Theoretical and Applied Climatology (2023) 151:1323–1335
https://doi.org/10.1007/s00704-022-04323-x

ORIGINAL PAPER

Vulnerability and drought risk assessment in Iran based on fuzzy logic and hierarchical analysis

Hengameh Shiravand[1] · Ali Bayat[2]

Received: 9 December 2021 / Accepted: 5 December 2022 / Published online: 16 January 2023

Abstract

Drought is an intangible natural disaster that can occur in any climate. The present study assessed drought vulnerability in Iran based on fuzzy logic and hierarchical analysis and weighted averaging process. Then, the weight and map of different components and values of ORness, GIS-OWA method were used to prepare a set of drought vulnerability maps based on effective drought index (EDI).

The study of vulnerable classes in terms of adaptation capacity showed that the northern regions of the country enjoy the highest adaptation capacity. The lowest level of compatibility is related to the cities located in the south of Kerman province, west of Khorasan Razavi province, and Ilam province. As far as the exposure component is concerned, vulnerability extends across the country. Also, cities in the provinces of Sistan and Baluchestan and south of Kerman are in a very vulnerable category regarding the sensitivity component. In other words, according to the type of component, different regions of the country are in the vulnerable category. Also, according to all computational ORness results, drought risk in Sistan-Baluchestan, Kerman, and Khuzestan provinces are in very high vulnerability category. Also, the risk of drought in the western and eastern regions of the country is moderate and high, and only are the central and desert regions of the country and parts of the north-western regions of the country in a state of vulnerability and, accordingly, enjoy lower risk than other parts of the country.

1 Introduction

Drought is one of the intangible natural disasters that can occur in any climatic situation. Thus, its study is of great importance due to its mysterious nature, casualties, economic losses, social effects, and crises in agricultural, natural resources, and ecosystems. Although different definitions have been proposed for this phenomenon, in general, drought is dubbed as a lack of rainfall over a long period of time through one season or more. Drought is actually a temporary disorder and is limited to areas with low rainfall and is a permanent part of the climate in these areas. In addition, drought is considered a climatic phenomenon that may occur in any type of climate, whether wet or dry (Wilhite and Vanyarkho 2000; Knutson 2008).

✉ Hengameh Shiravand
Shiravand@yahoo.com

1 Assessment the effects, adaptation and crisis management of climate disasters office, I.R. of Iran Meteorological Organization, Tehran, Iran

2 Department of Physical Geography, Kharazmi University, Tehran, Iran

Drought and water shortage in Iran have a long history, but since the late 1990s, special and continuous conditions of this phenomenon have emerged in the country. Continuity and occurrence of significant trends in climatic and hydrological variables, deterioration of water areas, widespread economic damage, and its social consequences have been only part of the outcomes of this situation. From another perspective, however, Iran is located in a geographical area for which “climate change” resulted in more negative consequences (Zahraei and Hosseini 2020). Iran is located in the dry belt of the earth and it is, consequently, far from the moisture sources of the Mediterranean Sea and the Atlantic Ocean. On the other hand, most parts of Iran are located in low latitudes. Hence, these two factors have caused drought to be considered an inherent feature of Iran’s climate and increased the length of the dry season in this country, especially in the southern half of the country. They have also caused irregularities in the country's rainfall regime, which has led to drastic changes in the rainy season (Goudarzi and Hosseini 2018).

There are namely two general approaches to drought management as risk management and crisis management. The prevailing approach to all activities and planning in the face of drought in Iran is the "crisis management" approach. In this approach, the maximum result, however, is achieved with the maximum cost. Hence, to prevent and reduce the severe damage resulted from drought, it is necessary to devise the necessary measures beforehand (Sun et al. 2014; Cheng 2011). Therefore, there is the need to replace the "crisis management" approach with the "drought risk management" approach in the country.

Preparation of drought vulnerability and risk maps is the first step towards implementing comprehensive drought management (Fatehi and Hosseini 2011). In this study, index-based methods were used to assess the vulnerability and risk of drought, which is based on the selection of a number of potential indicators and their combination with the relevant levels of vulnerability. Many researchers have applied the method locally and worldwide.

Pandey et al. (2008) mapped the drought vulnerability of the Sonar Basin in India. Cheng and Ping Tao (2010) conducted a comprehensive drought vulnerability assessment in Xiaogan, China, based on a hierarchical and fuzzy analysis process. The results showed that the level of drought vulnerability degree in Xiaogan City is high.

Slejko et al. (2010) mapped the drought vulnerability of the west part of Slovenia and prepared a categorical map of agricultural drought vulnerability for the study area. Ekrami et al. (2013) assessed the vulnerability of agricultural drought in arid and semi-arid regions in Yazd province and prepared a map of vulnerability. Karamouz et al. (2015) applied the concept of vulnerability in drought management in East Azerbaijan province in Iran by providing vulnerability maps. According to the results, the west part of East Azerbaijan province is the most vulnerable region to drought. Lestari and Pigawati (2018) determined the spatial distribution of drought on the agriculture sector to village units in Bringin district. They divided drought vulnerability into three categories: low, medium, and high. Gaucin et al. (2018) presented a method for obtaining indices and maps of vulnerability to drought in Mexico. Mohmmed et al. (2018) examined the socio-economic vulnerability in the five agricultural-based regions of Gadaref, Eastern Sudan. The results revealed that the most exposed farming communities of Alfaw, Algadaref, and Alfushqa regions show a relatively low capacity for adaptation. Nasabpour et al. (2017) used analytic hierarchy process to assess drought vulnerability in different regions of Iran using five indices including climate, topography, drainage density, land use, and groundwater resources. The results indicated that central, eastern, southern, northeastern, and southeastern regions are mainly located in two very low or very high vulnerability classes. Chou et al. (2019) assessed and estimated drought risk in China under the background of climate change. The results demonstrated that high hazards continue to be located in the arid zone. Mesgari et al. (2022) and Majdi et al. (2022) projected the precipitation based on different scenarios in the Middle East and North Africa. The results showed that the countries of the Middle East, including Iran, Iraq, and Syria, will face a decrease in precipitation, and as a result, the risk of drought and vulnerability to drought will increase. Helali et al. (2022) monitored drought and its effects on vegetation in the Urmia lake basin in Iran. The results showed that the risk of drought in the studied basin is high and if there is no management, the vegetation of the basin and the water level of Lake Urmia will be in crisis. The direct aim this study assessed drought vulnerability in Iran based on fuzzy logic and hierarchical analysis and weighted averaging process.

