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Assessing Climate Change by Comparing Precipitation Indices (Case study: Dezful-Andimeshk Plain)

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Abstract

Analysis of climate change by precipitation indices can help management of water resources and environmental planning. Meteorological parameters affect surface runoffs, river discharges, soil erosion, and water resources. Given the climatic conditions of Iran Plateau, occurrence of drought is inevitable in Andimeshk-Dezful plain, southwest Iran. The purpose of this research is to examine the climate change condition of the plain using the indices of SPI, SIAP, PNPI, RAI and moving average. The precipitation data of Safiabad and Dezful synoptic stations have been used for the analysis. After the homogeneity of the data has been explored by Runs test, they have been analyzed by the indices to examine the drought condition of the region. The results by the five indices have revealed normal state of drought in the study area. The results found that there is the highest similarity between the results of two indices of PNPI and RAI. The five indices have confirmed that the year 2005 has the highest drought condition and the year 2007 the highest wet condition in the period (2000-2020). According to SPI, PNPI, and RAI, the highest frequency of the events is related to normal droughts. It can be concluded that the beginning years of the period experienced drought. The study has also indicated that in reality the outcomes of SPI index are more accurate than those of other indices.

Keywords: Andimeshk-Dezful Plain, Drought, Precipitation Indices, Water Resources, Climate Change.

1- Introduction

Regional environmental condition is influenced by climate factors (Zhao et al., 2021). Climatic parameters are directly and indirectly affecting surface runoffs, river discharge, catchment erosion and groundwater reserves (Kalkuhl & Wenz, 2020; Zhang et al., 2021). Therefore, meteorological studies and analysis of the results are extremely important for proper and scientific management of water resources (Rad et al., 2017; Zhang et al., 2018), agriculture (Lu et al., 2017; Zhang et al., 2021), prevention of flooding and soil erosion (Gumus & Algin, 2017). Precipitation is the most important parameter to define climate change condition and its scarcity can represent the drought threshold. Water scarcity crisis is actually a widening gap between water demand and its supply. The larger the gap between water supply and demand, the larger is the resulted the crisis (Bărbulescu & Deguenon, 2014; Li et al., 2017). Therefore, in order to achieve the goals of sustainable development in the field of water resources, all countries in the world, including governments and the general public, must use their power in the protection and water resources management. The design and management of water resources requires public participation and the management of this vital element (water) needs to be subject to the conditions of the geographical environment. Drought as one of the natural disasters with a continuous gradual impact can cause great damage to human life and natural ecosystems. It is different from other natural disasters such as floods, storms and earthquakes. The main differences in the gradual impact of drought over a relatively long period of time are that it is hard to predict and determine the exact time of onset and end of the phenomenon and the geographical extent of its impact. Climate change and water scarcity occur frequently around the world. However, this situation is more common in the areas where it has climatically irregular occurrence and randomly affected by different climatic systems, and more detrimental effects in arid and semi-arid regions (Herrera-Estrada et al., 2017; Krueger et al., 2017). Generally, drought can be divided into four groups including meteorological drought (lack of rainfall in the region for a period of time), agricultural drought (lack of soil moisture and plant growth for a period of time without affecting surface water resources), hydrological drought (lack of surface water resources for specific water uses from a water resources management system) and socio-economic drought (failure of the water resources system to meet water demand for a proper water economy) (Escalante-Sandoval & Nuñez-Garcia, 2017; Habibi et al., 2018; Van Loon & Van Lanen, 2012; Zhang et al., 2021).

