Drought and flood characteristics evolution in peninsular region of Shandong Province based on standardized precipitation index

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Abstract. Data research in recent decades shows that drought and flood disasters occur frequently in China due to the uneven spatial and temporal distribution of rainfall. Taking Shandong Peninsula as an example, this work selected the standard precipitation index (SPI) as the precipitation characteristic analysis index, calculated the SPI values at 4 different time scales in multiple meteorological stations from 1961 to 2013, and analysed the inter annual and seasonal variation characteristics of drought and flood. The results show that: (1) the standardized precipitation index can better reflect the characteristics of inter annual and seasonal drought and flood changes in the study area on a long time series scale. (2) The most flood period occurred in 1964 and 2007, and the most drought period occurred in 1981, 1991 and 1998, and all reached the severity of extreme drought. (3) The intensity of drought and flood varied in different time scales. In spring, autumn and winter, the drought intensity and affected area showed a decreasing trend. However, the flood intensity and its affected area were on the rise in summer, and the rainfall intensity was on the rise in time scale.

1. Introduction

Drought and flood are two extreme situations of hydrological cycle and water distribution, and their harm is well known. In recent years, China's extreme climate events have a trend of frequent occurrence, leading to the increasingly serious problem of drought and flood, which has attracted great attention of scholars at home and abroad [1]. Drought and flood disaster is a natural disaster with a long time and a large range in Shandong coastal areas. Rainstorm and flood have certain regularity and randomness. Historical and flood data after the founding of new China show that the occurrence of large floods in Shandong is relatively frequent, and the loss of such flood disasters is very serious. The average annual precipitation of Shandong Province in 1964 was 1133.8mm, and the coastal areas suffered from different degrees of flood disasters. In the 1980s, the precipitation in the coastal areas of Shandong Province decreased significantly. The average annual precipitation in 1981, 1986, 1988 and 1989 was less than 500 mm, which was 30% - 40% less than that of the normal year [2]. Drought and flood disasters have a great impact on the natural environment and economic development of Shandong coastal areas. The long-term, complexity and arduousness of drought and flood prevention should be fully understood.
With regard to drought and flood, most scholars take the precipitation index as the standard to judge the level of drought and flood in a region [3-7]. The application of standardized precipitation index is relatively wide, and its multi-time and multi-scale can meet the needs of different applications and regions. At the same time, it has good calculation stability, and the calculation is simple and feasible. Guttman compared and calculated the standard precipitation index and PDI (Palmer Drain Index) based on the American precipitation data [8]. He believed that PDI spectrum characteristics would change with location changes, while standardized precipitation indexes would not. Moreover, standardized precipitation indexes were more stable than PDI and easier to operate. Piccarreta used the standardized precipitation index to analyze the drought situation of nearly 77 years in southern Italy from 1923 to 2000 [9]. Yuan Wenping, et al., used SPI and Z index to study dry and wet climate events in different regions of China [10]. Compared with Z index, SPI has better computational stability and can be used for water resources assessment and drought monitoring in different time scales. SPI is widely used because it can well reflect the standard of dry and wet grades and can be used for multi-time scale comparative analysis. Therefore, this work used SPI index to analyze the standardized precipitation index of Shandong coastal area from 1961 to 2013. The spatial and temporal distribution characteristics of precipitation in Shandong coastal areas were obtained, which offered support for evaluation and monitoring of drought and flood disasters. Furthermore, it offered scientific basis for the rational utilization of water resources and the reduction of drought and flood losses in this region.

This work studied SPI comparison on different time scales (1, 3, 6 and 12 months). According to the standardized precipitation index, the precipitation of each year is detected and the data are analyzed to monitor the interannual variation of drought and flood. The seasonal variation characteristics of drought and flood mainly analyze the variation characteristics of precipitation in each season, and monitor the situation of seasonal drought and flood. In order to do a good job in the construction and management of drought and flood prevention projects, it is necessary to strengthen non engineering flood control and drought relief measures to minimize the losses caused by floods and droughts. This work offers a scientific basis for this.

2. Study area
Shandong Province, located in the east coast of China and the lower reaches of the Yellow River, is between 114°36'-122°43'E and 34°25'-38°23'N. The important coastal cities are Qingdao, Yantai, Weihai, Weifang and Rizhao. The coastline of the whole province is 3024km, accounting for 1/6 of the whole country, ranking second only to Guangdong Province. The offshore sea area is 170,000 km², which is larger than the land area of the whole province. Shandong Province has a mild climate with concentrated rainfall and four distinct seasons, belonging to the warm temperate semi humid monsoon climate. Southerly wind prevails in summer, accompanied by hot and rainy weather. North wind blows in winter, and the weather is cold and dry. The weather is changeable in spring, and it is dry, rainy and windy. The weather in autumn is sunny and moderate. The average annual precipitation is 550-950 mm, mostly in June to September. The precipitation of Shandong Peninsula is abundant, with annual precipitation of 650-850mm. The south side of the peninsula is over 800mm, and thus it belongs to the semi-humid region.