2 Data and methodology

2.1 Study area

The study area is Iran in southwest Asia with 1,648,195 km^2; it is the second largest country in the Middle East. The study area is located in latitudinal coordinates between 25 and 39° N and longitudinal coordinates between 44 and 64° E (Ahmadi et al. 2022). The average annual precipitation of Iran is recorded by one-third of the average precipitation in the world (Salimi et al. 2018). Iran, as one of the most mountainous countries in the world, is dominated by rugged mountain chains such as the Zagros and Alborz in the west and north, respectively, separating different basins or plateaus. The geographical location of this mountain range has created large deserts (i.e., Lut and Kavir desert) significantly affecting the Iran's climate (Shiravand and Hosseini 2020). The climate of the northern part of Iran is Mediterranean and humid; however, most of the Iran exhibits arid or semi-arid climates (Helali et al. 2021). The geographical location of the study area is shown in Fig. 1.

In this study, the indicators related to the 5 main assets (natural, financial, human, physical, and social) provided by the Department of International Development were applied (Tables 1, 2, 3, 4, and 5). This variable provided by the Department of International Development from different sources (general census, agricultural census, household budget, results of some projects FAOs, culture of settlements, as well as extraction of some variables from digital layers, etc.) in the Iranian cities and were related to the 5 main capitals (natural, financial, human, physical and social) and were collected. Then, drought vulnerability was calculated based on fuzzy logic and the process of hierarchical analysis and weighted averaging. Subsequently, the GIS-OWA method was applied to prepare a set of drought vulnerability maps based on the effective drought index (EDI) using the weight and map of different components and values of ORness. In general, the OWA

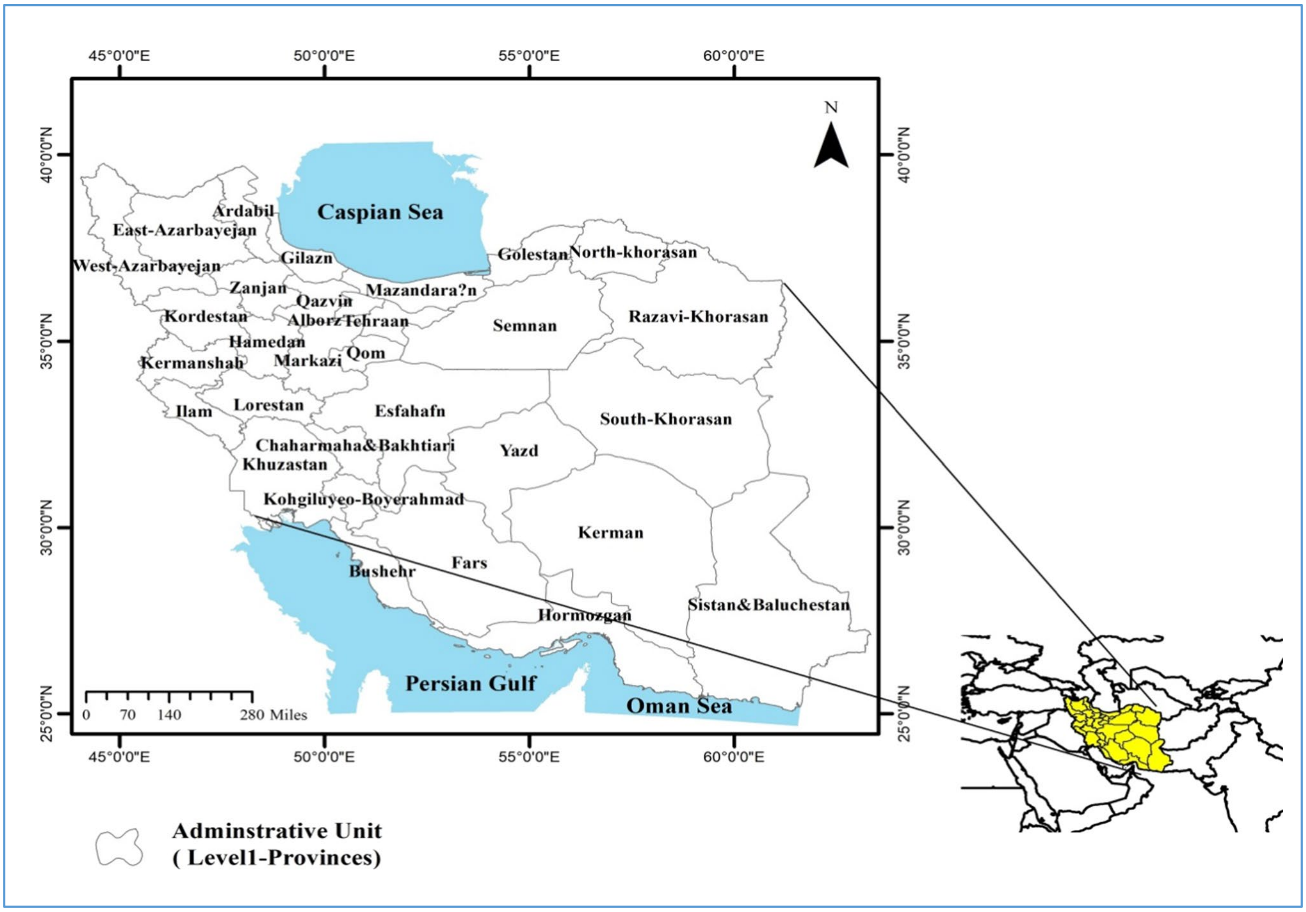

Fig. 1 Geographical location of the study area

model allows the experts to achieve the results of a spatial decision at different degrees of risk with very high flexibility in combining different inputs. Different degrees of risk in decision-making include a continuous chain from very pessimistic to very optimistic (Yager and Kelman 1999).

In this study, drought vulnerability was calculated based on fuzzy logic and hierarchical analysis process (Fuzzy AHP) and weighted average (OWA). Hierarchical analysis process is a general tool for creating a hierarchical model of spatial decision-making problems, overall process processing, and evaluation of each process. The evaluation process in hierarchical analysis uses a simple weighted linear combination to calculate the values of each raster cell. The OWA operator also provides a general framework for performing processes such as AHP. The nature and structure of these two algorithms are such that their combination can be used to create a powerful spatial decision-making tool (Yager and Kelman 1999; Boroushaki and Malczewski 2008; Eastman 2003).

