



Sensitivity Assessment to the Occurrence of Different Types of Droughts Using GIS and AHP Techniques

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Abstract

In this study, using Analytic Hierarchy Process (AHP) and Geographic Information System (GIS), the sensitivity to the occurrence of different types of droughts including meteorological drought (Med), hydrological drought (Hyd), and agricultural drought (Agd) were evaluated. In this research, at first, some of the effective indicators in each type of droughts were selected (four indicators in Med, three indicators in Hyd, and seven indicators in Agd), then using the ArcGIS 10.3 software, the sensitivity map of drought for each indicator were prepared (all indicators classified in four classes including mild, moderate, severe, and very severe). Then, using the AHP method the weight of each indicator in each type of droughts was determined and the final map of drought sensitivity for different types of droughts was prepared by superposition the maps of effective indicators in each drought. The final map of drought sensitivity was prepared by superposition the Med, Hyd, and Agd sensitivity maps (after determining the weight of each using AHP). In the Med, 43.29% of the study area (Fars province, Iran) was classified in the moderate class of drought sensitivity and 56.71% in the severe class. In the Hyd, 0.46%, 33.25%, 62.49%, and 3.80% of the study area were classified in the mild, moderate, severe, and very severe classes (respectively), and in the Agd, 1.18%, 50.23%, and 48.59% of the study area were classified in the mild, moderate, and severe classes. The results showed that in final drought sensitivity, the Med with a weight equal to 0.36 was the most effective variable, and based on the final map, 38.26% and 61.74% of the study area were classified in the moderate and severe classes of drought sensitivity.

Keywords Meteorological drought · Hydrological droughts · Agricultural drought · AHP · Drought sensitivity

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1 Introduction

The crisis of water is one of the main challenges in the current century (Chen and Costa 2021; Plummer and Baird 2021). In the recent decades, water shortage affected by global warming, decrease in precipitations, increase in water consumption, inappropriate management of available water resources, low productivity of water consumption in agricultural sectors, less attention to the principles of sustainable development in sections related to water resources and so on in different sectors is one of the most important concerns. In recent years, the above-mentioned issues had been direct and indirect effects on the occurrence of different types of droughts (Farsani et al. 2021; Orimoloye et al. 2021; Shen, 2021; Shi et al. 2021b; Zhang et al. 2021; Zarei and Moghimi 2019). Different regions of the world under the influence of different variables such as natural potentials of the region (suchlike climate conditions, annual average precipitation, soil conditions, conditions of endemic vegetation, conditions of surface and sub-surface water resources, etc.), human activities carried out in the region (Changes in land use, cultivation pattern, agriculture system used including irrigated or rain-fed systems, proper or improper management of pastures, overgrazing, etc.), and so on have different sensitivities to the occurrence of various types of droughts such as meteorological drought, hydrological drought, agricultural drought, and so on (Deng et al. 2021; Hellwig et al. 2021; Mu et al. 2021; Shi et al. 2021).

Therefore, determining the degree of sensitivity of different regions to the occurrence of different types of droughts can be effective in managing and reducing the negative effects of droughts on human life and wildlife. Many studies have been conducted in this field worldwide. Dai et al. (2020) assessed the agricultural drought risk in Pearl River Basin. The results of this research revealed that in the most areas of the study region, the risk of the agricultural drought was increasing. Sharafi et al. (2020) assessed the drought risk in western Iran, the result of this research indicated that the majority of villages in Kermanshah are at severe environmental risk. The results of drought risk assessment by Buurman et al. (2020) in Vietnamese communities indicated that the local conditions of each region as well as using the opinions of the residents of the region play an important role in investigating and reducing the risks of drought. Zhang et al. (2020) evaluated the agricultural drought risk in the Lancang-Mekong region and showed that the spatial distribution of the areas with high risk and sensitivity to drought is consistent with areas with the agricultural application. Keshavarz et al. (2017) evaluated the vulnerability of rural livelihoods in Fars province to meteorological drought and showed that the severity of drought, duration of drought, and their interaction due to the impact on agricultural systems can be considered a threat to rural livelihoods. Etemadi et al. (2014) assessed the social vulnerability to drought in Estahban, Fars Province. The results of this paper indicated that drought occurrence has negative impacts on empathy, health, the economy of family, etc. Shamsnia and Khodadadi Dehkordi (2020) assessed the agricultural drought in central and southern regions of Fars using GIS techniques and showed that the northern regions of the study area are more damaged from drought occurrence.

Hoque et al. (2020) used geospatial and AHP techniques to assess the drought vulnerability in the northwestern region of Bangladesh. According to the results of this research, about 77% of the study region was classified in moderately to extremely classes of vulnerability to drought. Kim et al. (2015) tried to assess the drought hazard, vulnerability, and risk using the drought hazard and drought vulnerability indices in South Korea. They suggested that the potential risk of drought can be assessed using a framework based on the

hydro-meteorological and socio-economic parameters. Rajsekhar et al. (2015) presented a hydrological drought atlas for Texas and indicated that from the west to east of the study region the pattern of drought severities was decreased. Zareiee and Masoudi (2014) presented a new method for assessing drought hazards using the GIS technique in Ghareh Aghaj Basin, Fars, Iran. The results of this paper revealed that the study area was classified in moderate and severe classes of drought hazard. Asrari et al. (2012) used the GIS technique and standardized precipitation index (SPI) for assessing the drought hazard in Iran. According to the results, about 43% of the study region was classified in the severe class of drought vulnerability that mainly located in the west and eastern parts of Iran. Many researchers around the world have tried to assess the risk of droughts, for example, Akbari et al. (2021); Hoque et al. (2021); Niaz et al. (2021); Rani et al. (2021); and Zhu et al. (2021).

According to the importance of the different types of droughts and their negative impacts on different sectors especially on human and wildlife food security as well as the effective role of determining the rate of the sensitivity of different regions to different types