The main manifestation of meteorological drought is an overwhelming decrease in rainfall below amerage (long-term average) in a certain place. The reduction in soil moisture and surface water and groundwater are the next consequences of the decreased rainfall. Plants and animals in a particular area are usually adapted to the average rainfall. When the rainfall falls below average, life in that area is disrupted by the conditions (Zhao et al., 2021). Hydrological drought, mainly resulted from the effects of scarcity on surface water or groundwater supply, occurs with a longer delay than meteorological or agricultural droughts (Lu et al., 2017; Zhang et al., 2021); because it takes a long time for the lack of precipitation (Ghadimi & Nezammahalleh, 2015) to manifest its effects on the components of the hydrological system such as soil moisture, surface water and groundwater reserves and river flow. Although climate is the primary factor in the occurrence of hydrological drought, other factors such as land use change, land degradation and construction of dams all affect the hydrological characteristics of the basin (Carrão et al., 2016; Ye et al., 2016).Due to special location of Iran on the global drought belt with the occurrences of recent droughts, the place usually experiences a sharp drop in groundwater levels in its plains and needs more careful attention in this regard (Rad et al., 2017). Today, the groundwater crisis and water shortage crisis can be seen in most areas of Iran. In general, all sectors of the environment are exposed to the damage caused by this crisis, but there is not enough information about the consequences. Improper use of groundwater has caused about 230 plains out of 609 plains in Iran to face groundwater crisis and, therefore, the water level in these plains has dropped sharply and in some cases it has led to land subsidence and numerous damage. Over-harvesting and drilling of illegal wells, especially during droughts, have exacerbated these crises in the plains of Iran and it also made water management difficult (Mahmoudi et al., Various indicators of precipitation have been developed and analyzed in many studies in the fields of meteorology, agriculture, ecology, and water resources management (Burgan & Aksoy, 2020; Hoek van Dijke et al., 2022; Tabari, 2021). Among these studies, the development and expansion of precipitation indicators based on meteorological variables has many applications in the studies. Examples of these indicators are including Rainfall Anomaly Index (RAI), the Bhalme and Mooley Drought Index (BMDI), the Drought Severity Index (DSI), the Standardized Precipitation Index (SPI); the Effective Drought Index (EDI), and Reconnaissance Drought Index (RDI) (Deo et al., 2017; Gumus & Algin, 2017). Another type of applied studies and research on drought indicators is agricultural drought (Lu et al., 2017; Zhang et al., 2021) indicators including Crop Moisture Index (CMI); Soil Moisture Drought Index (SMDI), Crop Specific Drought Index (CSDI), and Evapotranspiration Deficit Index (ETDI) (Fernandes et al., 2010; Ghazi et al., 2023; Liu et al., 2018; Tian et al., 2018).

Estimation of precipitation indicator using hydrological indices is also applied in many studies. Examples of these indices are including Regional Stream Drought Index (RSDI), Palmer Hydrological Drought Index (PHDI); Surface Water Supply Index (SWSI), Reclamation Drought Index (RDI) and the Agricultural Reference Index for Drought (ARID) (Schmith et al., 2021; Van Loon & Laaha, 2015; Woli et al., 2012). Among these, the SPI index has been widely used in many studies due to its reliability and ability to examine drought at different time scales and for different climatic regions in different parts of the world (Cooley & Chang, 2021; Cumbie-2019). In this study, with the aim to analyze precipitation data and compare rainfall indices and drought in Dezful-Andimeshk plain, we have used five indices of standard rainfall, rainfall anomaly, normal percentage of rainfall, annual rainfall, and moving average of three and five years.

2- Literature review

Ward & Boyles, 2016; Konapala et al., 2020; Stagge et al., 2015; Tian et al., 2022).

Many efforts and studies have been done to develop precipitation indicators and to evaluate and quantify various aspects of drought. The indices consider reduction in the effects of drought (WMO., 2013), spatial differences in drought risk (Huang et al., 2023; Leite-Filho et al., 2021; Li et al., 2024), and the possibility of early prediction and identification of drought and their severity and extent (Hosseinzadehtalaei et al., 2020; Tabari et al., 2021). (Eslamian et al., 2017), showed that the PNPI index gives the best results when used for a single region in a given season. The validation approach showed that drought zones, according to SWI, are highly correlated with grain production. Accordingly, a favorable correlation between SWI and SPI was found by many studies evaluated the indicators (Aragon et al., 2020; Breinl et al., 2020; Dogan et al., 2012). Many researchers explored many of the indicators confirmed the appropriateness of Percent Normal Precipitation Index (PNPI), ZScore Index (ZSI), Standard Precipitation Index (SPI), China Z Index (CZI), Modified CZI (MZCI), and Decile Precipitation Index (DPI).