In the next step, the figures related to the selected indicators were normalized. Equation (1) was used to normalize the indices whose increase increases the vulnerability index (Yager and Kelman 1999):

$$x_{ij} = \frac{X_{ij} - \mathrm{Min}_i\{X_{ij}\}}{\mathrm{Max}_i\{X_{ij}\} - \mathrm{Min}_i\{X_{ij}\}} \quad (1)$$

In this equation, *Xij* is the value of the index *j* in region *i*. Thus, the number 1 represents the region with the maximum value and the number zero represents the region with the minimum value. Equation (2) was used for variables whose increase reduces the vulnerability index (Yager and Kelman 1999):

$$y_{ij} = \frac{\mathrm{Max}_i\{X_{ij}\} - X_{ij}}{\mathrm{Max}_i\{X_{ij}\} - \mathrm{Max}_i\{X_{ij}\}} \quad (2)$$

After the normalization process, the obtained figures were used in the calculations according to their direction of effect (incremental or decreasing). The degree of drought vulnerability in each region depends on three factors, including the degree of drought exposure, the degree of vulnerability to drought, and the capacity to adapt to drought. Exposure refers to the degree to which a system is exposed to climate change. Sensitivity points to the degree to which a system responds

Table 1 Natural capital variables to assess drought vulnerability

No	Natural variables	Source	Definition
1	Height	This layer was prepared from the 30-m DEM map of Iran in ArcGIS software	Increasing the altitude due to decreasing temperature (resulting in reduced evapotranspiration) and relative increase in precipitation reduces vulnerability to drought. Therefore, the areas with the maximum height in the drought sensitivity layer were given less value in terms of altitude, and the areas with the lowest altitude were given more value
2	Slope	This layer was prepared from the 30-m DEM map of Iran in ArcGIS software	Increasing the slope causes the water to be removed from the plant quickly, thus giving more weight value to the areas with more slope
3	Waterway density	The layer of this index was obtained by using the waterway layer of Urmia Lake basin in ArcGIS software	The higher the density of the canal, the sooner water will be out of reach. Therefore, more weight value has been assigned to areas where the waterways are higher
4	Land use	The basic data of this index were obtained from the database of the Office of Basic Studies of Water Resources of Iran	The highest weight was given to areas with rain-fed agriculture and the lowest weight was applied to pastures and areas without cover
5	Average groundwater depth level	The basic data of this index were obtained from the database of the Office of Basic Studies of Water Resources of Iran	Each deeper watershed was given more weight because it would be more sensitive to drought
6	Average annual drop in groundwater	The layer of this index has been prepared using the land use layer	Each sub-basin with the highest average annual decline was given more weight because it would be more sensitive to drought
7	Blue statues	AgCensus	More weight was allocated to areas farther away from water sources
8	Per capita irrigated lands	General Agricultural Census	The higher the ratio of rain-fed land area (hectares) to the total population of the city, the greater the vulnerability
9	Dryland per capita	AgCensus	The higher the ratio of irrigated arable land area (hectares) to the total population of the city, the lower the vulnerability
10	soil pattern	Due to the importance of soil texture in the discussion of drought vulnerability using soil map and the opinion of experts in this field, soil texture map was prepared based on the degree of soil permeability in different areas	Areas with the lowest soil permeability have the highest vulnerability

Table 2 Financial capital variables to assess drought vulnerability

No	Financial variables	Definition	Source
1	Heavy livestock per capita	The higher the ratio of the number of heavy livestock (cattle and buffaloes) to the total population of the city, the less vulnerability is considered	FAO FHS Plan
2	Per capita garden lands	The higher the ratio of garden area (hectares) to the total population of the city, the less vulnerability is considered	
3	Activity in the agricultural sector	The higher the percentage of people working in the agricultural sector than the total number of employees, the greater the vulnerability	FAO FHS Plan
4	health insurance	The higher the percentage of people covered by health insurance, the less vulnerable they become	HEIS household budget
5	Home ownership	The higher the percentage of people in the landlord area, the less vulnerable they are	HEIS household budget
6	Seasonal employment percentage	The higher the percentage of active population who have seasonal jobs, the greater the vulnerability	FAO LFS design
7	Dependency ratio	The higher the ratio of rural workers to the total rural population, the lower the vulnerability	FAO VIE scheme
8	The unemployment rate	The higher the unemployment rate in the region, the greater the vulnerability	Census

Table 3 Human capital variables to assess drought vulnerability

No	Human capital variables	Definition	Source
1	population density	As population density increases, vulnerability to drought increases	Source
2	The cost of food	The higher the average shares of food expenditures in total household expenditures in the region, the greater the vulnerability	HEIS workforce
3	Literacy rate	The higher the percentage of literate people in the population aged 6 and older, the less vulnerable they become	Census-VIE
4	The youth population percentage	The higher the percentage of people between the ages of 15 and 29, the less vulnerable they become	Labor-VIE
5	Infant mortality	The higher the percentage of infant deaths in the region per year, the greater the vulnerability	Labor Force-Census

Table 4 Physical capital variables to assess drought vulnerability

No	Source	Definition	Physical capital variables
1	Labor-VIE	The higher the percentage of settlements in a city that have access to agricultural promoters, the less vulnerable they become	Access to agricultural promoters
2	Labor-VIE	The higher the percentage of settlements in a city that have access to public transportation, the less vulnerable they become	Public transportation
3	Census-VIE	The higher the percentage of settlements in a city that have pipelines, the less vulnerable they become	Water pipelines
4	Census-VIE	The higher the percentage of settlements in a city that have access to asphalt or dirt roads, the less vulnerable they become	Access to asphalt or dirt road
5	Household Budget—VIE	The higher the percentage of settlements in a city that have access to the railway station, the less vulnerable they become	Railway station
6	Census-VIE	Percentage of settlements in a city that have access to a veterinarian	Access to a veterinarian

to climate hazards. In this way, the more sensitive a system is, the greater the severity of its adverse reaction to a hazard. Drought adaptation capacity means all the capabilities, resources, and institutions of a country or region to implement adaptation measures and the ability of institutions responsible for land use planning to manage the risks of climate change through adopting appropriate strategies and policies in this regard. All selected and available indicators for this study (Tables 1, 2, 3, 4, and 5) were arranged in three vulnerability

Table 5 Social capital variables to assess drought vulnerability

No	Social capital variables	Definition	Source
1	Member outside the area	The higher the percentage of households from one member region living in another, the lower the vulnerability	Household Budget-Census
2	Rural Cooperative Company	The higher the percentage of settlements in a city that has a rural cooperative, the lower the vulnerability	Agricultural Census-VIE
3	Dispute Resolution Council	The higher the percentage of settlements in a city that has a dispute resolution council, the less vulnerable it becomes	Culture of settlements-VIE
5	Village Council	The higher the percentage of settlements in a city that has a village council, the less vulnerable it becomes	Culture of settlements-VIE
5	Internet access	The higher the percentage of people who use the Internet, the less vulnerable they become	Culture of settlements-HEIS

factors including drought exposure, drought sensitivity, and drought adaptation capacity (Table 6).

According to the results, the inconsistency rate for calculating the weight of the indicators based on the opinions of experts is less than 0.1. In other words, it shows the acceptability and compatibility of experts' opinions.