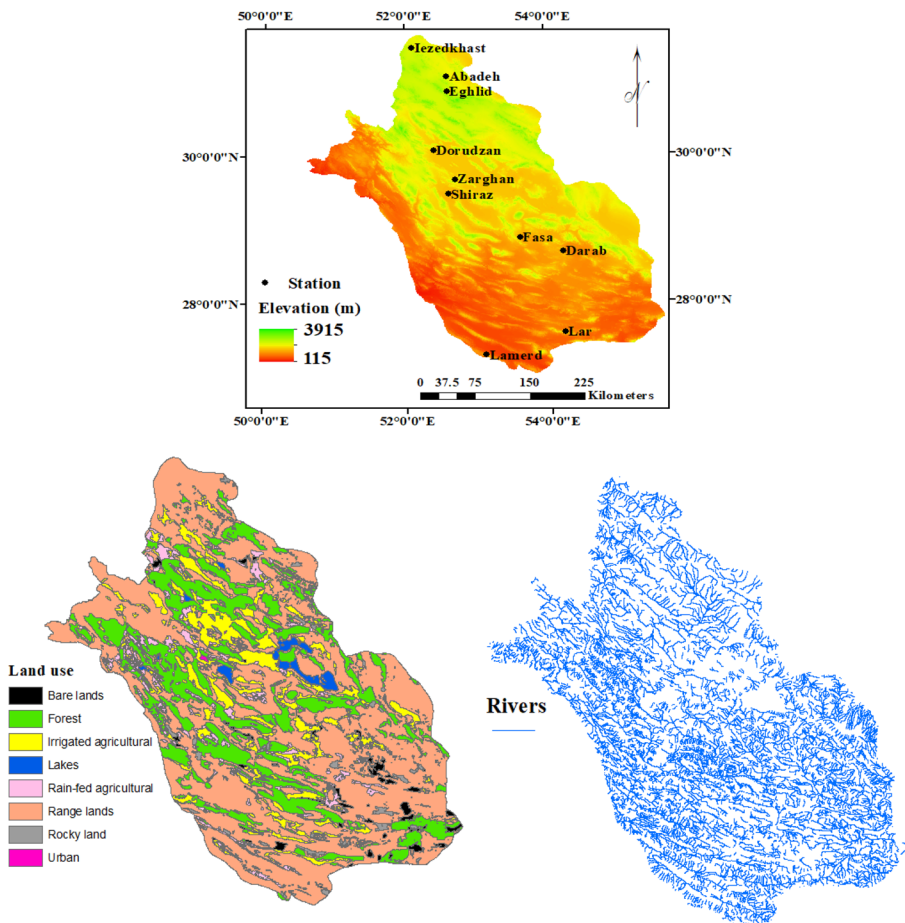


Fig. 1 Elevation map, spatial location of the meteorological stations, land use map and hydrographic network of the study area

of droughts on more appropriate management of impacts of droughts, the objective of this study is sensitivity assessment to the occurrence of different types of droughts including meteorological drought, hydrological drought, and agricultural drought using the GIS and AHP techniques.

2 Material and Methods

2.1 Study Area

The study region is Fars province located between 27.083° to 31.916° northern latitude and 50.116° to 55.90° eastern longitude with an area of about 122,000 square kilometers (Fig. 1). The main land uses of the study area are irrigated and rain-fed agriculture, forest, lakes, rangeland, rocky lands, urban and bare lands. The study area with an average altitude of about 2000 m from sea level located in the Southwest of Iran. Based on the climatic data series of 10 selected stations in Fars province, the mean rainfall of the study area varies from 136 mm per year in Abadeh to 474.17 in Dorodzan. The average temperature of the study area varies from 13.5 centigrade in Eqlid to 27.50 in Lamerd. Based on the UNEP aridity index (Zarei et al. 2019; UNEP 1992) the climate conditions of the study area are arid and semi-arid. The Fars province has a population of about 5,000,000 peoples whose main occupation is agriculture and husbandry. Some of the geographical and climatic properties of the study area are presented in Table 1.

2.2 Method

In this research, using AHP and GIS techniques the sensitivity of Fars province to the occurrence of different types of droughts including Med, Hyd, and Agd were assessed. The final map of drought sensitivity was prepared by superposition the Med, Hyd, and Agd sensitivity maps (after determining the weight of each using AHP). In this paper, the Arc-GIS 10.3 software, DEM and raster layers with a resolution of 30, and Identity method (for superposition of the layers) were used (Caceres 2021; Miller and Gongloff 2021). To calculate the final score of each region or each pixel based on the superposition of the effective layers in each type of droughts and calculation of final score of final drought sensitivity

Table 1 Selected stations for sensitivity assessment to meteorological drought

Station name	Latitude (N)	Longitude (E)	Elevation (m)	Mean Rainfall (mm/year)	Mean annual temperature
Abadeh	31.1	52.6	2030	136	14.42
Eqlid	30.9	52.6	2300	336.05	13.5
Ezadkhast	31.5	52.1	2188	159.84	15.1
Darab	28.7	52.4	1098.2	273.2	23.7
Zarghan	29.7	52.7	1596	317.9	18.8
Dorodzan	30.1	52.4	1652	474.17	18.26
Shiraz	29.5	52.6	1484	329.56	18.76
Fasa	28.9	53.6	1288	282.87	19.36
Lar	27.6	52.4	792	196.6	25.2
Lamerd	27.3	53.1	411	225.49	27.5

map based on the superposition of the final layers of drought sensitivity map in different types of droughts, the Eq. 1 was used:

$$score = \frac{\sum(W_i \times I_i)}{\sum W_i} \quad (1)$$

Where W_i is calculated weight of each indicator using the AHP and I_i is score of each indicator.

3 Sensitivity Assessment to Meteorological Drought

For assessing the sensitivity of Fars province to meteorological drought, four effective indicators on the increase or decrease of the severity of the impact of meteorological drought including the climate conditions (Me1), the average number of consecutive drought years (years with D5, D6, D7 or D8 classes of RDI) or Me2, the average of annual precipitation (Me3), and the trend of changes in climate conditions in long-term (Me4) were selected. Then, using the ArcGIS 10.3 software, a sensitivity map for each indicator was prepared (all indicators classified in four sensitivity classes including mild, moderate, severe, and very severe). To determine the climate conditions and drought severity classes the UNEP aridity index and reconnaissance drought index (RDI) were used, respectively (Supplementary file). Classification of climate conditions and drought severity based on the mentioned indices is presented in Table 2. For this way, the climatic data series of ten stations in Fars province from 1990 to 2017 were used (www.irimo.ir). For assessing the trend of changes in climate conditions in stations with normal data series the Pearson test (parametric trend test) and in stations with non-normal data series the Spearman Rho test (non-parametric trend test) was used. To prepare the interpolation map of each indicator the inverse distance weighting (IDW) method (in indicators with non-normal data series) and kriging method (in indicators with normal data series) were used. Finally, using the AHP method the weight of each indicator was determined and the final map of sensitivity to meteorological

Table 2 Classification of drought and climate based on RDI and UNEP aridity index (Zarei and Mahmoudi 2021; Tigkas et al. 2020; Tsakiris et al. 2007)

RDI classes			UNEP classes		
RDI values	RDI values	Symbol	UNEP values	UNEP classes	Symbol
$2 \leq \text{RDI}$	Extremely wet	D ₁	$0.65 < \text{UNEP index}$	Humid	C ₁
$1.5 < \text{RDI} \leq 1.99$	Very wet	D ₂	$0.5 < \text{UNEP index} \leq 0.65$	Sub-Humid	C ₂
$1 < \text{RDI} \leq 1.49$	Moderately wet	D ₃	$0.2 < \text{UNEP index} \leq 0.5$	Semi-Arid	C ₃
$0 < \text{RDI} \leq 0.99$	Normal	D ₄	$0.05 < \text{UNEP index} \leq 0.2$	Arid	C ₄
$-0.99 < \text{RDI} \leq 0$	Near normal	D ₅	$0.05 \geq \text{UNEP index}$	Hyper-Arid	C ₅
$-1.49 < \text{RDI} \leq -1$	Moderately dry	D ₆			
$-1.99 < \text{RDI} \leq -1.5$	Very dry	D ₇			
$\text{RDI} \leq -2$	Extremely dry	D ₈			

drought was prepared by overlaying the maps of Me1 to Me4 indicators. Sensitivity classes of selected indicators in meteorological drought are presented in Table 3. Table 6 was used to determine the final classification of sensitivity to meteorological drought based on the final score of each area (based on the weighting average of the determined weights for Me1 to Me4 layers using the AHP method).

