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# Comprehensive assessment of drought risk in the arid region of Northwest China based on the global palmer drought severity index gridded data

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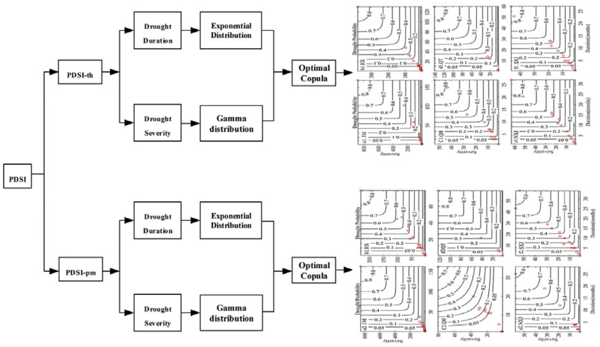
## HIGHLIGHTS

- The different drought risks were found in the different parts of NWC.
- The drought duration and drought severity were estimated.
- Copula functions can be applied to combine the different aspect of drought features.
- The message is useful for water management and decision-making.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Droughts are extremely widespread natural disasters, which cause the most severe losses among natural disasters. The comprehensive drought risk in Northwest China (NWC) was evaluated based on the self-calibrating (SC) Palmer Drought Severity Index (PDSI) and copula method. The major conclusions are the following: (1) based on the rotated empirical orthogonal function (REOF), a significant consistency in the spatial distribution of the monthly averaged SC-PDSI was observed in NWC, especially in the subregions Inner Mongolia Plateau (IM), Hexi Corridor (HX), and Qiangtang Plateau (QT); (2) the largest frequency was obtained for slight drought and slight wet conditions, while extreme drought and extreme wet showed the lowest values; (3) with respect to the PDSI-th, the Clayton, Arch12, Arch12, Arch12, Arch12, and Frank played the major roles in the copula weight in the subregions IM, HX, Qinghai River Basin (QH), QT, North Xinjiang (NXJ), and South Xinjiang (SXJ), respectively. In terms of PDSI-pm, Arch12, Clayton, Gaussian, Arch12, Clayton, and Clayton dominated the weights of multi-copula functions in the regions IM, HX, QH, QT, NXJ, and SXJ, respectively; and (4) the frequency and probability of droughts in each area differed. The least drought events occurred in the QT and the most emerged in the HX for SC-PDSI.

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## 1. Introduction

Drought is an extended period of water resource imbalance or excess evapotranspiration and moisture deficiency, which is due to the extremely dry weather in a given region (Akyuz et al., 2012; Mpelasoka et al., 2008; Dubrovsky et al., 2009; Paneque, 2015). Among agriculture, meteorological, and hydrological drought, more attention has been paid to hydrological drought because of its close relationship to human activities (Long et al., 2013; Liu et al., 2017). Generally, drought has a profound and far-reaching impact on ecology, living, and production, for instance, the reduction in water supply and quality, disturbed riparian and wetland habitats, loss of agricultural productivity, and diminished hydroelectric power generation (Vicenteserrano et al., 2012; Wilhite, 2000; Mishra and Singh, 2010). Moreover, the impact of drought on the agriculture, ecosystem, and local socioeconomic development is significantly intensifying due to climate change (Vandenberghe et al., 2011; She et al., 2013). For example, the drought frequency has increased during the past several decades (Keshavarz et al., 2014; Wilhite, 1993). In addition, drought events are complex hazardous hydrological processes, which can be described by the duration, severity, frequency, and areal extent (Tsakiris et al., 2016; Xu et al., 2015). Thus, it is insufficient to analyze the drought effect based on a single drought feature (Genest and Favre, 2007; Liu Z. et al., 2016).

Nowadays, many drought indexes have been proposed or developed to improve the assessment of droughts for drought investigation and prediction (Heim, 2002; Hao and Singh, 2015), which are important for water planning and decision-making (Hao and AghaKouchak, 2014). For example, the standardized precipitation index (SPI), standardized precipitation evapotranspiration index (SPEI), and PDSI have been widely applied (Mishra and Singh, 2011; Zou et al., 2017). Furthermore, the PDSI developed by Palmer (1965) is one the most common indexes applied by meteorologists, hydrologists, and government agencies to study droughts (Dai, 2011). It can be used to quantify the drought severity in diverse climate zones (Palmer, 1965). As a landmark for drought features (Heim, 2002), the PDSI is more representative than other meteorological drought indexes when considering the impact of precipitation and temperature on the soil moisture based on Palmer's drought model (Dai et al., 2004). Although there are major drawbacks affecting the accuracy of drought estimation (Zou et al., 2017), for example, the sample model does not take surface physical conditions into consideration for the original PDSI, the SC-PDSI automatically calibrates its expression by substituting the traditional constants with dynamically calculated values (Wells et al., 2004). A variety of predecessors applied the SC-PDSI to monitor droughts. For example, Yan et al. (2013) improved the computation of the PDSI based on the Soil and Water Assessment Tool (SWAT) and assessed the drought risk in the Luanhe River Basin. Ma et al. (2015) employed the Variable Infiltration Capacity (VIC) model to replace the original model of the PDSI computation and concluded that seasonal and annual drought index values showed a decrease in some regions of the Yellow River Basin. Zou et al. (2017) reported similar spatial patterns for drought in the Weihe River Basin based on SWAT-PDSI and principle component analysis.