3- Study area

Dezful-Andimeshk as the study area of this research is located in southwestern Khuzestan Plain, 130 km north Ahvaz, Iran. There are many rivers on the region with 2071 square kilometers in area. The most important rivers in the study area are Dez, Balaroud, Kahnak, Galal and Shavar. The water resources from the rivers are widely used for various purposes, especially for agriculture. Dez River, as one of the most important tributaries of Karun, originates from the northern highlands of Boroujerd and Aligudarz mountainous areas. This river enters Khuzestan plain from the north part of Dezful discharging into Karun River in the north Ahvaz (Figure 1).

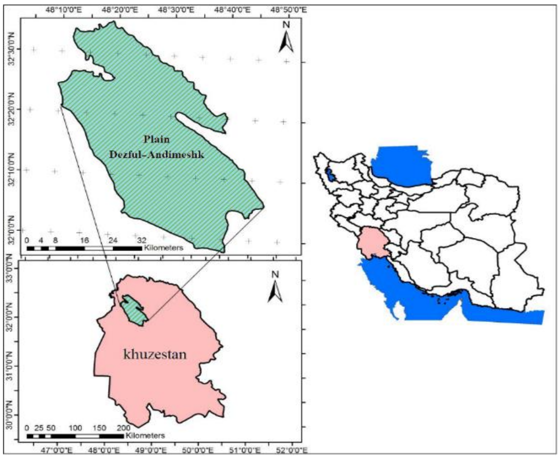

Figure 1- Map of the study area

4- Material and methods

In this study, meteorological data including precipitation, evaporation and temperature parameters of Safiabad and Dezful synoptic stations (time range 2000-2020) have been derived from Khuzestan Meteorological Organization. The Runs statistical test has initially been used to check the homogeneity of the data; then, five climatic indices of SPI, RAI, PNPI, SIAP and Moving Average have been calculated based on these data.

Standardized precipitation index (SPI): this index is based on probability of precipitation for each time scale and for each region according to long-term rainfall record (Karabulut, 2015). To calculate this index, the appropriate statistical distribution is fitted to long-term rainfall statistics and the collective distribution function is converted into a normal distribution using equal probabilities. The standardized and average values of the data are zero for each region and period (Equation 1). Positive SPI values indicate rainfall more than average and negative values mean lower than average. According to this method, the drought period occurs when the index values are continuously negative and reach the value of -1 or less, and it can end when the values become positive (Deo, 2011).

Table 1- The drought classification of SPI (Hayes et al, 2007)

SPI	Drought Severity
+2 <	**Extremely wet**
+1.5 to +1.99	**Very wet**
+1 to +1.49	**Moderately wet**
-0.99 to +0.99	**Near normal**
-1.5 to -1.99	**Moderately dry**
-1 to -1.49	**Severely dry**
-2>	**Extremely dry**

Rainfall Anomaly Index (RAI): The basis of this index is calculation of standard deviation from normal long-term rainfall (Khosravi et al., 2012, 58). If p> p or the anomaly is positive, the rainfall anomaly index is obtained from Equation 2, and if p <p or the anomaly is negative, it has to be obtained from Equation 3. Finally, the calculated values are classified according to Table 2.

$$\text{Rai} = 3\left[\frac{p-P^-}{m^- - p^-}\right] \quad (2)$$

$$\text{Rai} = -3\left[\frac{p-P^-}{m^- - p^-}\right] \quad (3)$$

Where, p is comparison of rainfall data (p) with long-term average rainfall; P - is long-term average rainfall in the desired stations; m is the average of 10 cases of the largest amounts of rainfall occurred in study periods; and x is extraction of the average of the 10 cases with the lowest rainfall in the study period.