3.1 Sensitivity Assessment to Hydrological Drought

For assessing the sensitivity of the study area to hydrological drought, three effective indicators including the stream density km/km² (Hy1), the average of soil permeability or SP inch per hour or Hy2, and the average of groundwater level depletion cm per year (Hy3) were used. Then, using the ArcGIS 10.3 software, a sensitivity map for each indicator was prepared. The sensitivity classes in selected indicators in Hyd were similar to the selected indicators in Med (mild, moderate, severe, and very severe classes). The Hy1, Hy2, and Hy3 indicators were assessed at the hydrological unite level. To prepare a stream map of the study area the digital elevation model (DEM) 30 m of Fars province was used. For evaluating the Hy2, the created map by Fars agricultural Jihad (www.fajo.ir) was used, and to prepare the map of Hy3 provided data series by Fars water organization was used. The AHP method was used to determine the weight of each indicator in hydrological drought. The final map of sensitivity to hydrological drought was prepared by superposition the maps of Hy1 to Hy3 indicators. Sensitivity classes of selected indicators in hydrological drought are presented in Table 4. Table 6 was used to determine the final classification of sensitivity to Hydrological drought based on the final score of each area (based on the weighting average of the determined weights for Hy1 to Hy3 layers using the AHP method).

3.1.1 Sensitivity Assessment to Agricultural Drought

To evaluate the sensitivity of the Fars province to agricultural drought, seven effective indicators including the average annual reference evapotranspiration mm/year (Ag1), the average spring reference evapotranspiration mm/season (Ag2), land use (Ag3), Slop percentage (Ag4), soil fertility (Ag5), Soil erodibility (Ag6), and the ratio of rain-fed cultivated area to total agricultural lands (Ag7) were used. Then, using the ArcGIS 10.3 software, a sensitivity map for each indicator was prepared (based on four sensitivity classes including mild, moderate, severe, and very severe classes). The sensitivity map of Ag1 and Ag2 indicators was prepared using the climatic data series of 10 selected stations in Fars province during 1990–2017 (Table 1). To prepare the interpolation map of each indicator the IDW and kriging methods were used. For assessing the Ag3, Ag5, Ag6, and Ag7 indicators, the created map by Fars agricultural Jihad (www.fajo.ir), was used and to prepare the slop map of the study area digital elevation model (DEM) 30 m of Fars province was used. To determine the weight of each indicator in agricultural drought the AHP method was used. The final map of sensitivity to agricultural drought was prepared by superposition the maps of Ag1 to Ag7 indicators. Sensitivity classes of selected indicators in agricultural drought are presented in Table 5. Table 6 was used to determine the final classification of sensitivity to Agricultural drought in based on the final score of each area (based on the weighting average of the determined weights for Ag1 to Ag7 layers using the AHP method) (Table 9).

Table 3 Selected indicators for sensitivity assessment to meteorological drought

Indicators	Symbol	Sensitivity classes			
		Mild (1)	Moderate (2)	Severe (3)	Very Severe (4)
		Range of values			
The climate conditions (Zarei et al. 2019)	Me1	C ₁ and C ₂	C ₃	C ₄	C ₅
The average number of consecutive drought years (years with D5, D6, D7 or D8 classes of RDI) (Tsakiris 2007; Masoudi and Elhaesahar 2019)	Me2	0 or 1	2 or 3	4 or 5	6 ≤
The average of annual precipitation (mm) (Zareice et al. 2011; Zaretee and Masoudi 2014)	Me3	500 ≤	250 to 499	100 to 249	< 100
The trend of changes in climate conditions in long-term (Zaretee et al. 2011)	Me4	Upward trend in UNEP index or without to observe the trend	Downward trend in UNEP index (non-significantly)	Downward trend in UNEP index (significant at 5% level)	Downward trend in UNEP index (significant at 1% level)

Class 1 has the least sensitivity to drought and class 4 has the most sensitivity to drought, the UNEP aridity index was used to determine climate conditions, for assessing drought conditions the RDI was used

Table 4 Selected indicators for sensitivity assessment to hydrological drought

Indicators	Symbol	Sensitivity classes			
		Mild (1)	Moderate (2)	Severe (3)	Very Severe (4)
		Range of values			
Stream density (km/km ²) (Zaretee and Masoudi 2014)	Hy1	0.3 >	0.3 to 0.59	0.6 to 0.89	0.9 ≤
The average of soil permeability or SP (inch per hour) (Mahdavi 2002)	Hy2	> 3	1.5 < SP ≤ 3	0.5 < SP ≤ 1.5	≤ 0.5
The average of groundwater level depletion (cm per year) (Zaretee and Masoudi 2014; Khosravi et al. 2014)	Hy3	5 >	5 to 79	80 to 150	150 ≤

all indicators of hydrological drought were assessed in the level of hydrological unit or plain

Table 5 Selected indicators for sensitivity assessment to agricultural drought

Indicators	Symbol	Sensitivity classes			
		Mild (1)	Moderate (2)	Severe (3)	Very Severe (4)
		Range of values			
Average annual reference evapotranspiration* (mm/year)	Ag1	≤ 1702	1702 to 2095	2095 to 2291	2291 <
Average spring reference evapotranspiration* (mm/season)	Ag2	≤ 251	251 to 318	318 to 352	352 <
Land use (Zakerinejad and Masoudi 2019; Zehtabian et al. 2005)	Ag3	Rocky lands and bare lands, Lakes	Irrigated agricultural lands, Urban	Forest and range lands	Rain-fed agricultural lands
Slop (%) (Jokar et al. 2015)	Ag4	0–5	5–15	15–30	More than 30
Soil fertility (Masoudi et al. 2020; Jokar et al. 2015)	Ag5	Good	Moderate	Low	Very low
Soil erodibility	Ag6	Low	Moderate	High	Very High
The ratio of rain-fed cultivated area to total agricultural lands (%) (Zarei et al. 2011; Masoudi and Asrari 2009)	Ag7	≤ 10	10 to 20	20 to 30	More than 30

* The FAO Penman–Monteith (FAO-56) was used to calculate the reference evapotranspiration

Table 6 The final classification of drought sensitivity in different types of droughts as well as overall drought

Class of drought sensitivity	The range of final score*
Mild (1)	Less than 1.5
Moderate (2)	1.5 to 2.499
Severe (3)	2.5 to 3.499
Very severe (4)	More than 3.5

*The final score of each area was determined based on weighting average of the determined weights for each layers using AHP method

3.1.2 Final Map of Drought Sensitivity

The final map of drought sensitivity was prepared by superposition the meteorological, hydrological, and agricultural drought sensitivity maps based on the determined weights for each using the AHP method. Table 6 was used to determine the final classification of drought sensitivity based on the final score of each area (based on the weighting average of the determined weights for Med, Hyd, and Agd layers).