3. Data sources and research methods

3.1. Data sources
The precipitation data is from China meteorological science data sharing service network. The data of stations in Shandong Peninsula are selected for strict quality control. The monthly precipitation data of 6 stations (Changdao, Longkou, Chengshantou, Qingdao, Haiyang and Rizhao) in the peninsula area from 1961 to 2013 are selected. Statistically speaking, such a long time series can obtain more reliable trend results.
3.2. Research methods
SPI is used as drought and flood index to classify drought and flood levels. SPI was proposed by McKee in 1993 [11]. It reflects the drought intensity and duration by studying the statistical distribution law of precipitation. It has strong spatiotemporal adaptability and has the characteristics of multi-time scales. The principle of SPI is based on the precipitation distribution. It should be noted that it is not a normal distribution, but a skew distribution. The index is obtained by taking the precipitation time series of a certain time scale as a γ distribution, and calculating the cumulative probability through the precipitation γ distribution probability density function, and then transforming it into the standard normal distribution. The purpose of normal standardized treatment is to eliminate the difference of precipitation in temporal and spatial distribution, so that SPI can be used to reflect the drought and flood situation in different regions and time scales. The specific calculation steps are shown in reference [12].
SPI is characterized by multiple time scales (1, 3, 6, 12, 24 months, etc.). This work mainly analyses SPI of 12-month and 3-month time scales. SPI on the time scale of 12 months can clearly reflect the periodic changes of drought and flood, and SPI on the time scale of 3 months can reflect seasonal drought, which is closely related to agricultural drought [13]. According to McKee and other drought grade standards, drought classification grade is added based on drought grade standard (Table 1) [11].

| Serial number | SPI values | Grade          |
|---------------|------------|----------------|
| 1             | 2.00<SPI   | Extreme flood  |
| 2             | 1.50<SPI<1.99 | Severe flood  |
| 3             | 1.00<SPI<1.49 | Moderate flood |
| 4             | -0.99<SPI<0.99 | Normal        |
| 5             | -1.49<SPI<-1.00 | Moderate drought |
| 6             | -1.99<SPI<-1.50 | Severe drought |
| 7             | SPI<-2.00  | Extreme drought |

4. Results and analysis
4.1. SPI comparative analysis at different time scales
The comprehensive application of SPI with multiple time scales can realize the comprehensive evaluation and monitoring of drought and flood. Figure shows that SPI-1 in short time scale fluctuates frequently above and below the zero line, which reflects the characteristics of short-term drought and flood. SPI-3 can reflect seasonal drought and is closely related to agricultural drought [14]. With the increase of time scale, the influence of SPI-6 and SPI-12 on short-term precipitation is slowed down, and the change of drought and flood is relatively stable with more obvious cycles. It can clearly reflect the long-term variation characteristics of drought and flood, and better reflect the soil moisture of underground layer, groundwater, river runoff and reservoir water storage.
Figure 1. The SPI variation process on the time scale of 1(SPI-1), 3(SPI-3), 6(SPI-6) and 12(SPI-12) months in Shandong peninsula from 1961 to 2013.

In the one month time scale, the SPI values in July and August 1964 reached 2.2, reaching the extreme flood level. The SPI values in January and February 1963 were below -1, and even reached -3.0 in February, which was classified as extreme drought.

The difference between the three-month time scale and the one-month time scale is not obvious. Under the 6-month time scale, heavy flood occurred from April to September in 1964, and moderate flood occurred in March and October, and then tended to be normal. It was within the normal range around January 1962.

Under the 12-month time scale, the change trend is obviously different from that of the other three scales. It can be seen that the change tends to be gentle and stable with stronger regularity. The whole year of 1964 showed heavy flood, and 1963 and 1962 also showed moderate flood. With the increase of time scale, it can be seen that the drought and flood level will change correspondingly, and some even have the opposite grade change. Moreover, the start and end time of drought and flood are also delayed, which can fully reflect the cumulative impact of precipitation changes in the previous period.