Table 2- The drought classification of RAI

Interval Index value	Drought Severity Intensity
-0.3 to 0.3	**Near normal**
-1.2 to -0.3	**Slightly dry**
-2.1 to -1.2	**Moderately dry**
-3.0 to -2.1	**Severely dry**
-3>	**Extremely dry**

Percentage of Normal Precipitation Index (PNPI): This index, also called the Percentage of Normal Index (PNI), is used to measure long-term precipitation data for each station and then their percentage changes from long-term normal precipitation on a monthly or annual basis. To calculate this index, Equation 4 and Table 3 are used for the data (Hayes et al., 2007).

$$Pnpi = \frac{Pi}{P}.100 \quad (4)$$

Where, Pi is annual rainfall of year i and P is the average rainfall in statistical period.

Table 3- The drought classification of PNPI

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Standardized Index Annual Precipitation (SIAP): This index is obtained from Equation 5 and the calculated values are given in Table 4 (Ghorbani et al., 2010).

$$\text{SIAP} = \frac{Pi-P^-}{SD} \quad (5)$$

Where Pi is rainfall of the ith hydrological year; p- is the average of rainfall during the statistical period; and Sd is the standard deviation of the rainfall series.

Table 4- The drought classification of SIAP

Annual rainfall index SIAP	Drought Severity
<1.28	Very, very humid
0.84 to 1.28	Very humid
0.52 to 0.8	Average humid
0.25 to 0.52	Mild humid
-0.25 to 0.25	Normal
-0.52 to -0.25	Slightly dry
-0.84 to -0.52	Moderately dry
-1.28 to -0.84	Severely dry
-1.28>	Extremely dry

4- Results

In this study, the non-graphical Runs test has confirmed the homogeneity of the data of the study area (Table 5). If the Sig value is greater than 0.05, the data are homogeneous; if less than 0.05, the data are heterogeneous. According to the results, it is observed that the value of Sig is 0.491 (more than 0.05).

Table 5- Results of Runs Test

Statistical test	N	Mean	Std. Dev.	Min	Max	Percentiles		
						25th	50th (Median)	75th
Annual Precipitation	20	18.9243	11.19355	2.40	35.58	7.6175	19.5330	28.5500

Runs Test

Satistical Test	Annual Precipitation
Test Value[a]	18.9243
Cases < Test Value	10
Cases >= Test Value	10
Total Cases	20

Results of SPI index: According to the annual SPI index, normal situation is observed in most statistical periods and the relative drought conditions can be observed in the early years of the statistical period (from 2000 to 2005). In this period, rainfall is relatively low with high evaporation and high temperature. Subsequently, the conditions have changed the situation into normal state. The transformations can be attributed to climate change and increase in rainfall during this period (Figure 2).

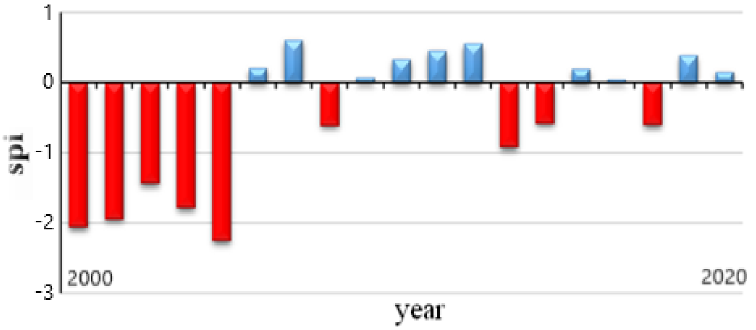

Figure 2- SPI chart of the study area

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Results of SIAP index: According to this index, wet and very humid periods have been identified in the study area, so that after a drought period, there have been wet years and normal conditions in the region. The index has indicated that from the beginning of the statistical period (2000-2020), the region is faced with a severe drought period that in addition to lack of rainfall, this situation can be attributed to increased temperature. In the year 2005, the situation is changed and wet and normal years with rainfall up to 41.33 mm are widely observed in the region (Figure 3).

