



Copulas-based probabilistic characterization of the combination of dry and wet conditions in the Guanzhong Plain, China



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SUMMARY

It is of great significance to investigate the joint probabilities of the combination of dry and wet conditions between adjacent seasons under the background of global warming. The Guanzhong Plain, a very important agricultural production area, was selected as the study area. The joint probabilities of the combination of dry and wet conditions between adjacent seasons based on the Standardized Precipitation Index (SPI) in 1961–2010 were computed by copulas functions. The Mann–Kendall trend test method and wavelet analysis were used to investigate the trend and period of dry and wet conditions, respectively, and the Bayesian copula selection method was used to choose the best copula. Furthermore, the cross wavelet analysis was utilized to reveal the correlation between dry and wet conditions and sunspot activities. Results indicate the following: (1) the Guanzhong Plain is characterized by an relatively obvious trend towards dry in non-flood season and a relatively striking tendency towards wet in flood season; (2) the dry and wet conditions in the Guanzhong Plain have a statistically significant in-phase relationship with sunspot activities in 1983–1997 with a period of 8–12 years, whilst they have a non-statistically significant anti-phase relationship with sunspot activities in 1961–1973 with a period of 9–12 years, hence, sunspot activities exert a strong influence on dry and wet conditions in the Guanzhong Plain; (3) the plain is characterized by a high-frequency continuous dry condition in the entire year and a high risk of continuous wet condition in the season of Summer–Autumn; (4) the joint return period of the combination of dry and wet conditions between adjacent seasons gradually increases from east to west in the west and middle of the Guanzhong Plain, which is possibly closely linked to different geomorphic terrains, intensity of human activities and ENSO events.

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1. Introduction

Over the past century, the global climate and environment have witnessed an obvious change, in which the global warming is one of the most striking characteristics, which leads to accelerating the rate of water circulation, thereby resulting in high-frequency extreme events such as drought and flood on a global scale (Roy and Balling, 2004; Beniston and Stephenson, 2004; Kunkel, 2003; Christensen and Christensen, 2004). The societal influences of these disasters are increasingly intensifying and the development of society and economy tends to be more and more vulnerable (Zhang et al., 2012). Therefore, it is increasingly becoming a focus to investigate extreme weathers and their related societal effects (Zhang et al., 2010a, 2010b; Mudelsee et al., 2003). Burke and Brown (2010) investigated the regional drought over the UK and its changes in the future.

Serinaldi et al. (2009) used copulas to study the probabilistic characterization of drought properties. Grimaldi and Serinaldi (2006) applied asymmetric copula to analyze multivariate flood frequency. Although these researches help to further understand the extreme disasters and their impacts, they pay attention to drought or flood separately. Nevertheless, as the impact of climate changes is increasingly intensifying, the continuous drought and the sudden alternation of drought and flood events between the adjacent seasons are more common than before.

The continuous drought has extremely negatively influenced on industrial and agricultural production for a long period, which greatly increases the severity of damage, while the sudden alternation of drought and flood events is characterized by sudden turning and its negative effects exhibit a multi-dimensional and multi-level characteristics. Hence, the separation of drought and flood cannot reflect the characteristic of the continuous drought and the alternation of drought and flood events. Additionally, a separate analysis of droughts or floods events is also very difficult to satisfy the require-

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ment of water resources optimal allocation and hazards risk management under the background of increasingly accelerating rate of global water cycle. Since droughts and floods events are closely associated with dry and wet conditions, it is of great importance to investigate the probabilistic characterization of continuous dry (wet) and the alternation of dry and wet conditions between the adjacent seasons. Furthermore, given the flexibility of copulas in studying hydro-meteorological extreme events (Genest and Rivest, 1993; Genest and Favre, 2007), copula functions were used to investigate the probabilistic properties of the combination of dry and wet conditions in the Guanzhong Plain, China.

Recently, the use of copulas is increasingly growing, for instance, Genest and Rémillard (2008) applied parametric bootstrapping to drought and hydrological analysis; Bárdossy (2006) used a copula-based geostatistical models to compute groundwater quality parameters; Shiau (2006) used a two-dimensional copulas to investigate drought duration and severity. Hence, it is essential to find a simple and reliable method to select an appropriate copula family (Huard et al., 2006). Although numerous researchers used copulas to investigate hydro-meteorological extremes (Wang et al., 2010; Palynchuk and Guo, 2011; Zhang et al., 2012; Kao and Govindaraju, 2010), most of them used a likelihood method to choose an appropriate copula, which was used to assess the performance, such as, the Akaike Information Criteria (AIC) (Huard et al., 2006). However, the existing methods present some drawbacks and none is completely satisfactory due to their limitation to compare distributions by hardly specifying an optimal parameter set for each one of them (Huard et al., 2006). However, the Bayesian copula selection method proposed by Huard et al. (2006) has solved this problem, which puts a prior distribution on Kendall's τ rather than on the parameter. Thus, the Bayesian copula selection method was applied to select the appropriate copula in this study.