4.2. Interannual variation characteristics of drought and flood

4.2.1. Interannual variation characteristics of flood. The interannual variation of SPI can reflect the specific period of drought and flood. It can be seen from Figure that SPI value fluctuates up and down,
but generally shows an upward trend (i.e., it develops towards the wet direction). Flood and drought occurred alternately in Shandong Peninsula from 1961 to 2013. It can be seen from the year-on-year change of SPI-12 in Figure that the flood disaster is specifically manifested as the value above 1 from 1961 to 1964. Among them, the flood disaster was serious in 1964, and the value in 1962 and 1964 was more than 2.0, resulting in extreme flood. From the second half of 1969 to 1976, there were also values above 0, and SPI values above 1.5 in 1970 and 1975. Apart from the values from 1971 to 1972, which were less than 0, the other years were also flood prone. During 1983-1985 and 1989-1990, SPI fluctuated between 0 and 1.5, which belongs to normal precipitation year. From 1992 to 2005, the remaining years were between -1 and 1 apart from 1996, 1998 and 2001. Drought and flood occur alternately, yet also belong to normal years. In 2006-2008, there was more precipitation, and the heavy flood disaster occurred in 2007. There was no extreme drought and flood in 2008-2013, yet it was wet on the whole. Accordingly, the main rainfall and flood years in Shandong Peninsula in recent 53 years are 1961-1964, 1970, 1975, 1984, 1989-1990 and 2006-2007. The most flood period occurred in 1964 and 2007.

4.2.2. Interannual variation characteristics of drought. The specific manifestation of drought disaster was that SPI value was mainly below 0 from 1965 to 1969, which was relatively dry yet did not reach the severity of drought. From 1977 to 1982, the other years were below 0 apart from 1978. Especially in 1981, the SPI value reached -2.4, which belonged to extreme drought disaster. This disaster was also one of the most serious drought disasters in Shandong Peninsula in recent 50 years. In 1986-1989, there was also a series of moderate drought disasters. After a slight respite in 1990, the extreme drought struck again in 1991, with the SPI value reaching -2.3. The SPI in winter of 1996, 1998, 2001 and 2005 were all below -1.1. The SPI value reached -1.7 in 1996, which belonged to severe drought. In 1998, SPI value was -2.3, and severe drought occurred again. The main drought years in recent 53 years are 1977, 1980-1983, 1985-1987, 1991, 1996 and 1999. Among them, the most drought period appeared in 1981, 1991 and 1998, which reached the serious degree of extreme drought. In 1998-2002, the drought in Shandong Province was particularly serious, and the surface water storage was nearly exhausted and the groundwater level dropped significantly.

4.3. Seasonal variation characteristics of drought and flood The results show that SPI on 3-month time scale can be used to analyze seasonal drought, and can better represent the agricultural drought changes (Figure)[15]. The spring drought and flood in Shandong Peninsula is characterized by stages. The main year of spring flood was 1961, and the SPI value reached 1.8. The spring flood was the most serious in 1990 with SPI value of 2.0. The main year of spring drought was 1999. Summer flood occurred in 1962-1965, and the SPI value reached 2.8 in 1963, which was the extreme flood year. On the other hand, summer flood also occurred in 1970 and 1985 with SPI of 2.4. Summer flood occurred in 1974, 1990, 2001 and 2007-2009. The summer drought years were 1981, 1989, 1991, 1999 and 2002, of which 1999 was more serious. Autumn flood year was in 1993. It was autumn drought in 1973, 1983, 1988 and 1995. The winter flood years were 1992 and 1997, and the flood was not very serious. The winter drought years were 1987, 1993 and 1998, of which 1998 was more serious, reaching -2.0. On the whole, the frequency of flood in summer is significantly higher than that in winter. Measures must be taken to deal with the seasonal drought and flood disasters to reduce the losses caused by disasters.

5. Conclusions Therefore, the following main conclusions were drawn: (1) SPI change trend: the monthly average has an upward trend in recent 53 years, yet it is not very obvious. After reaching the peak in 2006-2008, there is a downward trend. However, it is still moist on the whole.
(2) Interannual variation of drought and flood: drought was frequent in Shandong Peninsula from 1978 to 1999, and three serious drought events occurred in this period. Flood occurred in 1961-1964, 1968-1976 and around 2006.

(3) Seasonal variation of drought and flood: overall, the frequency of flood in summer is significantly higher than that in other three seasons, and the frequency of drought in winter is significantly higher than that in other three seasons.

Acknowledgments
This study was supported by the National Natural Science Foundation of China (41907050), the Natural Science Foundation of Shandong Province (ZR2019MD031), and the Shandong Colleges and Universities Scientific Research Program (J18KA197).

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