	13381.52	2.64
Occasional	III	25-40	773013813.79	77301.38	15.24
Frequent	IV	> 40	3209459747.35	320945.97	63.26

Program IIa

With an area of 6811.44 ha (an area equivalent to 1.34 per cent), constitutes the least area. Range land, irrigated and rainfed agriculture and forest lands with low density, were the dominant in this area. Here exists approximately 20 km of urban and rural paved roads and 82 km rural, graveled and dirt roads. In terms of surface and groundwater resources, about 32 km watercourse and seasonal rivers and 172 deep or shallow wells and with a depth between 5 to 230 m, as well as five permanent and seasonal Aqueduct, undertake the nutrition of orchard, irrigated and rainfed lands with products such as fruits, vegetables, beans, and rice paddies. In terms of management plan, this part of the region, due to being located in the piedmont and plain areas, could be benefited by an optimum management with an emphasis on ecosystem sustainability to be much less under the risk of land degradation and desertification.

Program IIb

This class with an area of approximately 10337.77 hectares (equivalent to 2.04 %), is considered as one of the minor classes mainly distributed in the Northeast of the area. Most land-uses are poor range lands, rainfed agriculture, salty and marshy lands, fish breeding areas, and storage dams. Due to the high groundwater levels and water logging, cultivating tolerant crops in the company of rainfed agriculture, by taking into account biological and ecological conditions, will be effective. Means of communication in the region include 55 km rural and gravel roads in addition to 9 km asphalted roads.

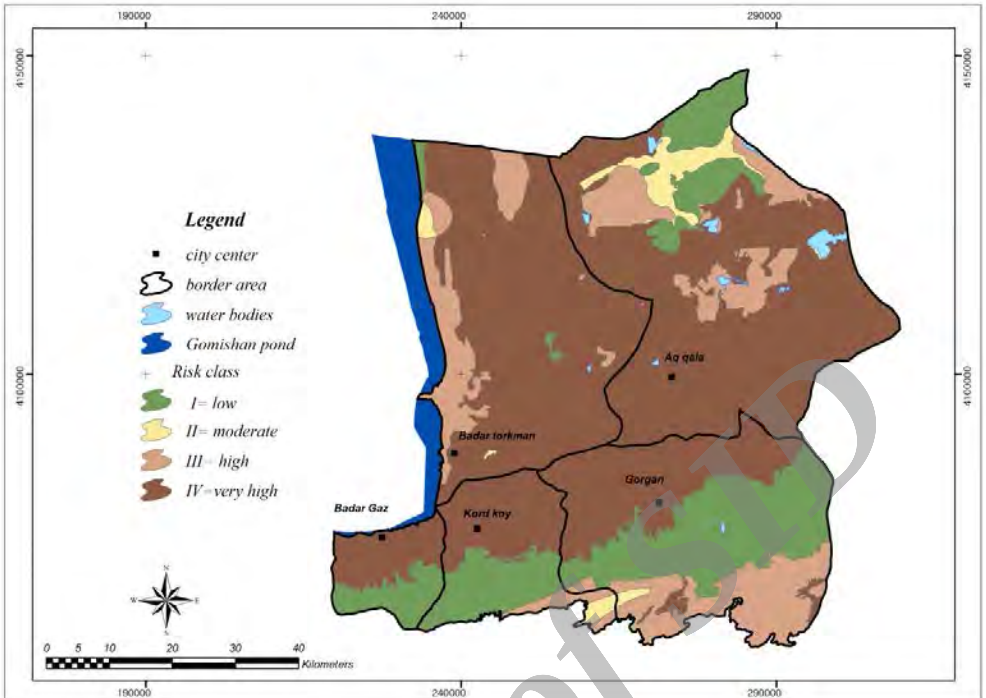

Fig. 6: Desertification risk map of the study area

Table 15: Frequency distribution of the surface area of the management plans for the study location

Risk class	Management plan	Proposed actions	Area (ha)	Area (%)
I	No action	No management plan proposed	0	0
II	Sustaining status quo	Prevention of land-use changes, vegetation removal and grazing control	61779.46	12.17
III	Risk avoidance	II-a: using appropriate methods to maintain the stability of ecosystems	6811.44	1.34
		II-b: cultivation of salt resistant crops - targeted cultivation of crops	10337.77	2.04
IV	Control measures	III-a: increase in vegetation, especially resistant plant to drought and salinity	225707.42	44.48
		III-b: mechanical operation, construction of Open Drains	89258.19	17.59
		III-c constructing facilities and infrastructure more resilient (resistant to earthquakes, floods, and etc)	113464.63	22.36

Application of control measures (III)

This program includes three sets of management practices such as planting cover crops tolerant to salinity and drought, the mechanical operation of constructing drainage networks and more resilient infrastructure (resistant to earthquakes and floods, etc.).

