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Spatial and temporal variability of daily precipitation concentration in the Lancang River basin, China

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SUMMARY

The Lorenz Curve, a concept used in economic theory, is used to quantify spatial–temporal variability in the daily time series of precipitation concentrations. The Lorenz Curve provides a graphical view of the cumulative percentage of total yearly precipitation. In addition, further extraction of the data using the Gini coefficient and Lorenz asymmetry coefficient provides a two-parameter measure of precipitation concentration and an explanation of the basis for the underlying inequalities in precipitation distribution. Based on the calculation of the precipitation concentration index (CI) and the Lorenz asymmetry coefficient (S) values from 1960 to 2010, variations in the trends and periodic temporal–spatial patterns of precipitation at 31 stations across the Lancang River basin are discussed. The results are as follows: (1) highest precipitation CI values occurred in the southern Lancang River basin, whereas the lowest precipitation CI values were mainly observed in the upper reaches of the Lancang River basin, which features a more homogeneous temporal distribution of rainfall. S values throughout the entire basin were less than one, indicating that minor precipitation events have the highest contribution to overall precipitation inequality. (2) Application of the Mann–Kendall test revealed that a significant, decreasing trend in precipitation CI that exceeding the 95th percentile was detected in the upper and middle reaches of the Lancang River basin. However, there was only one significant (0.05) S value trend throughout the river. (3) Climate jumps in annual CI occurred during the early 1960s, 1970s and 1980s at Jinghong, Deqin and Zaduo stations, respectively. (4) Dominant periodic variations in precipitation CI, with periods of 4–17 years, were found. These results allow for an improved understanding of extreme climate events and improved river basin water resource management.

1. Introduction

The long-term observation of climatic variables as a practical approach for monitoring climate change is receiving considerable attention from researchers throughout the world. Of the common climatic variables, precipitation is the most changeable in time and space, directly affects natural cycles of water resources and provides information on the state of the climate (IPCC, 2007). The intensity, amount, duration, timing and rate of precipitation are impacted by climate change with precipitation irregularities being primary indicators of these impacts. These precipitation anomalies, such as droughts (Zhang et al., 2013) and floods (Parajka et al., 2010), are highly variable, cause economic and ecological damage and, in the worst cases, increased mortality. In recent decades, extreme events are frequently occurring worldwide (Beniston and Stephenson, 2004; Kunkel, 2003; Peterson et al., 2002; Zhang et al., 2005b) and adverse impacts on eco-hydrological processes are intensifying. This is the case in the Lancang River basin, China, located in the upper reaches of the Mekong River. Therefore, it is necessary to study temporal–spatial characteristics of precipitation–variation patterns in a backdrop of changing climate and intensified human activities using long-time data series collected at a river basin scale.

To date, numerous studies that analyze rainfall variability at different temporal scales (from daily to annual) in China (Chen et al., 2011; Gong et al., 2004; Liang et al., 2011; Zhang et al., 2012b), Nigeria (Oguntunde et al., 2011) and Italy (Brunetti et al., 2012; Cannarozzo et al., 2006) have been carried out. Furthermore, with an increase in recent natural disasters, including a spring drought in Southwestern China and floods in Pakistan and Thailand (Liang et al., 2011) an interest in extreme weather events and erratic changes in rainfall patterns in China has developed (Fischer et al., 2011; Li et al., 2012; Nie, 2012; Xu et al., 2009; Zhang et al., 2009, 2012a). Previous analyses of daily precipitation series

