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Multi-scale assessments of droughts: A case study in Xinjiang, China

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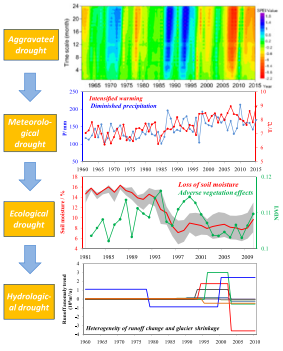
HIGHLIGHTS

- Aggravated drought based on the SPEI in Xinjiang, China
- Intensified warming and diminished precipitation increase the severity of the drought.
- Increased ET_0 amplifies the risk of ecological drought.
- Hydrological drought is not entirely comparable to SPEI and SPI drought.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding the multi-scale variation of drought is essentially important in drought assessment. Now, a comprehensive assessment is still lacking on the meteorological, ecological and hydrological drought perspectives. In order to better investigate multi-scale droughts, we carried out a comprehensive analysis of their long-term variation based on the two drought indices and observation data in Xinjiang, China, from 1961 to 2015. The two indices are the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). The results show that the SPI and SPEI are highly consistent for most stations and time scales in Xinjiang. Based on multi-scale and considered evaporative demand, the SPEI from 1961 to 2015 showed a wetting trend followed by a drying trend (as of 1997), giving an overall slight drying trend (-0.0122 ± 0.0043 per year) for the 54-year period. We assessed the sensitivity of the two drought indices to precipitation (P) and potential evapotranspiration (PET) and found that the SPEI shows different sensitivity to P and PET. In arid regions characterized by high PET, drought severity is mostly determined by changes in PET. The intensified warming and diminished precipitation in Xinjiang that have been observed over the past two decades have resulted in SPEI-drought severity. These changes also amplify the risk of ecological drought. However, the hydrological drought was highly complex and not entirely comparable to the SPEI and SPI droughts. Hydrological records indicate that runoff in most rivers in the Tianshan Mountains has increased, whereas runoff in the Kunlun Mountains is either stable or has slightly decreased over the past 20 years. A moderately high and statistically significant correlation between the runoff anomaly and the SPEI and SPI was revealed for four major rivers in the region. This implies that the accelerated river runoff in Xinjiang is a function of both precipitation and increasing glacier melt.

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1. Introduction

Drought is a central concern for regional management in water-stressed regions (Van Loon and Van Lanen, 2013; Zhang et al., 2017). Over the past few decades, the frequency and intensity of drought has increased (Zhang and Zhou, 2015) in Asia, resulting in an accelerated expansion of drylands (Huang et al., 2016). The impact of drought has been particularly high in Central Asia, where a mixture of drying and wetting variability account for 42% and 58% of the land area, respectively (Li et al., 2017). Indeed, for the past several decades, an overall drying trend has been observed in both Central Asia (Li et al., 2017) and the arid regions of China (Wang et al., 2015).

Located thousands of kilometers inland in the arid latitudes of the Northern Hemisphere, the Xinjiang region of China is particularly sensitive to global warming (Yao et al., 2017). Due to its continental location, Xinjiang is largely cut off from large, moist air masses. As a result, water resources are severely limited and climate change exacerbates the region's vulnerability to water shortages (Li et al., 2017). Climate change in Xinjiang is both highly complex and highly sensitive to global warming (Chen et al., 2012; Chen et al., 2015), and the sparsely populated province frequently experiences drought. For instance, Xinjiang experienced 17 severe droughts and 9 major droughts between 1961 and 2000 (Wen and Shi, 2006). However, Zhang et al. (2012) showed that drought trends differed across Xinjiang and had a tendency to weaken in the western portions in 1957–2009. Tao et al. (2014) found that extreme drought increased in frequency in the Tarim River basin in 1961–2010, while Zhang et al. (2015) also assessed the vulnerability to drought in the Tarim River basin. Thus, given its aridity and extreme sensitivity to weather patterns, Xinjiang provides an ideal testing ground for multi-scale drought assessments. However, in most previous studies have focused on the spatial and temporal variation of drought in Xinjiang, a comprehensive discussion for investigating long-term droughts that identifies meteorological, ecological and hydrological perspectives is still lacking.