To calculate the drought risk index, a map of drought incidence rates with different intensities was prepared based

Table 6 Weight and direction of the effect of the indicators used

Factor	CR or incompatibility rate	Index	Weight	CR or incompatibility rate	Effect direction
Exposure	0.0056	population density	0.22	0.004	Enhancing
		Dryland per capita	0.18		Enhancing
		Activity in the agricultural sector	0.2		Enhancing
		Heavy livestock per capita	0.11		Reducing
		Per capita irrigated lands	0.15		Reducing
		Per capita garden lands	0.14		Reducing
Sensitivity		Ratio of rural employees to the total rural population	0.18	0.003	Reducing
		Average annual drop in groundwater	0.12		Enhancing
		Insurance	0.14		Reducing
		Infant mortality	0.05		Enhancing
		Home ownership	0.11		Reducing
		The cost of food	0.1		Enhancing
		Seasonal employment percentage	0.14		Enhancing
		The unemployment rate	0.16		Enhancing
Compatibility capacity		soil pattern	0.07	0.0002	Enhancing
		Height	0.09		Reducing
		Slope	0.09		Enhancing
		Waterway density	0.08		Enhancing
		Land use	0.15		Reducing
		Average groundwater depth level	0.13		Reducing
		Literacy rate	0.12		Reducing
		Young percentage	0.04		Reducing
		Public transportation	0.02		Reducing
		Water pipelines	0.01		Reducing
		Access to asphalt or dirt road	0.03		Reducing
		Railway station	0.03		Reducing
		Member outside the area	0.06		Reducing
		Water areas	0.08		Reducing

on the effective drought index (EDI). The main advantage of an effective drought index over other known indicators is that it possesses a daily time scale. It should be noted that just rainfall data is required for this method data. The computational stages of this index begin with the hypothetical period of water scarcity selection and are determined through the continuation of the actual period of operation. The purpose of the hypothetical period is to consider a period of hypothetical precipitation deficiency before the statistical period begins.

Relevant experts were consulted to determine the degree of importance of each drought intensity in relation to each other, and previous valid studies were used as well. Drought risk map was calculated using Table 7 and the equation below (Goudarzi and Hosseini 2018).

$$\mathrm{DHI} = \left(\mathrm{MD_r} \times \mathrm{MD}_w\right) + \left(\mathrm{SD_r} \times \mathrm{SD_w}\right) + \left(\mathrm{VSD_r} \times \mathrm{VSD_w}\right) \quad (3)$$

In this regard, DHI is drought risk index, $\mathrm{MD_r}$ is degree related to moderate drought, $\mathrm{MD_w}$ is weight related to moderate drought, $\mathrm{SD_r}$ is degree related to severe drought, $\mathrm{SD_w}$ is weight related to severe drought, $\mathrm{VSD_r}$ is degree related to very severe drought and $\mathrm{VSD_w}$ means that the weight associated with drought is very severe.

Table 7 Weights and degrees related to drought intensity maps

Drought intensity	weight	Percentage of occurrence	Degree
Moderate	1	< 3	1
		3–5	2
		5–8	3
		8–12	4
		> 12	5
Severe	2	< 3	1
		3–4	2
		4–5	3
		5–6	4
		> 6	5
Very severe	3	< 1	1
		1–2	2
		2–3	3
		3–4	4
		> 4	5

3 Results and discussion

Having weighed the studied variables using the standardized index map and their ranking points, we prepared the map of the three components of drought vulnerability, i.e., drought exposure, drought vulnerability, and drought adaptation capacity in Iran (Figs. 2, 3, and 4) and the maps were divided into 5 categories based on the degree of vulnerability namely as: very low (0.2–0), low (0.2–0.4), medium (0.4–0.6), high (0.6–0.8), and very high (1–0.8).

The study of vulnerable classes regarding the component of adaptation capacity shows that the northern

