Evaluation of Drought Characteristics based on Markov Chain Model and Transition Probability Matrix in Different Climatic Regions of Iran

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1. Introduction

Drought is one of the inseparable phenomena of climate fluctuation. Reduction of rainfall and fluctuation of other climatic parameters affect the types of drought. Drought indices have been developed to monitor the drought situation and to evaluate its quantitative effects. The most widely used variable in meteorological drought monitoring was the amount of precipitation, which was the only determining parameter in the initial drought indices. In the recent years, indices based on precipitation and evapotranspiration were also developed.

One useful method of predicting drought is using a Markov chain. Vulnerability, reliability and resiliency are very common criteria in evaluating the performance of water resources systems that have been used in various studies on drought. The total probability of droughts based on the drought indices is the same as the vulnerability. Resiliency indicates the probability that the system will return to normal condition after a period of drought. Reliability means the probability that a drought will not occur within a certain period of time.

According to the mentioned issues, the main purpose of this study was to investigate the characteristics of drought including vulnerability, reliability, resiliency and persistence in three wet, normal and drought conditions within eighteen synoptic stations of the country (Iran). These stations are located in different geographical and climatic locations. These characteristics will be examined based on four drought indices including SPI, SPEI, RDI and eRDI, in the scales of water year and plant growth periods.

2. Study Area

Iran is located in a arid and semi-arid zone of the world with an average annual precipitation of about 250 mm. Iran is classified into six climatic zones including coastal wetland, mountainous, semi-mountainous, semi-desert, desert and coastal desert.

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In this study, three stations from each climatic zone and a total of 18 synoptic stations were used. For this purpose, monthly statistics of meteorological variables of precipitation, minimum temperature, maximum temperature, relative humidity, sunny hours and wind speed were used for 18 synoptic stations. The statistical period of the studied stations is from 1957 to 2016 (59 years), except for one station.

3. Materials and Methods

The SPI Index is one of the most widely used indices in recent decades to monitor drought around the world. The standardized precipitation-evapotranspiration index (SPEI) is proposed using precipitation and evapotranspiration data. The Reconnaissance Drought Index (RDI) is proposed based on the concepts of the SPI index and the ratio of precipitation to evapotranspiration to monitor drought and take into account climate change. The effective Reconnaissance Drought Index (eRDI) is presented in the RDI index to improve the results of drought assessment, especially agricultural drought.

In many hydrological and water resources models, forecasts at one time are influenced by values at other times, which is a Markov chain process. Most researchers have used a one-step change in the Markov chain to predict drought. The probability of occurrence of the phenomenon is conditional on the occurrence of a particular phenomenon at a previous time itself. In the present study, the number of rows and columns of the matrices is proportional to the three humid or dry status classes including drought, normal and wet conditions. Then, the statistical criteria of drought characteristics of durability, vulnerability, resiliency and reliability were determined through the values of matrices, according to the definitions provided in the introduction.

4. Results and Discussion

Results show that the probability of resiliency on an annual scale, according to all indices for all stations has an average of 0.83, which indicates that the average probability of drought in two consecutive years is about 0.17. The results of the reliability characteristic on an annual scale also show that according to all indices for all stations, its value varies between 0.78 to 0.92. In terms of vulnerability, on an annual scale in all stations and indices, the probability of vulnerability varies between 0.08 to 0.22. In general, the SPEI index shows higher values of drought vulnerability than other indices in this time scale. The resiliency in the growth period in all stations and indices varies between 0.46 to 1. Reliability also varies between 0.75 to 0.92. In this time scale, the eRDI index shows higher values of reliability and lower values of vulnerability than the RDI index in all stations. The same is true for the annual time scale. In terms of vulnerability, this characteristic varies between 0.08 to 0.25.

The probability of the normal condition persistence on an annual scale is between 0.4 to 0.9 and its average is 0.67, for all stations and the desired indices. On average, the eRDI index shows higher values of normal status, and among the climates, the humid coastal climate shows the lowest probability of persistence. The probability of remaining in the normal conditions in the time scale of the growth period in average is 0.67. Among the climates, the lowest and highest values are related to the humid coastal and desert climates, respectively. Also, the probability of remaining in drought conditions in this time scale in average is 0.16. Among the climates, the lowest probability of persistence in this situation is related to the coastal desert climate according to all indices except the SPEI index.

5. Conclusion

Markov chain model and transition probability matrix can be good tools for drought monitoring and forecasting. In general, the SPEI index shows higher values of drought vulnerability than other drought indices. Hypersensitivity of SPEI index to evapotranspiration has caused this index to show more variability in drought conditions. Results of this index show that, compared to other indices, in almost all stations there is less reliability but more vulnerability to drought. Based on the results of the transition probability matrix, it can be stated that in most cases the values of the original diameter of each matrix are larger than the values of the other elements of the matrix, which indicates that the probability of persistence of that condition is higher than other states. In addition, the probability of normal condition persistence is much higher (more than 50%) compared to both wet and drought conditions. According to the obtained results, it is suggested that in the analysis of drought characteristics, their characteristics such as vulnerability, resiliency and reliability should be examined according to the type of climate.

Keywords: Drought Indices, Markov Chain, Drought Characteristics, Transition Probability Matrix, Iran

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