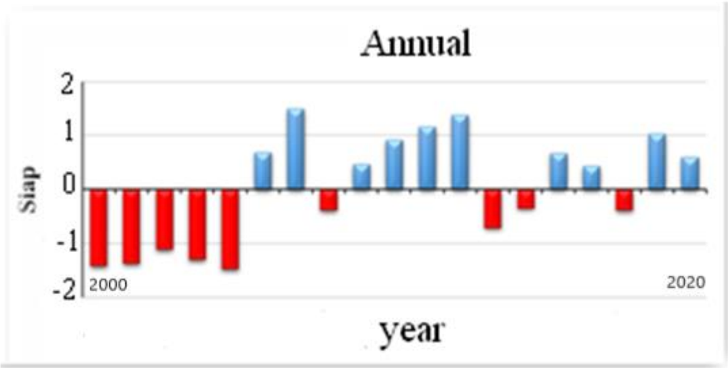


Figure 3- SIAP chart of the study area

Results of RAI index: According to RAI index, the study area has been faced with many drought years and normal years can also be observed during the statistical period. According to this index, from the beginning of the statistical period (2000-2020), the study area has been faced with a severe drought situation. In the period, the year 2005 is the wettest and the year 2004 is the driest in the region (Figure 4).

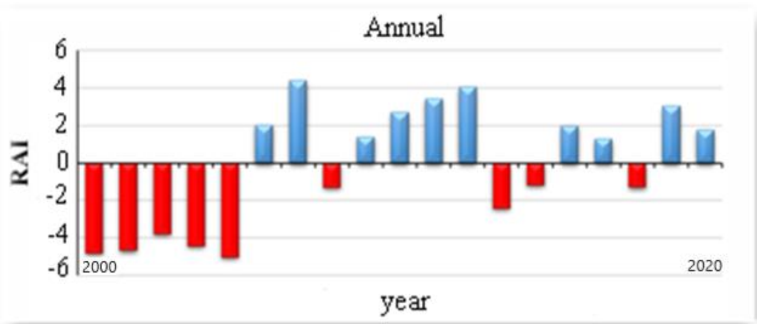


Figure 4- RAI chart of the study area

Results of PNPI index: According to the PNPI index, from the beginning of the statistical period (2000), Dezful-Andimeshk plain was faced with severe drought and this drought continued until 2006. As mentioned about other indicators in the region, the precipitation factor has had the greatest impact on the drought of these years. Following these years, the region has reached a normal state, which has continued for two years with a reoccurring drought year again. At the end of the study period, the situation in the region changed into normal (Figure 5).

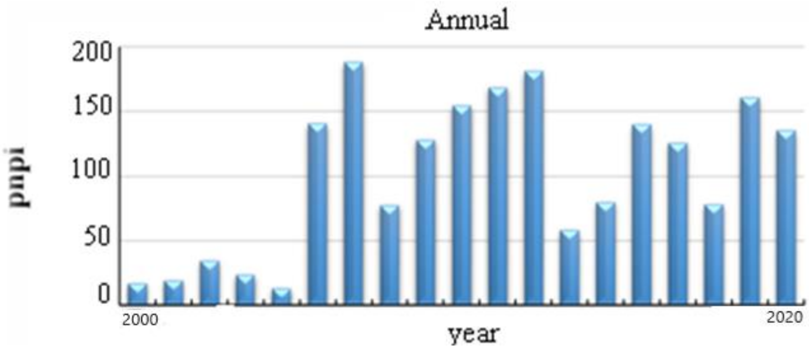
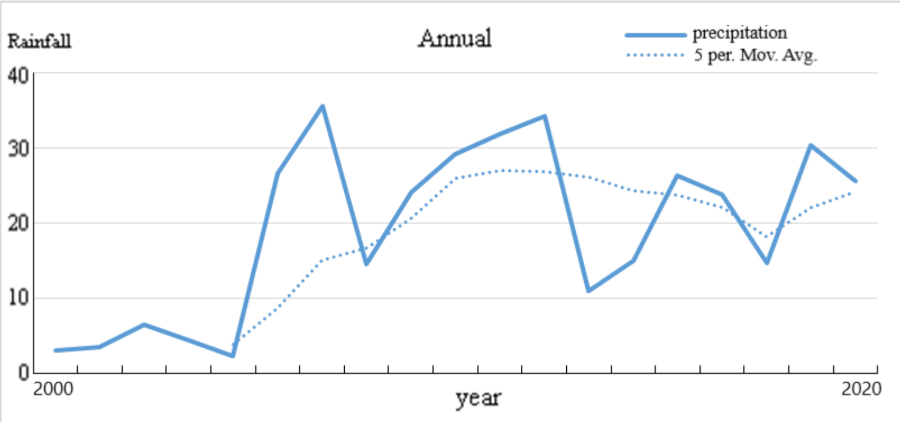