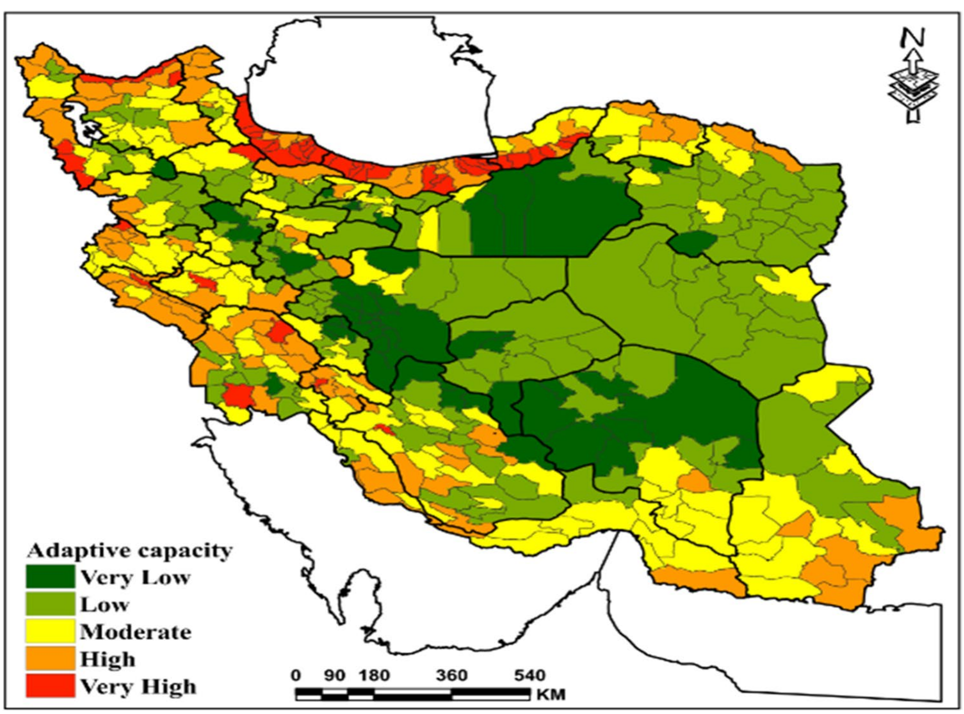

Fig. 2 Drought vulnerability in Iran based on the adaptive capacity component

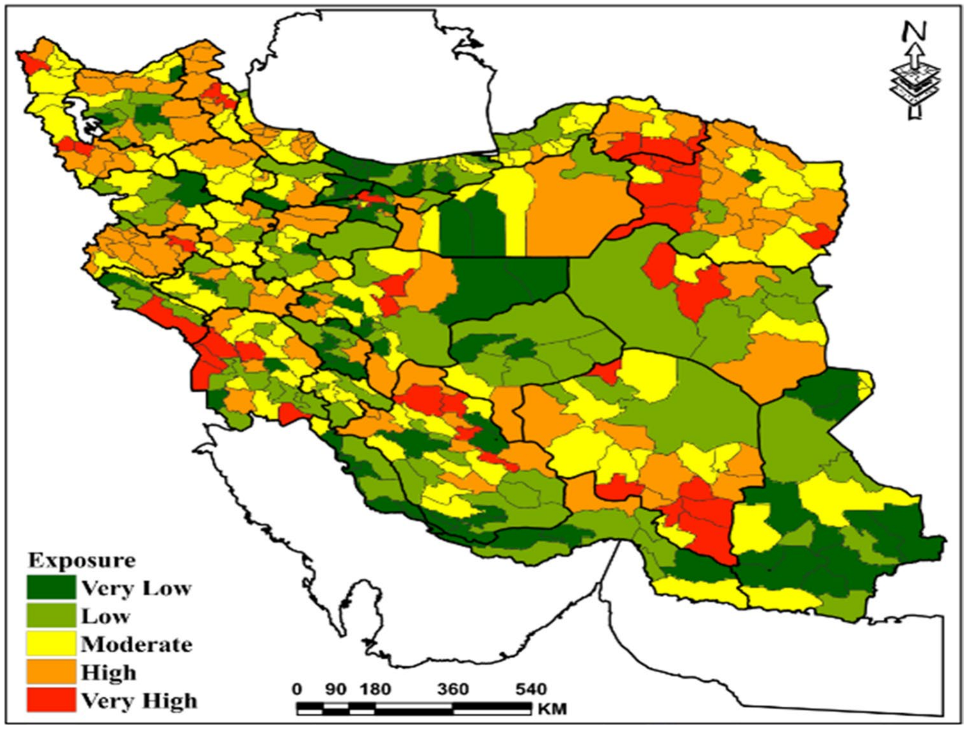

Fig. 3 Drought vulnerability in Iran based on exposure component

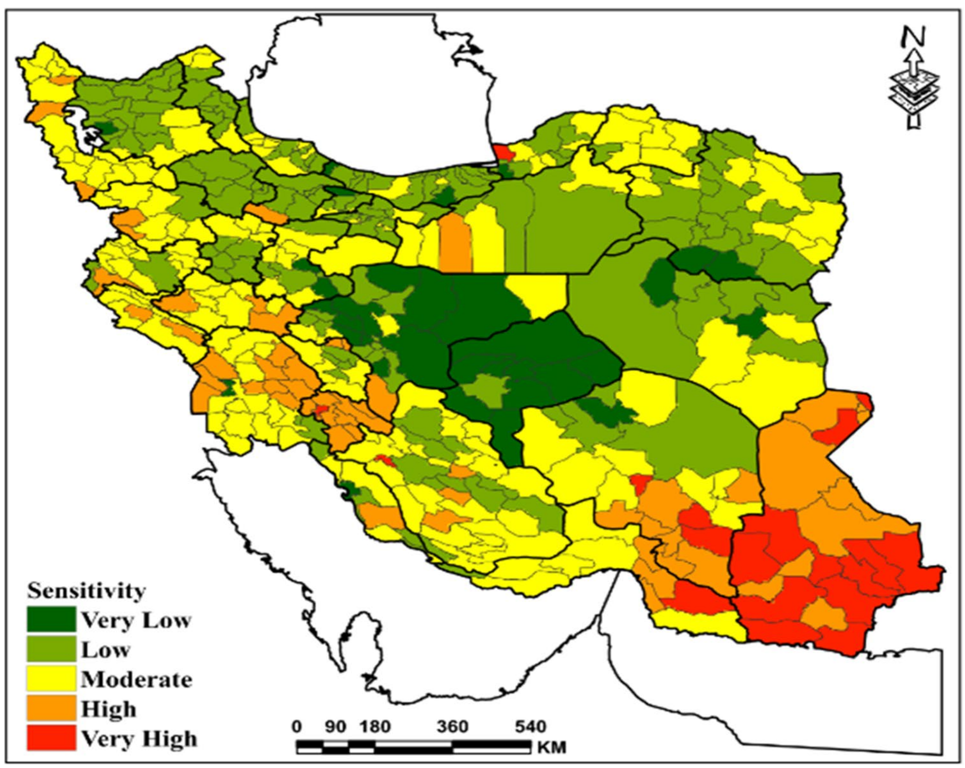

Fig. 4 Drought vulnerability in Iran based on the sensitivity component

regions of the country, i.e., the provinces of Mazandaran, Golestan, and Gilan have the highest adaptation capacity. Also, parts of the northwest, west, and southwest of the country which are mainly considered as rainy areas of the country have considerable adaptation capacity, while the central and low-rainfall areas of the country have the least adaptive capacity. Based on the results, the amount of adaptation capacity shows a twofold difference in the