3.1.3 Analytic Hierarchy Process (AHP) Method

The AHP is a method for organizing and analyzing complex decisions, using math and psychology. This method is one of the most widely used multi-criteria decision-making methods and developed by Saaty (1980). It has been used to solve unstructured problems in various fields. The AHP method converts evaluations into numbers, which can be compared to all of the possible criteria and is used to find the weight (relative importance) and rank of each parameter. In this method to determine the weight of the layers, a pairwise comparison method has used (Mokarram and Zarei 2018). In AHP, the elements of each level are compared and weighed relative to each other in pairs. The comparisons and weights of the elements are recorded in a $K \times K$ matrix (in this study a 19×19 matrix). Parallel comparison is done by valuing the line element relative to the column element and a distance scale from 1 to 9 is used to evaluate. The higher the value given, the more important and preferable the row element is to the columnar element. So that the value of 9 expressions is quite important and the value of one expression is the same with preference and importance (Table 7) (Cai et al. 2007). It allows you to calculate a synthetic score (value between 0 and 1) aggregated on the basis of a ranking and a weighting of all the criteria taken into account in the decision. Some advantages of the AHP method are including: its ability to structure a complex, multi-criteria, multi-person and multi-period problem in a hierarchical manner,

Table 7 Scales for pairwise comparisons

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

the binary comparison of the elements (alternatives, criteria, and sub-criteria), and the ease of its IT support, the Expert Choice software. For the determination of the accuracy of the AHP method, the incompatibility and reliability coefficients were used. The compatibility rate is calculated using Eq. 2 (Saaty 1984, 2008; Lin and Yang 1996).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

where λ_{max} is the eigenvector element and n is the number of criteria.

4 Results and Discussion

4.1 Sensitivity to Meteorological Drought

The sensitivity map of the Me1 indicator indicated that the study area based on the climate conditions can be classified into two classes of sensitivity including moderate (6.77% of the study area) and severe (93.23% of the study area) classes. Based on the results, the

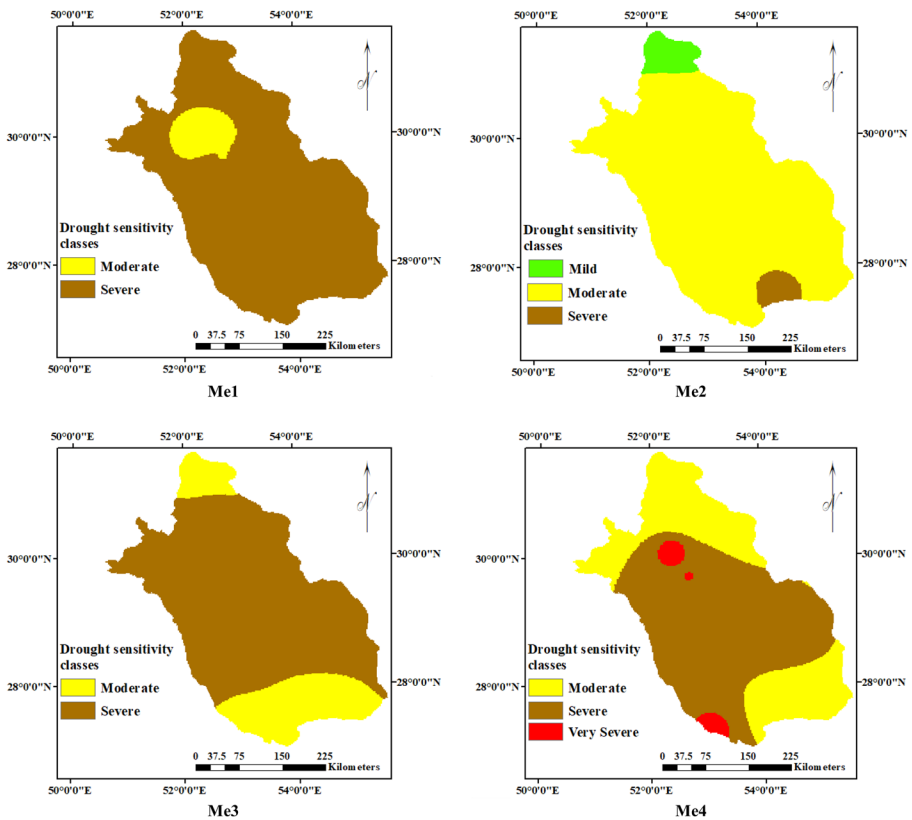


Fig. 2 The map of sensitivity to drought in the indicators of meteorological drought. Me1 is the climate conditions, Me2 is the average number of consecutive drought years, Me3 is the average of annual precipitation and Me4 is the trend of changes in climate conditions in long-term

Table 8 The area percent of study area in different classes of sensitivity to drought in each indicator

Type of drought	Symbol of indicator	Sensitivity classes			
		Mild (1)	Moderate (2)	Severe (3)	Very Severe (4)
The area percent					
Meteorological drought	Me1	0.00	6.77	93.23	0.00
	Me2	4.51	92.52	2.97	0.00
	Me3	0.00	21.85	78.15	0.00
	Me4	0.00	36.40	60.85	2.75
Hydrological drought	Hy1	30.59	37.81	18.55	13.05
	Hy2	12.05	36.98	5.80	45.17
	Hy3	0.00	10.37	86.97	2.66
Agricultural drought	Ag1	1.27	93.34	4.85	0.53
	Ag2	2.57	94.41	3.02	0.00
	Ag3	9.26	30.58	40.83	19.33
	Ag4	36.60	25.19	19.32	18.89
	Ag5	23.18	58.24	16.80	1.79
	Ag6	19.65	29.21	14.47	36.67
	Ag7	25.69	15.02	20.50	38.79

areas with the moderate class of sensitivity were located in the northern regions of the study area (Sepidan and Dorodzan regions). This can be due to the more average rainfall and the lower average temperature (which can affect the reduced potential evapotranspiration) in mentioned areas. Based on the Me2 indicator the study area can be classified into three classes of sensitivity including mild (4.51% of the study area), moderate (92.52% of the study area), and severe (2.97% of the study area) classes. According to the results, the areas with the severe class of sensitivity were located in the southern regions of the study area (Lar region). This can be due to the low average altitude of the region from above sea level, low topography in the region, low average rainfall, high average temperature, and

Table 9 The weight of each of the studied indicators in different types of drought based on the AHP method

Type of drought	Symbol of indicator	The weight
Meteorological drought	Me1	0.15
	Me2	0.38
	Me3	0.27
	Me4	0.20
Hydrological drought	Hy1	0.21
	Hy2	0.35
	Hy3	0.44
Agricultural drought	Ag1	0.11
	Ag2	0.13
	Ag3	0.24
	Ag4	0.06
	Ag5	0.09
	Ag6	0.08
	Ag7	0.29

Table 10 The incompatibility and reliability coefficients of specified weights for each indicator in different types of drought based on the AHP method

Type of drought	Incompatibility coefficient	Reliability coefficient
Meteorological drought	0.06	0.94
Hydrological drought	0.09	0.91
Agricultural drought	0.08	0.92

so on that all mentioned factors can be played an important role (directly or indirectly) in increasing the likelihood of drought occurrence. The sensitivity map of the Me3 indicator indicated that the study area based on the average annual precipitation can be classified into two classes including moderate (21.85% of the study area) and severe (78.15% of the study area) classes, and based on the trend of changes in climate conditions in long-term or Me4 indicator the study area can be classified into three classes including moderate (36.40% of the study area), severe (60.85% of the study area), and very severe (2.75% of the study area) classes. The results indicated that the areas with the severe and very severe classes were located in the east, west, and central regions of the study area (Fig. 2 and Table 8).