Northwest China (NWC) is a typical arid and semi-arid area in which the water resources mainly originate from snow and ice melting in the mountain area (Chen et al., 2016). It often suffers from droughts because of the decreasing water resource supply and the drought frequency increases due to climate change (Chen et al., 2016). Although there were a variety of studies about dry or wet conditions and their tendency (i.e., Yang et al., 2017a, 2017b; Li et al., 2016; Deng et al., 2014), attention was mainly paid to the single feature of water resources and its cycle factors without focusing on the joint effects of multidimensional drought characteristic. Thus, these studies could not comprehensively reveal the real drought risk. However, the emergence of the copula function gives way to comprehensive assessment of the drought risk (e.g., Guerfi et al., 2016; Salvadori and Michele, 2015; Zhang and Singh, 2007). Nelsen (2006), Joe (2014), and Durante and Sempi (2015) introduced detailed copula functions theory. The merit of copula functions is that they can produce a combination of different features without generating a margin effect (Zhang et al., 2017). In the practical process, the copula functions are usually used to combine the drought duration and severity to assess the drought risk (Genest and Favre, 2007; Salvadori and Michele, 2007; Salvadori et al., 2007). For instance, Zhang et al. (2015) reported the drought risk in the East River Basin of China based on the joint probability of drought duration and severity and the Plackett copula. Tsakiris et al. (2016) detected the probability distributions of drought severity and areal extent in Greece applying the Archimedean copulas. However, previous studies also had disadvantages. For example, the computation of evaluation indexes [e.g., ordinary least square (OLS), Bayesian information criterion (BIC), and Akaike information criterion (AIC)] for the selection of optimal copula functions is complex. Additionally, there are not enough types of alternative copula functions.

Thus, to provide more alternative functions and reduce the calculation of evaluation indexes, the Bayesian method was used to select the

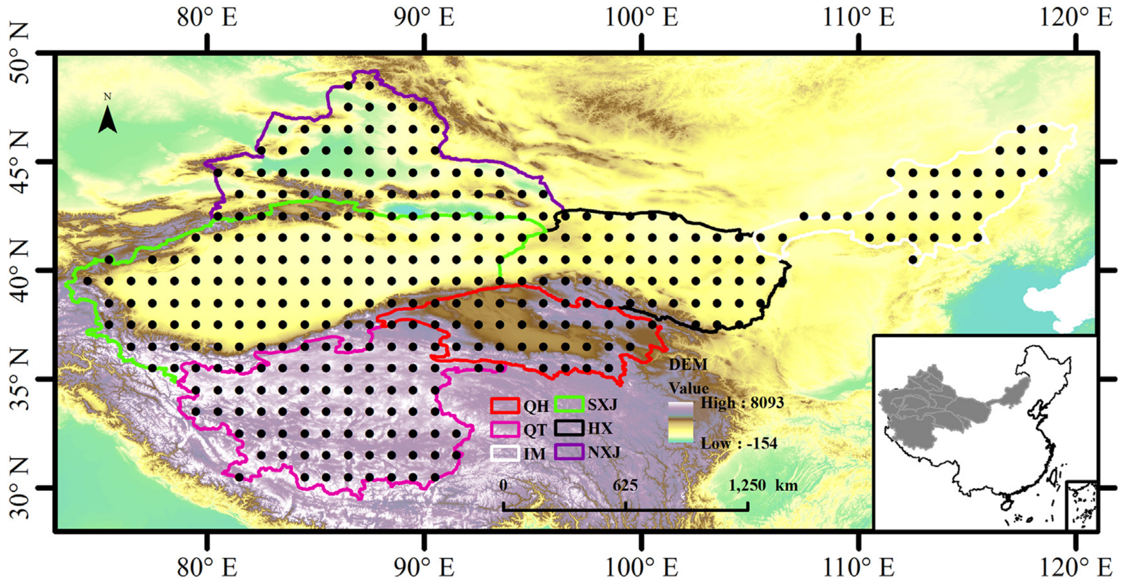

**Fig. 1.** Study area. (The left up is the main sketch of the study area and the right down is the location of the study area in China).