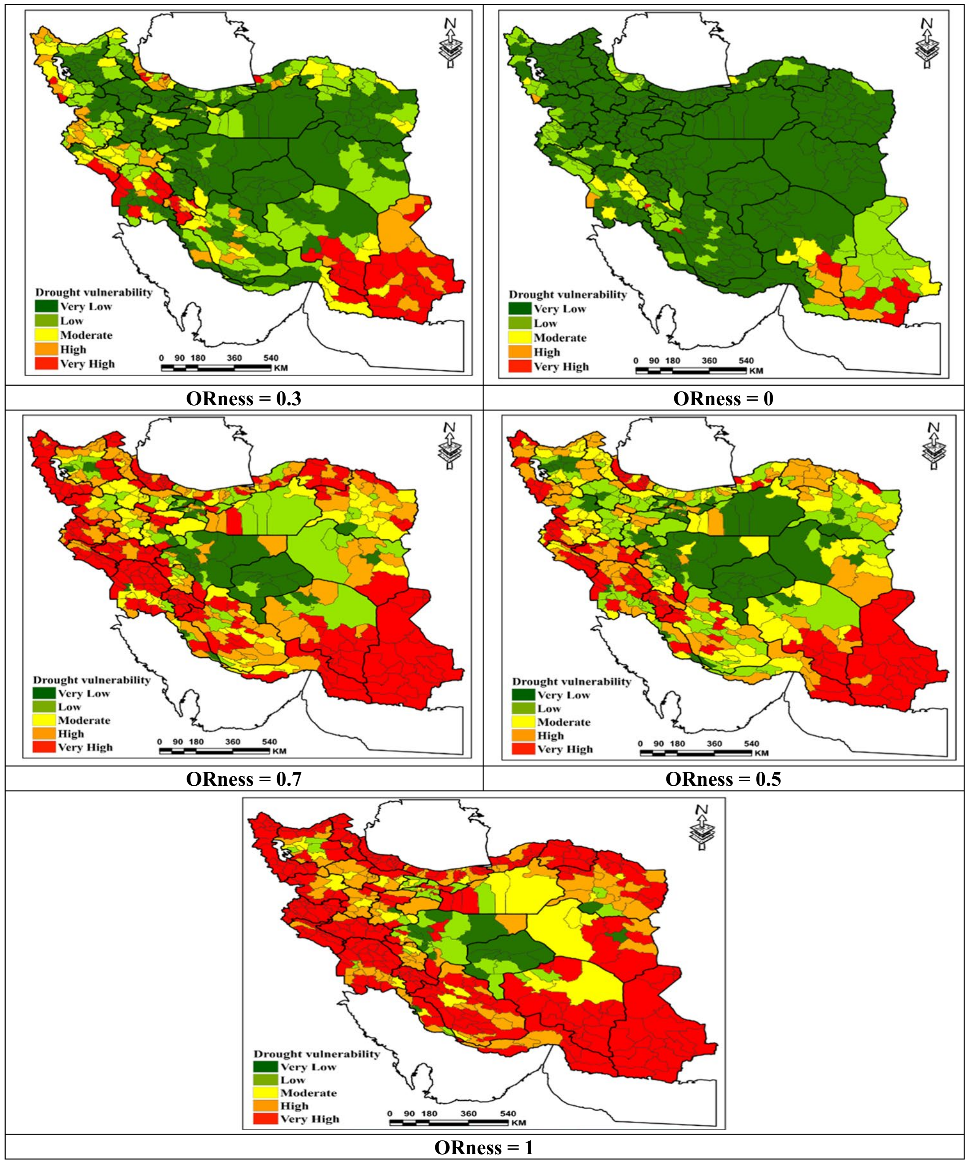

Fig. 5 Drought vulnerability map in Iran based on different ORness

zones that have the most capacity compared to the zones that have the least adaptation capacity (Fig. 2).

The exposure component shows that the areas exposed to drought are scattered in most parts of the country, i.e., the southern, north-eastern and south-western regions of Khorasan Razavi, Kerman the provinces, and Ilam and also the southern areas of Lake Urmia. However, other areas of northern and somewhat western central and south eastern parts of the country are reportedly less exposed to drought (Fig. 3).

The drought vulnerability map also shows that the sensitivity in the south eastern regions, especially in the provinces of Sistan and Baluchestan, and Kerman is higher than other regions of the country, whereas the central and desert regions of the country are the least sensitive to drought. Accordingly, most regions of the country are sporadically exposed to drought vulnerability in different areas (Fig. 4). According to the results, the minimum level of vulnerability in any part of the country is not equal to zero and consequently, the whole country is somewhat vulnerable to drought. Also, according to the results of the rainy regions of the country, there is not necessarily less vulnerability to drought and, also, there is no direct relationship between rainfall and vulnerability to drought in the country.

Then, GIS-OWA method was applied to prepare a set of drought vulnerability maps using the weight and map of

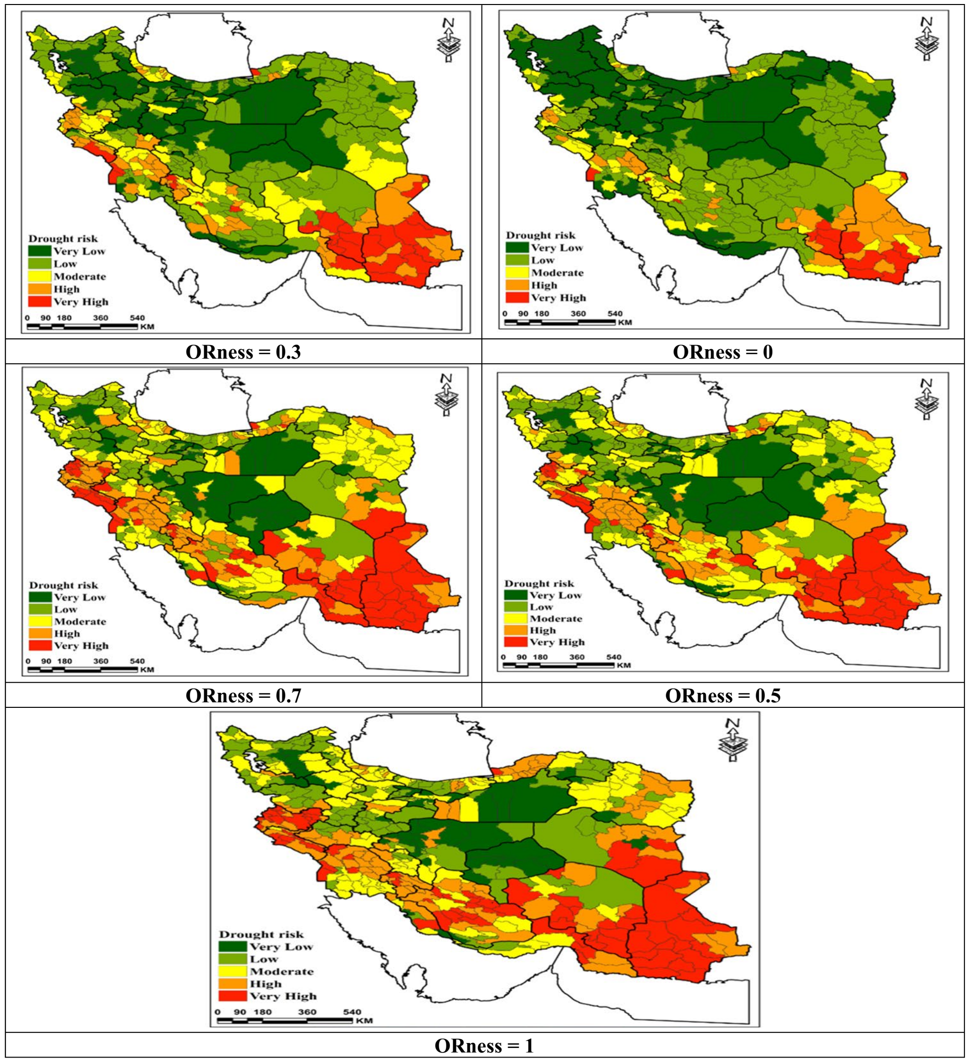

Fig. 6 Drought risk map in Iran based on different ORness

different components and values of ORness. In fact, drought vulnerability maps are prepared implying that the weight of the criteria is the same for all ORness and only does the ORness value change. ORness values range from zero (risky or pessimistic) to 1 (risky or optimistic). Different ORness maps are also based on the degree of suitability into 5 categories: very low (0.2–0), low (0.2–0.4), medium (0.4–0.6), high (0.6–0.8), and very high (1–0.8). Figure 5 shows drought vulnerability maps using the OWA operator with different ORness values. These maps show drought vulnerability ranging from risky to risk aversion. There is a direct relationship between the amount of ORness and the degree of drought risk. In this way, the risk of drought increases along with increasing the amount of ORness, and the risk decreases as the amount of ORness diminishes. According to the ORness = zero in the southern regions of Sistan and Baluchestan province, the south-eastern regions of Kerman province, and also scattered areas in the south western regions of the country are included in a very high vulnerability class (Fig. 5).