Program IIIa

This region has an area of 225707.42 ha (44.48 %) which has the highest operational level. Irrigated and rainfed agricultural land, poor range lands, forest lands with semi to low densities, saline lands, waterlogging areas and some installations such as water, lake and storage dams, and fish ponds, are the most common types of land-use in this class. In terms of spatial extent, this class is dominant to the central, north eastern and some southern parts of the region. There are 252 km main paved roads along with 625 km secondary, graveled and rural roads in the region. Due to the wide spatial extent of the area, approximately 25 villages could be found from which, the majors are Ziarat, Haji Nazar, Ghalahjigh Paein, Tomakhlar, Hashmali and Syaabad.

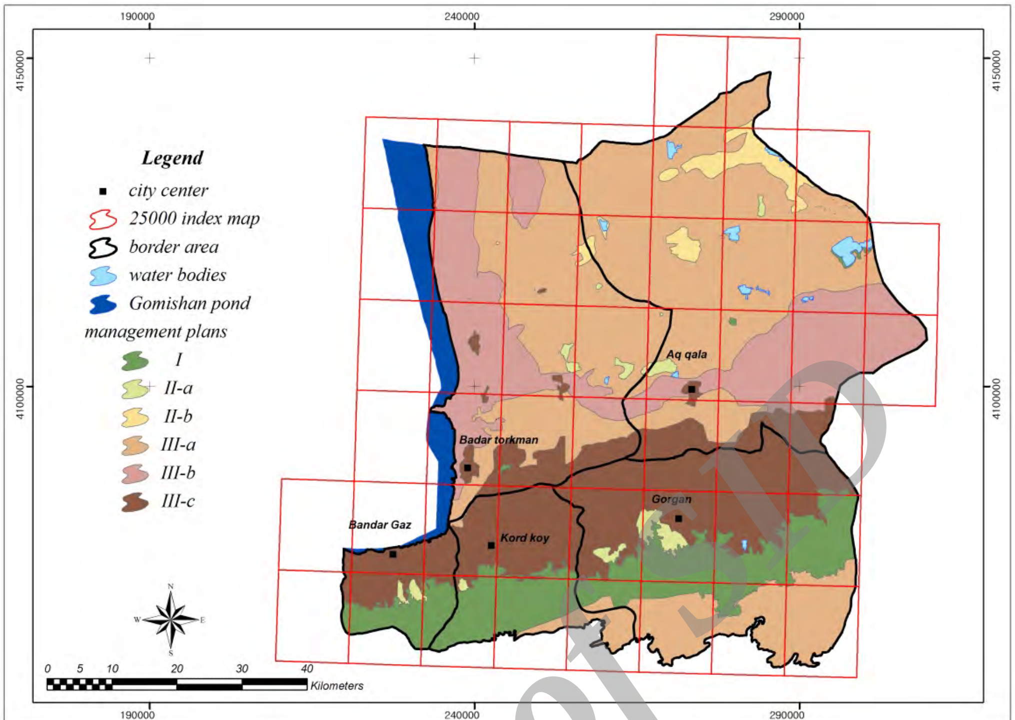

Fig. 7: Management plan map of the study area

Program IIIb

This area is restricted to the central (on Gorganroud's sedimentary deposits) and western (Land Caspian Sea) parts of the study area, covering more than 89258.19 ha, equivalent to 17.59% of the area. Most land-uses include irrigated agricultural, poor to medium range and coastal and saline lands. In this area, there are 74 villages and towns, among which are Khwaja Nafas, Ghaffar Hajji, Basirabad, and Shoghaltappeh. The roads, as one of the elements at risk and increasing factor of the risk of desertification consist of ways 154 kilometers main paved roads and 754 kilometers secondary rural roads. The length of the watercourse and waterways reaches 427 km, which along with groundwater, have an important role in the cultivation of crops. In this regard, 3453 shallow, semi-deep and deep wells provide the irrigation water, for rice paddies, vegetable farming, wheat, cotton and soybean. Because of the high groundwater level, mechanical management operations of constructing surface drains in conjunction with other control measures will have a very important role in reducing the risk of desertification.