Based on the results of the AHP technique to determine the weight of each of the indicators in determining the sensitivity to meteorological drought, the weight of Me1, Me2, Me3, and Me4 indicators were estimated equal to 0.15, 0.38, 0.27, and 0.20, respectively. Therefore, the average number of consecutive drought years was the most effective indicator in Med (Table 9). The incompatibility and reliability coefficients

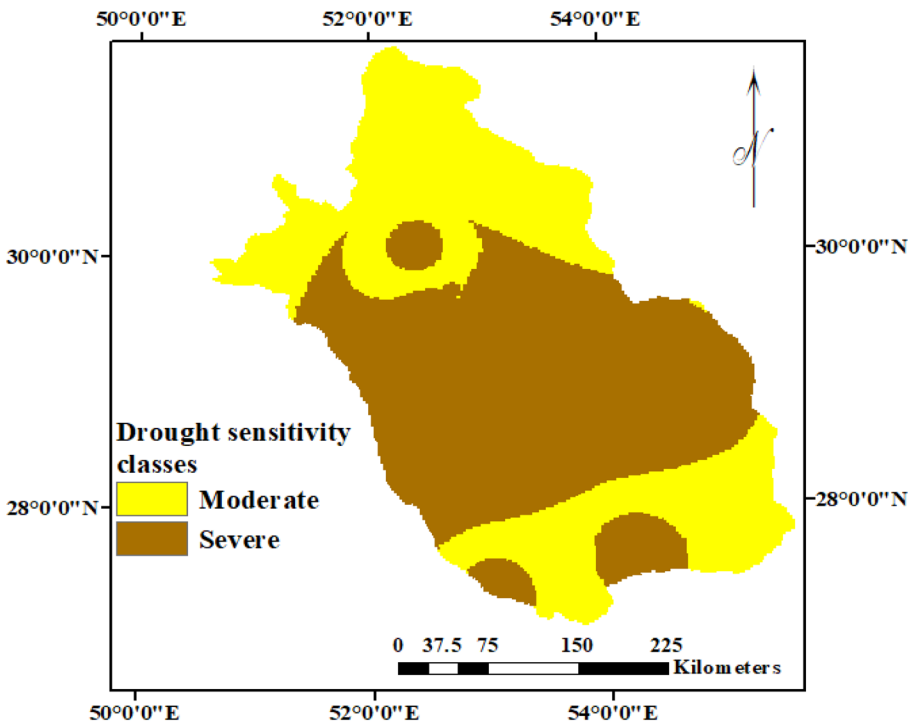


Fig. 3 The final map of sensitivity to meteorological drought

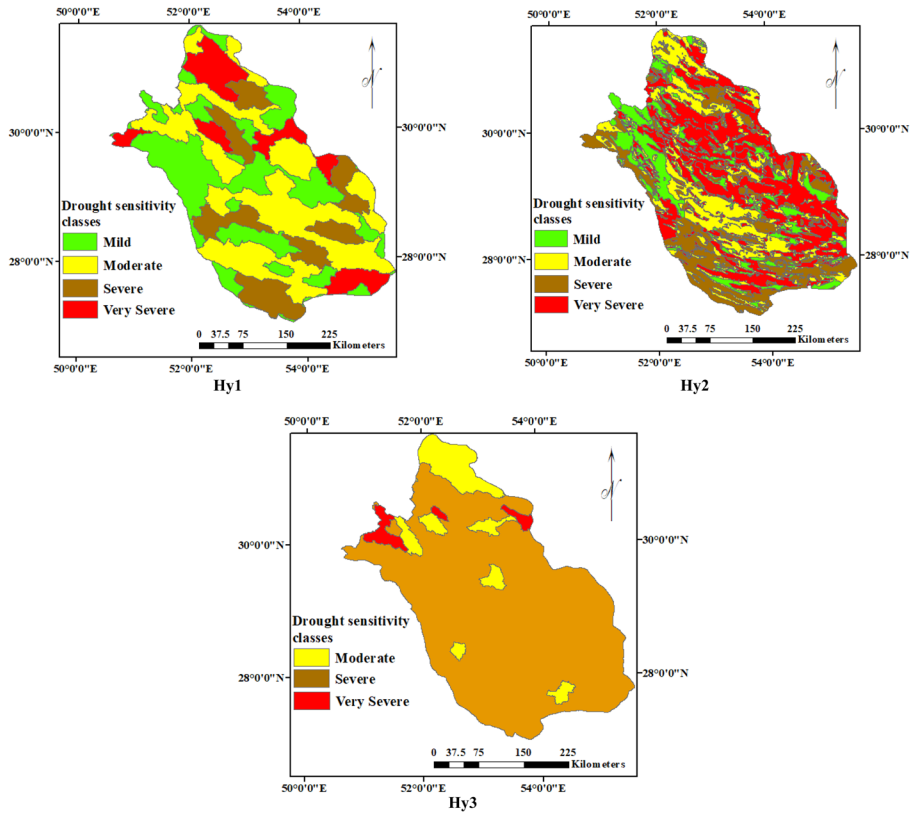


Fig. 4 The map of sensitivity to drought in the indicators of hydrological drought. Hy1 is the stream density, hy2 is the average of soil permeability or SP and Hy3 is the average of groundwater level depletion

of specified weights for the effective indicators on the sensitivity to meteorological drought were equal to 0.06 and 0.94, Therefore, the determined weights were reliable (Table 10). The final map of sensitivity to meteorological drought (after superposition the sensitivity maps of Me1 to Me4 based on their specified weights) indicated that the Fars province was classified into two sensitivity classes including moderate (43.29% of the study area) and severe (56.71% of the study area) classes (Fig. 3 and Table 12).