According to ORness equal to 0.3, the south eastern and south-western regions of the country and also scattered areas in the southwest of Lake Urmia and the eastern and western parts of the Caspian Sea in the provinces of Golestan and Gilan are in the upper and very high vulnerable category. This ORness implies that most parts of the country are categorized in the very low to medium vulnerability class (Fig. 4).

According to ORness equal to 0.5, most areas of the country are categorized in moderate to very high vulnerability class, the highest of which is related to the provinces of Sistan and Baluchestan, Kerman, Khuzestan, and the western strip of the country. Nevertheless, only are the central regions of the country, which cover most of the desert and desert areas of the country, classified in a very low vulnerability category (Fig. 5). According to ORness equal to 0.7, other parts of the country except for the central regions of the country and scattered areas in East Azerbaijan and Khorasan Razavi are in the vulnerable category of medium to

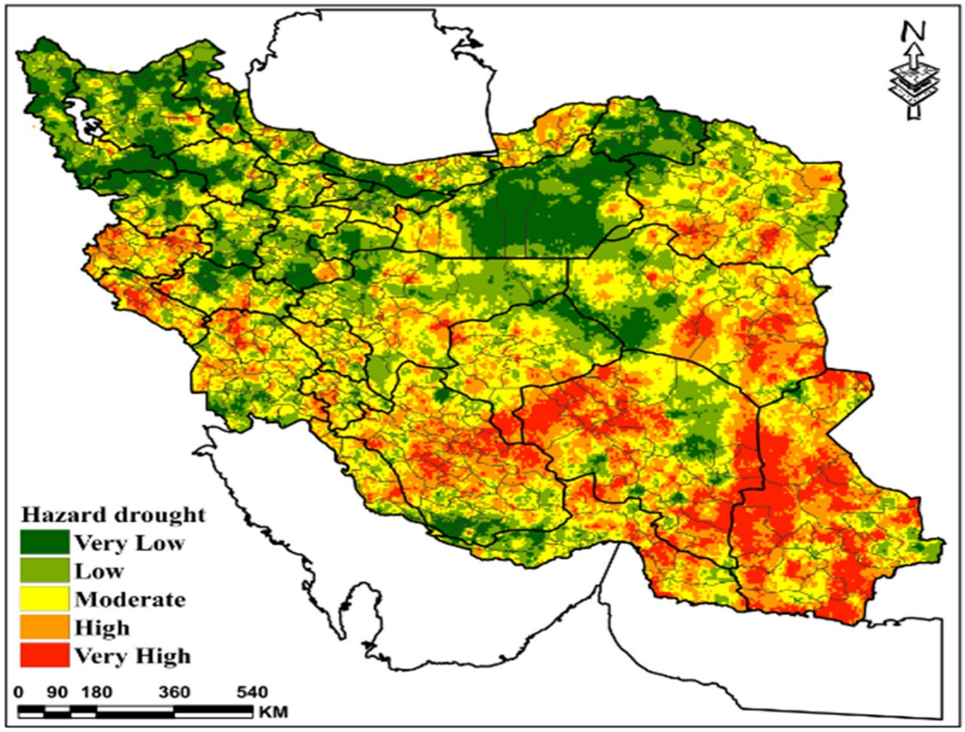

Fig. 7 Severe drought risk map in Iran

very high (Fig. 5). According to ORness equal to one, all regions of the country other than parts of Isfahan, Yazd and Khorasan Razavi provinces are in the medium to very high vulnerability class, which is dominated by the very vulnerability class (Fig. 5).

Overall, based on the results of drought vulnerability based on different ORnesses (Fig. 5), vulnerable areas with higher values also increase as ORness values increase, while areas with lower values decrease. According to the results, most areas of the country, including the provinces of Sistan and Baluchestan, Khuzestan, and Kerman are in a very high vulnerable category, and only are the central areas of the country, which are mainly consistent with low rainfall areas of the country less vulnerable than other areas. In general, when combined with different inputs, the OWA model with very high flexibility allows experts to come up with a spatial decision at different risk degrees. Therefore, managers and planners in different fields can make decisions based on different degrees of risk in planning. Thus, Risk management managers and planners in drought vulnerability reduction schemes are increasingly looking for areas where here all criteria are effective at best. In fact, managers involved in drought vulnerability reduction-related projects in these areas are more likely to achieve the expected returns, because in these areas the criteria are more comprehensive and have the best possible conditions. This situation applies when the financial credit is limited, though.

Figure 6 shows the drought risk maps of the country in different ORnesses. According to all computational ORNs results, the risk of drought in the southeastern regions of the country, including the provinces of Sistan Baluchestan, Kerman, and South Khorasan, is in very high and high vulnerability category. The risk of drought in the western regions of the country and scattered areas in the southern and northeastern regions of the country is also moderate and high. The lowest risk of drought based on different ORnesses is related to the central and northwestern regions of the country.

The drought risk situation in the country also shows that most areas come across a high risk of drought, the highest rate of which is related to the south eastern regions of the country. In general, it can be stated that other areas of the country are in the middle to very high class except for the north-western and to some extent north-eastern regions and the provinces located on the slopes of Alborz, which are in the lower and very lower floors in terms of drought risk and in general there is a risk of severe drought in most parts of the country (Fig. 7). The findings this study were consistent with a previous study by Goudarzi and Hosseini (2018) regarding the higher risk of the south eastern of Iran to drought and another research by Helali et al. (2022) on monitoring drought in Urmia lake basin in Iran.

4 Conclusion

Needless to say that one of the best tools to adapt to drought and reduce the damage caused by this phenomenon in various social and economic areas, including water resources, food security, agriculture, watershed management, migration, and regional development plans is assessing drought vulnerability using different investments and preparing vulnerability zoning maps. Therefore, the present study considered 5 different capitals (natural, financial, human, physical, and social) and related variables in order to assess drought vulnerability in the country using fuzzy logic methods and hierarchical analysis model (AHP). The results of drought vulnerability assessment based on the 5 capitals studied showed that the southeastern and southwestern regions of the country, including the provinces of Sistan and Baluchestan, Kerman, and Khuzestan are in a very high vulnerable category and droughts risk in these areas are at a very high and vulnerable level considering all computational ORness. Also, the risk of drought in the western and eastern regions of the country is in the medium to high condition, and only are the central and desert regions of the country less vulnerable than other regions. According to the results, there is no direct relationship between rainfall and drought exposure, and rainy areas can be more prone to drought at the same time. The findings also showed that areas that have a higher urbanization ratio but also receive less rainfall are above the level of drought adaptation capacity.