The Guanzhong Plain is located in the middle of Shaanxi province, which is a very important national agricultural production region. In order to enhance the security level of local grain, the Shaanxi Provincial Government attempts to build the Guanzhong Plain as a core area of grain production ensuring stable yields despite drought or excessive rain. In fact, the plain is located in the edge of the continental monsoon climate zone, which is extremely sensitive to global climate change and the change in environmental factors, and its annual precipitation varies greatly. As a result of these factors outlined above, the frequency of droughts and floods in this plain is very high, which vastly restricts the agricultural production. Thus, there are some difficulties for the government to fulfill its goal because of the high-frequency droughts and floods in this plain. In addition, there is a large number of industrial parks in the plain, which need a great deal of water to keep their normal operations. Hence, the high-frequency occurrence of droughts or floods will lead to considerable industrial and agricultural damages. Additionally, it is worth mentioning that the Guanzhong Plain is designated as a state key economic development zone, having a strong effect on the economic development of its surrounding areas. However, the high-frequency droughts and floods will greatly hinder the social and economic development of the whole plain.

Many researchers investigated the probability of drought in the Guanzhong Plain. Mao (2010) used the empirical mode decomposition (EMD) method to analyze the drought oscillation on multiple scales in the Guanzhong Plain during the last century. Li et al. (2005) analyzed the climatic changes in east, middle and west areas of the Guanzhong Plain. Nevertheless, to the best knowledge the authors, there is no study concerning the probabilistic characterization of continuous dry (wet) and the sudden alternation of dry and wet conditions between the adjacent seasons, which is of great importance to the local water resources planning and hazards risk management. Therefore, the main objectives of this study

are: (1) to study the trend and period of precipitation based on the Standardized Precipitation Index (SPI); (2) to investigate the probabilistic characterization of continuous dry (wet) and the alternation of dry and wet conditions between the adjacent seasons; and (3) to reveal the correlation between dry and wet conditions in the Guanzhong Plain and sunspot activities.

2. Study area and data

2.1. The Guanzhong Plain

The Guanzhong Plain, as shown in Fig. 1, is selected in this research. It is located in the middle and lower of the Wei River, which is the largest tributary of the Yellow River. The Guanzhong Plain covering a total area of 39064.5 km² is also located in the middle of Shaanxi province, its south border is near to Qinling Mountains, its north boundary is close to the loess plateau, its west border approaches to the Baoji gorge, and its east boundary is near to the Yellow River. Topographically, the altitude decreases from the west to the east, ranging from 900 to 325 meters. Located in the edge of the continental monsoon climate zone, the Guanzhong Plain is characterized by abundant precipitation and high temperature in summer, however, by sparse precipitation and low temperature in winter, which tends to result in droughts and floods. Note that the Guanzhong Plain is a quite important agricultural production area, in which there are 9 large irrigation areas (e.g., Jinghuiqu, Baojixia, Luohuiqu, Jiaokou, Yangmaowan, Taoqupo, Fengjiashan, Shitouhe and Shibaochuang), whose total area accounts for approximately 45% of all the effective irrigation area of Shaanxi province. Nevertheless, the high-frequency droughts and floods will restrict the development of agricultural production, thereby leading to a reduction of agricultural output. Furthermore, as a state key economic development zone, the economic development of the Guanzhong Plain has a great effect on the sustainable development of Shaanxi province. Thus, the high-frequency droughts and floods will directly affect its integrated development of society and economy. In view of the great importance of the water safety in the Guanzhong Plain, it is of great significance to investigate the probabilistic characterization of the combination of dry and wet conditions in the plain, which will help to guide relevant department in water resources and hazards risk management.

2.2. Data

Daily precipitation data collected from Baoji, Wugong and Xian meteorological stations, respectively in the west and middle of the Guanzhong Plain was used in this study, whose stations are presented in Fig. 1. Each station has daily precipitation data covering January 1, 1961–December 31, 2010, which was acquired from the National Climate Center (NCC) of the China Meteorological Administration (CMA). The CMA has constructed 21 meteorological stations in the Wei River Basin, and three of them have been built in the Guanzhong Plain. Thus, the available stations in the plain are Baoji, Wugong and Xi'an. We believe that the CMA selected the location and number of weather stations in the Guanzhong Plain after considering their representativeness. Thus, based on the precipitation data of the three stations, the spatial characteristic of dry and wet conditions in the western and middle plain can be investigated. Additionally, Li et al. (2005) used the meteorological data of the three stations to study climatic changes in the Guanzhong Plain. Hence, we think that we can use the daily precipitation data of the three stations to investigate the probabilistic characteristic of dry and wet conditions of the western and middle of the Guanzhong Plain. The data quality was strictly controlled during their release by the authors. Amongst the 3 stations, there are some missing val-

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