Various indices have been developed to allow for the measurement and quantification of drought. Among these, the Standardized Precipitation Index (SPI) (McKee et al., 1993; Hayes et al., 1999; Moreira et al., 2006; Silva et al., 2007; Zhang et al., 2012) and the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Vicente-Serrano et al., 2010a, 2010b; Beguería et al., 2010; Paulo et al., 2012; Beguería et al., 2014; Vicente-Serrano et al., 2015) have been widely used to monitor drought severity. The SPI utilizes precipitation data without considering evaporative demand and is employed by the World Meteorological Organization as the primary reference drought index (Hayes et al., 1999; WMO, 2012). The more recently developed SPEI is based on the monthly climatic water balance (P-ET) and combines the multi-scale utility of the SPI with the sensitivity of the Palmer Drought Severity Index (PDSI) to depict changes in evaporative demand (Vicente-Serrano et al., 2010a, 2010b; Wang et al., 2015a). Vicente-Serrano et al. (2015) showed that the SPEI has the greatest sensitivity to PET (Potential evapotranspiration) variability and used the index to demonstrate the link between increasing drought severity and temperature rise. Thus, the SPEI is an effective tool for studying and monitoring recent drought under warming conditions. Recently, it has been used in diverse studies that have analyzed drought variability, drought atmospheric mechanisms, and drought impacts over many parts of the world, including Asia, North America, Africa, Europe, and Australia (Allen et al., 2011; Potop, 2011; Potop et al., 2012; Fuchs et al., 2012; Paulo et al., 2012; Abiodun et al., 2013; Sohn et al., 2013; Wang et al., 2015; Zhang et al., 2017).

To this end, we used the long-term hydro-meteorological data and multi-scale drought indices to evaluate multi-scale assessments of droughts that recognize meteorological, ecological, and hydrological perspectives over Xinjiang, China. Time series for the SPEI and SPI were calculated for the investigation. Ultimately, our study findings will be helpful for understanding the variability of droughts and can serve as a scientific reference for drought hazard and drought impact assessment.

2. Study materials, data and methodology

2.1. Study materials and data

The province of Xinjiang is located in the Eurasian hinterland in northwestern China. It is the largest province in the country, covering

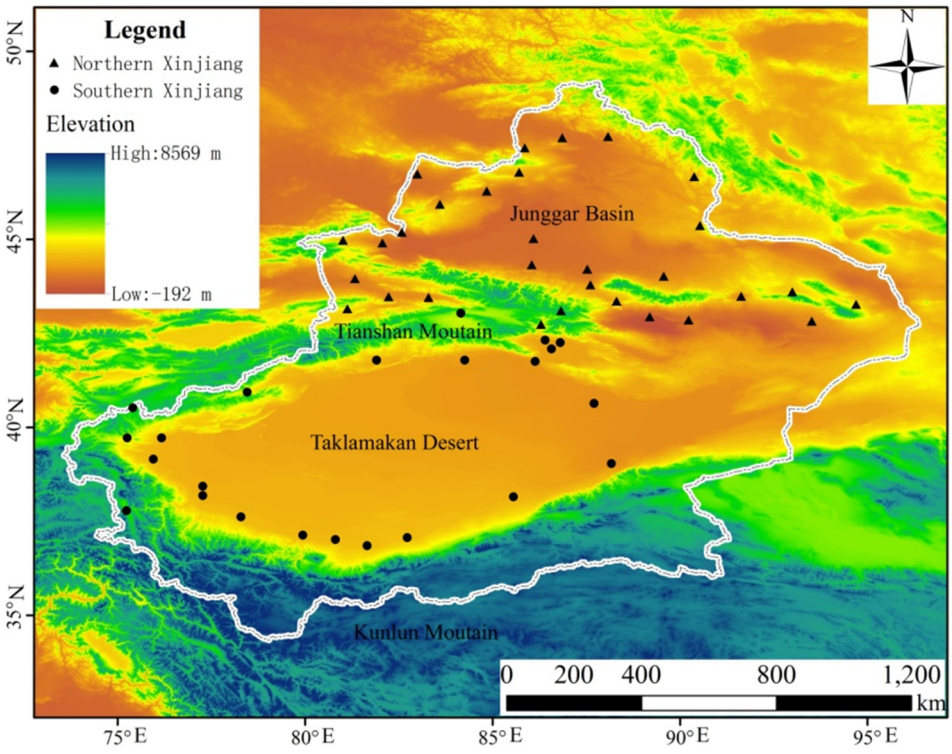

Fig. 1. Study area and meteorological stations in Xinjiang.