Program IIIc

In terms of spatial extent, this class is extended to central and southern parts of the area covering about 113464 ha (22.36 %). Most of the land uses are devoted to agricultural land irrigated fields, rain fed, forests with medium to low density, poor range lands, urban areas, water bodies and storage dams. There are 155 villages and towns in the region which incorporate the major population and residential centers. Important cities are Gorgan, Kordkoy, AghGhala, Gomishan, Bandar Gaz, Bandar Turkmen, and villages such as; Karkandeh, Sarkalateh, Hyderabad, and Soltanabad. Regarding groundwater resources, the greatest number of wells (10455 cases), 43 non-permanent mineral springs and 149 seasonal and permanent Aqueducts can be seen in the region. These resources, along streams and waterways (637 km) provide irrigation water for agricultural land with crops such as citrus, rice, cotton, vegetables, soybeans and corn. Urban and inter-city asphalted main roads and highways (505 km) and rural secondary graveled roads, (1351 km), comprise the main body of the communication lines in the region. Considering control measures, constructing resilience infrastructure (resistant to earthquakes and floods, etc.), along with other development plans consistent with the ecosystem, may be appropriate in reducing the risk.

CONCLUSION

Arid regions due to their sensitive and fragile nature are constantly exposed to degradation and desertification. In this study, desertification assessment was carried out according to the IMDPA model using appropriate physical, biological, socio - economic and land degradation factors. Effective and important criteria of desertification and land degradation indicate the improper operations of beneficiaries in the area. In the meantime, the criterion of agriculture the development of irrigated and rainfed fields, and the development and conversion of rangeland to arable lands, were determined as the most important factors in the process of desertification. Vicinity to the sea, high groundwater level especially in the western parts of the region which is causing waterlogging, adjacency to Karakum desert in Turkmenistan in the northern parts, and continuous drought have been exacerbated wind erosion in these areas. Livelihood dependency of people on agriculture and animal husbandry (northern parts) in conjunction with other factors in desertification, salinization, degradation of vegetation cover and waterlogging are the most important factors to be considered in land degradation assessment in the region. According to Table 10 results, important and effective indices of desertification with the IMDPA model include climate (drought), land (slope gradient index and rock sensitivity), vegetation (utilization and vegetation condition), agriculture (performance index of crops and cropping pattern), water erosion (land use and erosion density), wind erosion (emergence of wind erosion facies and vegetation cover), socioeconomic (poverty and economic), soil (salinity and drainage), underground water (saline) and Technogenic (the amount of green space per capita), criteria. As with the model structure, the influence of the human factor such as poverty has been considered as the main cause of desertification in the area. In addition to assessing the severity of desertification, knowledge-based risk management, based on a joint analysis of natural hazards and environmental vulnerability requires regular collection of information and analysis at the appropriate spatiotemporal scale and studying the vulnerability dynamics as the result of natural, social and economic forces. The main economic and biological elements at risk, included forests, rangelands, agricultural fields, surface and groundwater sources such as wells, springs, Aqueducts, infrastructure, communication lines, industries and mines. In this regard, the destruction and loss of each can change the ecology of the area. The risk assessment showed that about 78 % of the area in the central and northern parts is classified with high to very high degree of risk (areas with the most population, residential, agricultural and horticultural centers). In addition, surface and groundwater resources in this section are constantly at risk of desertification. To mitigate the effects of desertification risk management plans, based on risk values, strategies and conservational and control measures were divided in four activities with two priorities (under critical and non-critical conditions). Land degradation management measures are increased in the study area in risk classes I, II, III and IV with a spatial pattern, from the southern to northern parts in a geo-ecological gradient. As for most part of the study area, due to falling in the very high risk classes, control measures and strategies such as the establishment of vegetation adapted to the salt and drought conditions, along with the construction of drainage networks and resilience infrastructure could be recommended. Other management plans, such as maintaining the status quo and avoiding risk were recommended for high and medium risk.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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