4.2 Sensitivity to Hydrological Drought

The sensitivity map of the stream density (Hy1) indicator indicated that based on Hy1 the study area can be classified into four classes of sensitivity including mild (30.59% of the study area), moderate (37.81% of the study area), severe (18.55% of the study area), and very severe (13.05% of the study area) classes. The areas with a very severe class of sensitivity were located in the northeast regions of the study area. It seems this can be due to the more topography of mentioned areas. So that under the influence of more topography, stream density will be increased and the converting ratio of rainwater to runoff will be increased. Therefore, the occurrence probability of hydrological drought will be increased. Based on the Hy2 indicator the study area can be classified into four classes including

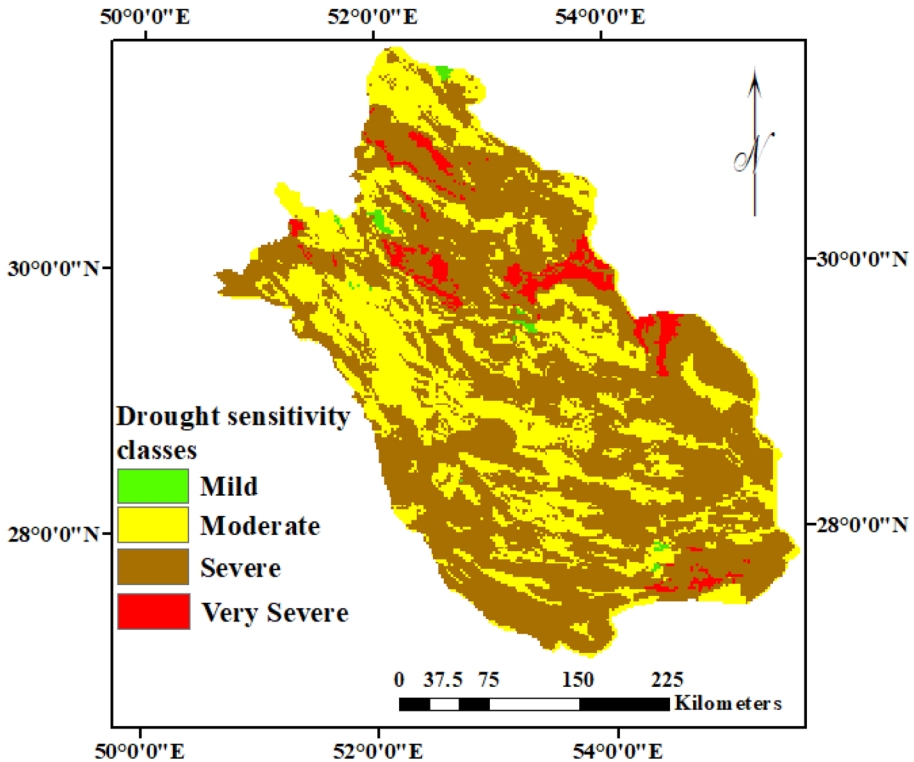


Fig. 5 The final map of sensitivity to hydrological drought

mild (12.05% of the study area), moderate (36.98% of the study area), severe (5.80% of the study area), and very severe (45.17% of the study area) classes. The areas with a very severe class of sensitivity were located in the southeast, east and central regions of the study area. This can be due to the geological formations of these regions. The sensitivity map of the Hy3 indicator indicated that the study area based on the average of groundwater level depletion can be classified into three classes including moderate (10.37% of the study area), severe (86.97% of the study area), and very severe (2.66% of the study area) classes. The results indicated that the areas with the severe class had the highest spatial distribution (Fig. 4 and Table 8).

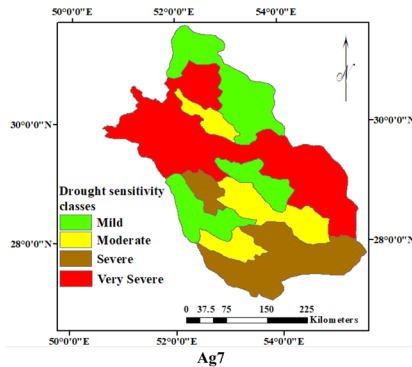
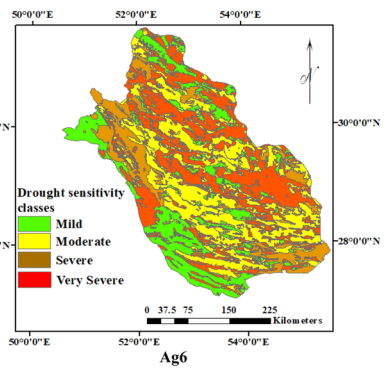
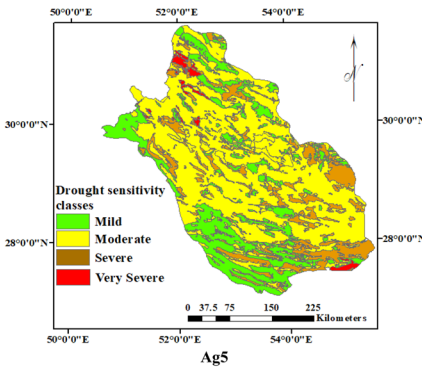
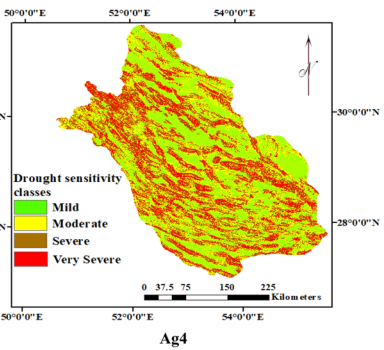
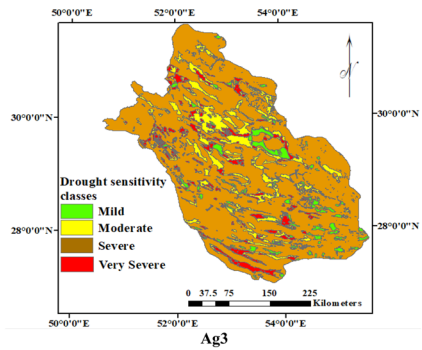
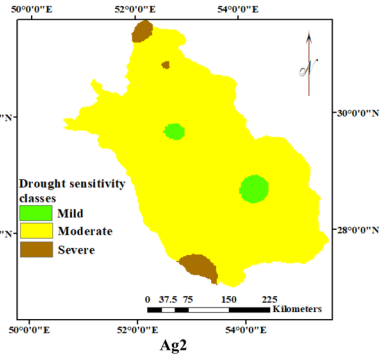
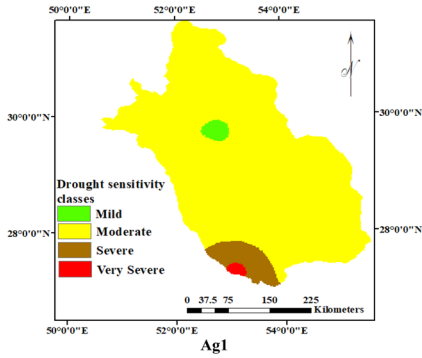
Based on the results of the AHP technique the weight of Hy1, Hy2, and Hy3 indicators was estimated equal to 0.21, 0.35, and 0.44, respectively. Therefore, the average groundwater level depletion was the most effective indicator in Hyd (Table 9). The incompatibility and reliability coefficients of specified weights for the effective indicators on the sensitivity to hydrological drought were equal to 0.09 and 0.91 (Table 10). The final map of sensitivity to hydrological drought (after superposition the sensitivity maps of Hy1 to Hy3 based on their specified weights) indicated that the Fars province was classified into four classes including the mild (0.46% of the study area), moderate (33.25% of the study area), severe (62.49% of the study area), and very severe (3.80% of the study area) classes that the areas with the severe and moderate classes had the highest spatial distribution (Fig. 5 and Table 12).