Also, some measures that can be taken to reduce the risk of drought in the country include establishing a drought monitoring and awareness system, educating the community to save water resources as much as possible, and improving the Water management and agriculture systems, capacity building of responsible institutions, using of new technologies in agriculture and finally utilizing of resistant and high-yielding species.

Acknowledgements The authors of the present paper are grateful to the I.R. of Iran Meteorological Organization (IRIMO) for providing the data needed to conduct this research.

Author contribution Author 1: conceived of the presented idea, developed the theory and performed the computations and verified the analytical methods, and supervised the findings of this work. Author 2: encouraged and developed the theoretical formalism. All authors discussed the results and contributed to the final manuscript.

Data availability The data used in this paper have been prepared by referring to the I.R. of Iran Meteorological Organization (IRIMO) from this link: https://data.irimo.ir/

Code availability In this paper, custom code in MATLAB software has been used fuzzy logic and hierarchical analysis.

Declarations

Ethical approval Not applicable, because this article does not contain any studies with human or animal subjects.

Consent to participate The data of this research were not prepared through a questionnaire.

Consent for publication There is no conflict of interest regarding the publication of this article. The authors of the article make sure that everyone agrees to submit the article and is aware of the submission.

Conflict of interest The authors declare no competing interests.

References

Ahmadi M, Kamangar M, Salimi S, Hosseini SA, Khamoushian Y, Heidari S, Maghami Moghim GH, Saeidi V, Bakhshi I, Yarmoradi Z (2022) A new approach in evaluation impacts of teleconnection indices on temperature and precipitation in Iran. Theor Appl Climatol 150:15–33

Boroushaki S, Malczewski J (2008) Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. Comput Geosci 34(4):399–410

Cheng J, Ping Tao J (2010) Fuzzy Comprehensive Evaluation of Drought Vulnerability Based on the Analytic Hierarchy Process. Agriculture and Agricultural Science Procedia 1:126–135

Cheng J (2011) A study on agricultural drought hazard vulnerability and risk management: a case of Xiaogan city in Hubel province. PHD Dissertation. HuaZhong agricultural university. Wuhan, China

Chou J, Xian T, Zhao R, Yuan Xu, Yang F, Sun M (2019) Drought risk assessment and estimation in vulnerable eco-regions of China: under the background of climate change. Sustainability 11(16):4463

Ekrami M, Mahdavi Najaf abadi R, Rezai M, vagharfard H, Barkhordari J (2021) Spatial Analysis and Assessment of Agricultural Drought Vulnerability in Arid Regions (Case Study: Pishkouh Watershed, Yazd Province). Watershed Engineering and Management 13(1):197–212

Eastman JR (2003) IDRISI Kilimanjaro: guide to GIS and image processing

Fatehi A, Hosseini F (2011) Development of agricultural drought risk management program of Alamut Qazvin pilot. Research project of Soil Conservation and Watershed Management Research Institute

Gaucin DO, De la Cruz Bartolón J, Castellano Bahena H (2018) Drought vulnerability indices in Mexico. Water 10(11):1671

Goudarzi M, Hosseini SA (2018) Drought (Assessment, Vulnerability), Salam Sepahan publications, 1st edn. Isfahan, Iran

Helali J, Asaadi S, Jafarie T, Habibi M, Salimi S, Momenpour SE, Shahmoradi S, Hosseini SA, Hessari B, Saeidi V (2022) Drought monitoring and its effects on vegetation and water extent changes using remote sensing data in Urmia Lake watershed Iran. J Water Clim Chang 13(5):2107–2128

Helali J, Momenzadeh H, Oskouei EA, Lotfi M, Hosseini SA (2021) Trend and ENSO-based analysis of last spring frost and chilling in Iran. Meteorol Atmos Phys 133(4):1203–1221

Karamouz M, Zeynolabedin A, Olyaei MA (2015) Mapping regional drought vulnerability: a case study. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-1/W5, 2015 International Conference on Sensors & Models in Remote Sensing & Photogrammetry, 23–25 Nov 2015, Kish Island, Iran

Knutson CL (2008) The role of water conservation in drought planning. J Soil Water Conserv 63(5):154A-160A

Lestari DR, Pigawati B (2018) Drought disaster vulnerability mapping of agricultural sector in Bringin District Semarang Regency. IOP Conf Series: Earth Environ Sci 123(2018):012031

Majdi F, Hosseini SA, Karbalaee A, Kaseri M, Marjanian S (2022) Future projection of precipitation and temperature changes in the Middle East and North Africa (MENA) region based on CMIP6. Theor Appl Climatol 147(3–4):1249–1262. https://doi.org/10.1007/s00704-021-03916-2

Mesgari E, Hosseini SA, Hemmesy MS, Houshyar M, Golzari Partoo L (2022) Assessment of CMIP6 models performances and projection of precipitation based on SSP scenarios over the MENAP region. Journal of Water and Climate Change 13(10):3607–3619

Mohmmed A, Li J, Elaru J, Mohammed MAE, Keesstr S, Artemi C, Kabenge M, Makomere R, Zeben T (2018) Assessing drought vulnerability and adaptation among farmers in Gadaref region Eastern Sudan. Land Use Policy 70:402–413

Nasabpour S, Heidari A, Khosravi H, Vesali A (2017) Zoning of drought vulnerability in Iran using AHP model and fuzzy logic. J Agric Meteorol 6(2):1–213

Pandey RP, Mishra SK, Singh R, Ramasastri KS (2008) Streamflow drought severity analysis of Betwa river system (INDIA). Water Resour Manag 22(8):1127–1141

Salimi S, Balyani S, Hosseini SA, Momenpour SA (2018) The prediction of spatial and temporal distribution of precipitation regime in Iran: the case of Fars province. Model Earth Syst Environ 4:565–577

Shiravand H, Hosseini SA (2020) A new evaluation of the influence of climate change on Zagros oak forest dieback in Iran. Theor Appl Climatol 141:685–697

Slejko M, Gregorič G, Bergant K, Stanič S (2010) Assessing and mapping drought vulnerability in agricultural systems (a case study for Slovenia). 10thEMS/8thECACZürich, 13. September 2010

Sun Z, Zhang J, Zhang Q, Hu Y, Yan D, Wang C (2014) Integrated risk zoning of drought and waterlogging disasters based on fuzzy comprehensive evaluation in Anhui Province, China. Nat Hazards 71:1639–1657

Wilhite DA, Vanyarkho O (2000) Drought: pervasive impacts of a creeping phenomenon, drought: a global assessment (Volume I. Rout ledge Publishers, London, pp 245–255

Yager RR, Kelman A (1999) An extension of the analytical hierarchy process using OWA operators. J Intell Fuzzy Syst 7(4):401–417

Zahraei A, Hosseini SA (2020) Climate change and effect on water resource. Hawar publication, Ilam, Iran