Figure 5- PNPI chart of the study area

Moving Average Index: This index has been calculated according to two periods of five yearsband three years. The moving chart also shows the wet and drought years during the statistical period. According to the three-year chart, the year 2001-2002 experienced a wet season. According to the five-year moving average chart, the region in two periods of 2007 and 2012 again experienced the wet years (Figure 6).



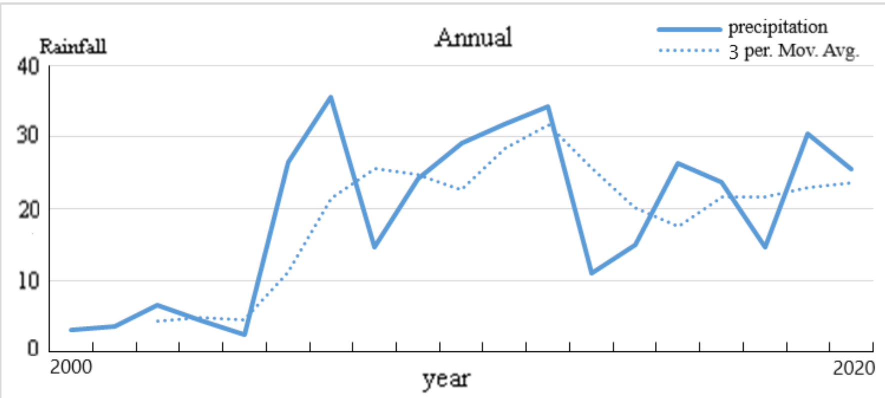


Figure 6- five year and three years moving average

6- Discussion and Conclusion

In this study, drought has been assessed using SPI, SIAP, PNPI, RAI and moving average in Dezful-Andimeshk plain. According to the results, all indicators showed almost the same outcomes about the drought condition. According to the five indicators, in the beginning of the statistical period, we observed drought conditions in the area, which continued until 2005 and, the situation changed into normal state in 2006. Among the studied indicators, SPI index is more capable to show the real drought conditions. Due to its high and better computational capability in different time periods. This can confirm the results of other researchers about the accuracy of this index (Sienz et al., 2012; Stagge et al., 2015; Stricevic et al., 2011; Zhai et al., 2010). According to SIAP, RAI and PNI indices, normal drought is the most common condition in the region. However, according to the SIAP index, the frequency of drought and wet events is almost the same for the region. The similarity between the five indicators is that the beginning years of the statistical period (2000-2020) had drought condition in the region. In the study area, there is the greatest similarity between the results of PNPI and RAI indices. Comparison of the studied indicators shows different frequencies and severity of drought conditions in Dezful-Andimeshk plain. According to the results of the indicators, the year 2005 was the most widespread year of drought in the area. In general, these indicators show the approximation in the results obtained from the spatial analysis of drought. The results of statistical analysis and comparison between the five indicators showed that the dominant state sensitivity to precipitation changes, the SPI index compared with other indicators has indicated more accurate classification

in this region is almost normal. For water resources management in the region, it is essential to investigate the severity, continuity and frequency of drought events and also determine the possible time delay between the occurrences of this type of droughts. This can help make useful planning for proper and scientific management of water resources in the study area. Water scarcity and its adverse effects on crop production have in-depth implications for both the economy and the environment. However, by optimizing water use through techniques such as crop monitoring, smart irrigation, or the use of poly-irrigation, it is possible to mitigate the effects of drought on agriculture and ensure sustainable farming practices.

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