Fig. 6 The map of sensitivity to drought in the indicators of agricultural drought. Ag1 is the average annual reference evapotranspiration, Ag2 is the average spring reference evapotranspiration, Ag3 is the land use, Ag4 is the slope, Ag5 is the soil fertility, Ag6 is the soil erodibility and Ag7 is the ratio of rain-fed cultivated area to total agricultural lands

4.3 Sensitivity to Agricultural Drought

The sensitivity map of the average annual reference evapotranspiration (Ag1) indicator revealed that the study area can be classified into four classes of sensitivity including the mild (1.27% of the study area), moderate (93.34% of the study area), severe (4.85% of the study area), and very severe (0.23% of the study area) classes. The results indicated that the areas with mild and very severe classes are very small and the areas with the severe class located in the southwest of the Fars province. This can be due to the higher average temperature of these areas. The sensitivity map of the Ag2 indicator showed that the study area can be classified into three classes of sensitivity including mild (2.577% of the study area), moderate (94.41% of the study area), and severe (3.02% of the study area) classes. The spatial distribution of drought sensitivity classes in the Ag2 indicator is very similar to the Ag1. According to the prepared sensitivity map based on the land use indicator (Ag3), the study area can be classified into four classes including the mild (9.26% of the study area), moderate (30.58% of the study area), severe (40.83% of the study area), and very severe (19.33% of the study area) classes. The areas with severe and very severe classes located in agricultural lands especially rain-fed agriculture. The created sensitivity map based on the slope indicator (Ag4), indicated that the study area can be classified into four classes including the mild (36.60% of the study area), moderate (25.19% of the study area), severe (19.32% of the study area), and very severe (18.89% of the study area) classes. The areas with severe and very severe classes mainly located in lands with higher topography. According to the prepared sensitivity map based on the soil fertility indicator (Ag5), the study area can be classified into four classes including the mild (23.18% of the study area), moderate (58.24% of the study area), severe (16.80% of the study area), and very severe (1.79% of the study area) classes. It seems that the spatial distribution of different drought sensitivity classes based on the Ag5 indicator is highly dependent on the geological formations of different regions. Of course, proper soil management and preventing soil salinization also effective in this regard. The sensitivity map of the soil erodibility (Ag6) indicator revealed that the study area can be classified into four classes of sensitivity including the mild (19.65% of the study area), moderate (29.21% of the study area), severe (14.47% of the study area), and very severe (36.67% of the study area) classes. According to the results, the areas with the severe class of sensitivity were located in the east, northeast and central regions of the study area. According to the prepared sensitivity map based on the ratio of rain-fed cultivated area to total agricultural lands (Ag7), the study area can be classified into four classes including the mild (25.69% of the study area), moderate (15.02% of the study area), severe (20.50% of the study area), and very severe (38.79% of the study area) classes (Fig. 6 and Table 8).

Based on the results of the AHP technique the weight of Ag1, Ag2, Ag3, Ag4, Ag5, Ag6, and Ag7 indicators were estimated equal to 0.11, 0.13, 0.24, 0.06, 0.09, 0.08, and 0.29, respectively. Therefore, the ratio of rain-fed cultivated area to total agricultural lands indicator in Agd (Table 9). The incompatibility and reliability coefficients of specified weights for the effective indicators on the sensitivity to agricultural drought were equal to 0.08 and 0.92 (Table 10). The final map of sensitivity to agricultural drought (after superposition the sensitivity maps of



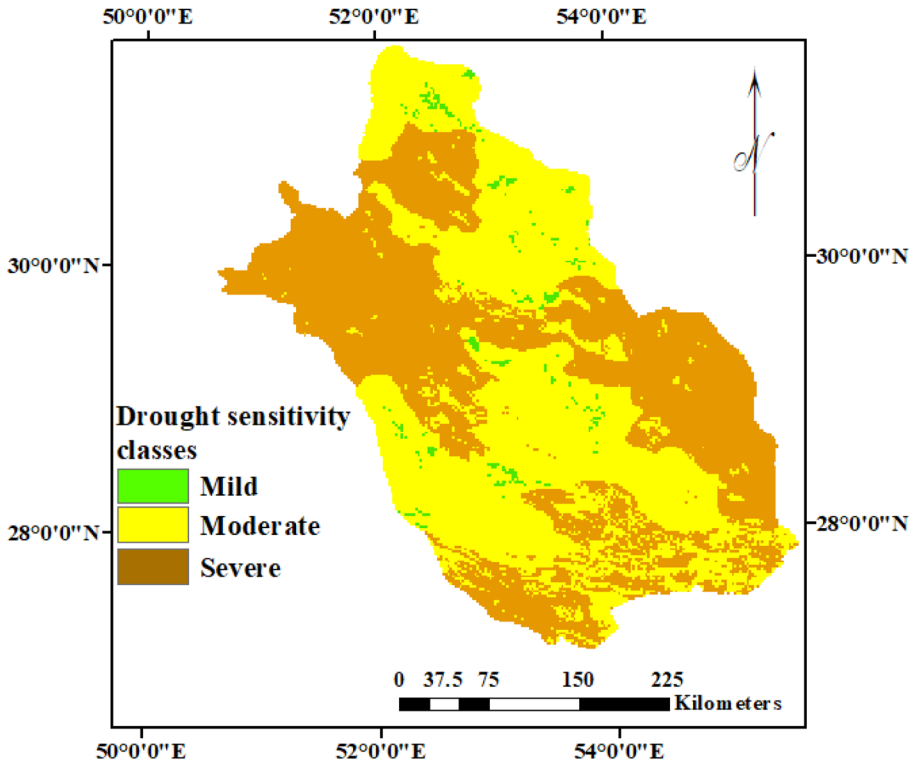


Fig. 7 The final map of sensitivity to agricultural drought

Ag1 to Ag7 based on their specified weights) indicated that the Fars province was classified into three sensitivity classes including the mild (1.18% of the study area), moderate (50.23% of the study area) and severe (48.59% of the study area) classes (Fig. 7 and Table 12). The areas with a severe class of sensitivity were located in the northwest and southeast regions of the study area.

4.4 Final Map of Drought Sensitivity

After preparing the sensitivity maps to meteorological (Med), hydrological (Hyd) and agricultural (Agd) droughts the AHP method was used to estimate their weight to prepare the final map (overall drought) of sensitivity to drought. Based on the results the weight of Med, Hyd, and Agd indicators was estimated equal to 0.36, 0.31, and 0.33, respectively (Table 11). The incompatibility and reliability coefficients of specified weights for each type of droughts on the final sensitivity map were equal to 0.06 and 0.94. The final map of sensitivity to overall

Table 11 The weight of each drought type in determining the overall drought sensitivity based on the AHP method

Type of drought	The weight
Meteorological drought	0.36
Hydrological drought	0.31
Agricultural drought	0.33

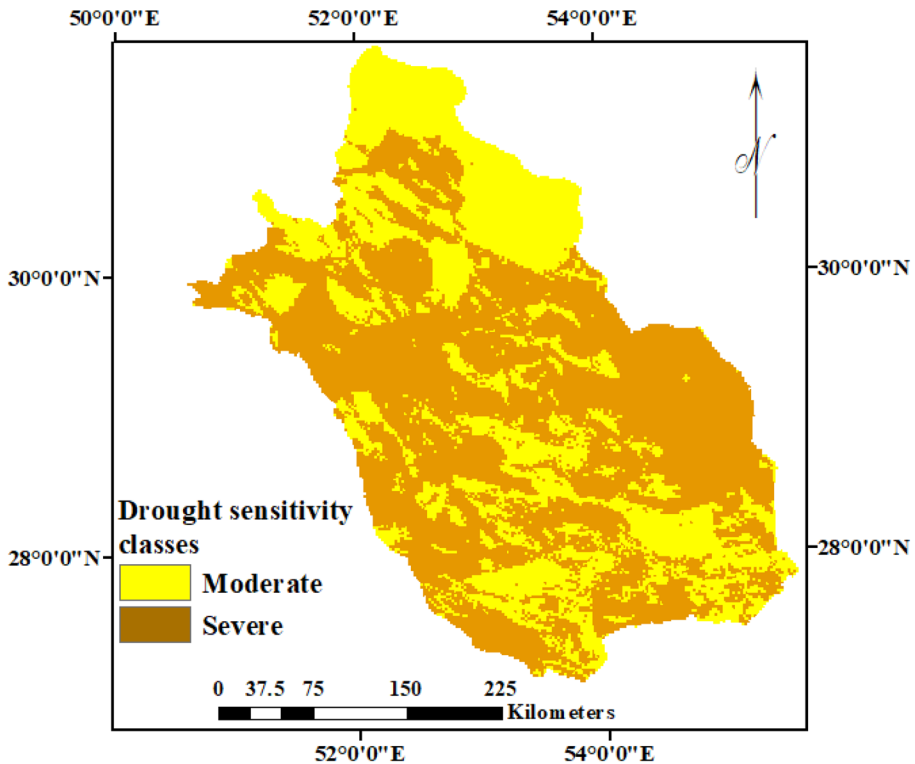


Fig. 8 The final map of sensitivity to drought

drought (after superposition the sensitivity maps of Med, Hyd, and Agd based on their specified weights) indicated that the Fars province was classified into two sensitivity classes including the moderate (38.26% of the study area), and severe (61.74% of the study area) classes (Fig. 8 and Table 12). Figure 8 showed that the areas with the severe class of sensitivity mainly were located in the west, east and central regions of the study area.

Table 12 The area percent of study area in different classes of sensitivity to drought in each drought type

Type of drought	Sensitivity classes			
	Mild (1)	Moderate (2)	Severe (3)	Very Severe (4)
	The area percent			
Meteorological drought	0.00	43.29	56.71	0.00
Hydrological drought	0.46	33.25	62.49	3.80
Agricultural drought	1.18	50.23	48.59	0.00
Overall drought (Final map)	0.00	38.26	61.74	0.00

5 Discussion

The sensitivity map of meteorological drought showed that the areas with a higher class of sensitivity located in the central region of Fars province. This can be due to the less topography and less relative humidity of these areas compared to the northern and southern regions of the Fars, respectively. Based on the sensitivity map of hydrological drought, the areas with a higher class of sensitivity located in regions with higher stream density and higher concentration of agricultural lands and overexploitation from groundwater resources. Based on the sensitivity map of agricultural drought, the areas with the more rain-fed cultivated area (north-west regions) and the areas with more evapotranspiration (southeast regions). Finally, based on the above-mentioned reasons and other reasons such as population density, old and inefficient irrigation systems, low water use efficiency in agriculture, industrialization, land-use change, deforestation, and so on, in the final map of drought sensitivity, the areas with a higher sensitivity class located in central, western and eastern regions of Fars province. The results of research by Shamsnia and Khodadadi (2020) showed that the northern regions of Fars province have been further affected by agricultural drought, which these results are consistent with the results of our research. Zareiee and Masoudi (2014) presented a vulnerability drought hazard map for Ghareh Aghaj Basin, Fars with and indicated that the study area was classified in moderate and severe classes of drought hazard, which these results consistent with the results of our research.

6 Conclusion

The occurrence of different types of droughts including meteorological drought, hydrological drought, agricultural drought, and so on, have different impacts on various sectors, especially sectors with more dependency on water. Present and applying the principles of proper management (based on sustainable development) can be affected to reduce their impacts. On the other hand, determining the sensitivity of different parts to droughts occurrence has an effective role in the selection of the most appropriate solutions to manage drought impacts. Therefore, in this study, using the AHP and GIS techniques, the sensitivity of different regions of Fars province to the occurrence of different types of droughts including Med (Based on Me1 to Me4 indicators), Hyd (Based on Hy1 to Hy3 indicators), Agd (Based on Ag1 to Ag7 indicators), and overall drought (based on superposition the meteorological, hydrological, and agricultural drought sensitivity maps) were evaluated. The results indicated that the Me2 indicator with a weight equal to 0.33, the Hy3 indicator with a weight equal to 0.44, and the Ag7 indicator with a weight equal to 0.29 was the most effective indicator on sensitivity to meteorological, hydrological, and agricultural droughts, respectively. In final sensitivity maps to drought (overall drought), the weight of the Med was more than the weight of the Hyd and Agd. According to the results, the study area can be classified into two classes of sensitivity (including a moderate class with an area equal to 43.29% of the study area and severe class with an area equal to 56.71% of the study area) to meteorological drought, can be classified into four classes of sensitivity (including mild, moderate, severe, and very severe classes with an area equal to 0.46%, 33.25%, 62.49%, and 3.8%, of the study area, respectively) to hydrological drought, can be classified into three classes of sensitivity (including mild, moderate, and severe classes with an area equal to 1.18%, 50.23%, and 48.59%, of the study area, respectively) to agricultural drought, and can be classified

into two classes of sensitivity (including a moderate class with an area equal to 38.26% of the study area and severe class with an area equal to 61.74% of the study area) to overall drought.

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Data Availability The data used in this research are available with the corresponding author and can be shared upon reasonable request.

Declarations

Ethics Approval The authors confirm that this article is based on original research and has not been published or presented previously in any journal or conference in any language (in whole or in part).

Competing Interests The authors have no conflict of interest.

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