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show a significant decrease in the number of rainy days and an increase in rainfall intensity during extreme events over the last few decades (Ren et al., 2000). Despite a low frequency in observed extreme events, heavy rainfall occurring over a few days accounts for a high percentage of the total annual rainfall and has the potential to cause flooding. Heavy rainfall is also characterized by the timing and rate of concentration of total annual rainfall. A better technique for describing the varying involvement of daily rainfall is to consider the contribution of days with the greatest amount of rainfall to the total amount of rainfall. This concept, known as the rainfall concentration index (CI), is based on the Lorenz Curve (Alijani et al., 2008; Coscarelli and Caloiero, 2012; Li et al., 2011c; Martin-Vide, 2004; Zhang et al., 2009) and is an important index for specifying the statistical characteristics of daily precipitation. It measures irregularities in rainfall distribution by determining the total amount of rainfall in each precipitation class. A higher precipitation CI indicates a more heterogeneous precipitation distribution. Martin-Vide (2004) explored the spatial distribution of the computed precipitation CI in Spain. The results of this study showed a clear division of peninsular Spain into two regions. The eastern region has a high precipitation concentration with 25% of the rainiest days accounting for more than 70% of the total annual rainfall, and the rest of the country, which consists of more regular daily amounts. Martin-Vide (2004) found the frequency of rainy days to be greater in the lower classes and decreasing with the higher classes. Alijani et al. (2008) confirmed the infrequent and irregular nature of daily rainfall across Iran by analyzing precipitation CI. Their study indicated that at least 20% of the country is exposed to a risk of extreme rainfall. Zhang et al. (2009) used daily rainfall series to examine spatial and temporal patterns of precipitation CI and to analyze precipitation CI trends at each rain gauge in the Pearl River basin. Li et al. (2011c) calculated precipitation CI in Xinjiang and demonstrated that the Kaidu River basin and Southern Xinjiang have higher precipitation CIs, with most of the precipitation occurring on only 25% of the rainy days, than Western Xinjiang. Coscarelli and Caloiero (2012) noted that on the eastern side of southern Italy, one quarter of the rainy days accounted for almost three quarters of the total pluviometric amount of rain. These precipitation CI studies focused on the major plain basins and arid inland areas rather than mountainous watershed areas. Previous studies that used the precipitation index, a less rigorous test than the Lorenz Curve, showed that 25% of the rainiest days made up most of the index which illustrated the cause of precipitation inequality (Coscarelli and Caloiero, 2012; Li et al., 2011c; Martin-Vide, 2004; Zhang et al., 2009). The Lorenz asymmetry coefficient was used to describe inequalities in precipitation distribution. Though, the combination of the Lorenz Curve in conjunction with the Gini coefficient was found to be a more efficient methodology.

The Lancang River is of great importance not only to southwestern China, but also to the rest of Southeast Asia. Understanding the effects of spatial–temporal variations in the precipitation concentration index in the Lancang River basin is a key to understanding the hydrological cycle, especially in the context of climate change and human activities. In the last 3 years, a decrease in spring precipitation caused droughts, degradation of soil quality and even soil erosion (Li et al., 2011b). A few studies have addressed these changes in precipitation within the Lancang River basin. These studies identified precipitation trends during dry and wet spells (Li et al., 2011b; Zhou et al., 2011), as well as extreme rainfall events (Li et al., 2011a). However, few studies have analyzed the contribution of disproportionately heavy rainfall to the basin's rainfall distribution or the statistical structures of daily precipitation over the past several decades. Investigating precipitation CI in the Lancang River basin could provide a solid basis for analyzing the relationship between water resources and climate change within the basin. At the same time, this investigation will provide support for making decisions about international river affairs, development of mitigation measures for natural hazards and facilitation of human adaptation to increasing risks of hazard-induced impacts.

Therefore, the objectives of this study were: (i) to investigate temporal–spatial variation characteristics of the precipitation CI using daily precipitation datasets at annual and seasonal scales from 1960 to 2010 under climate change in the Lancang River basin; (ii) to analyze and quantify non-uniform distribution of daily precipitation using the Gini coefficient and Lorenz asymmetry coefficient in the context of the Lorenz Curve; and (iii) to explore the trends and periodicities of precipitation CI by virtue of non-parametric tests and wavelet analysis.

2. Study area and data

Mekong River, the largest international river in Southeast Asia, originates on the Tibetan Plateau at an elevation of approximately 5100 m and flows through China's Yunnan Province, Myanmar, Laos, Thailand, Cambodia and Vietnam before entering the South China Sea through the Mekong Delta in Vietnam. Constituting the upper reaches of the Mekong River basin, the Lancang River lies between approximately 94 to 102°E and 21 to 29°N, has a drainage area of about 1.67×10^5 km^2 and has an elevation between 500 and 6000 m above the mean sea level (Fig. 1). The geomorphology of the Lancang River varies from high mountains and deep valleys that run in a north–south direction to medium/low Mountains and wide valleys (He et al., 2005). The river spans seven climate zones, crosses different geographic environments and connects different cultural, social and economic communities (Hu et al., 2009). Because of its high mountains and deep valleys, the Lancang River

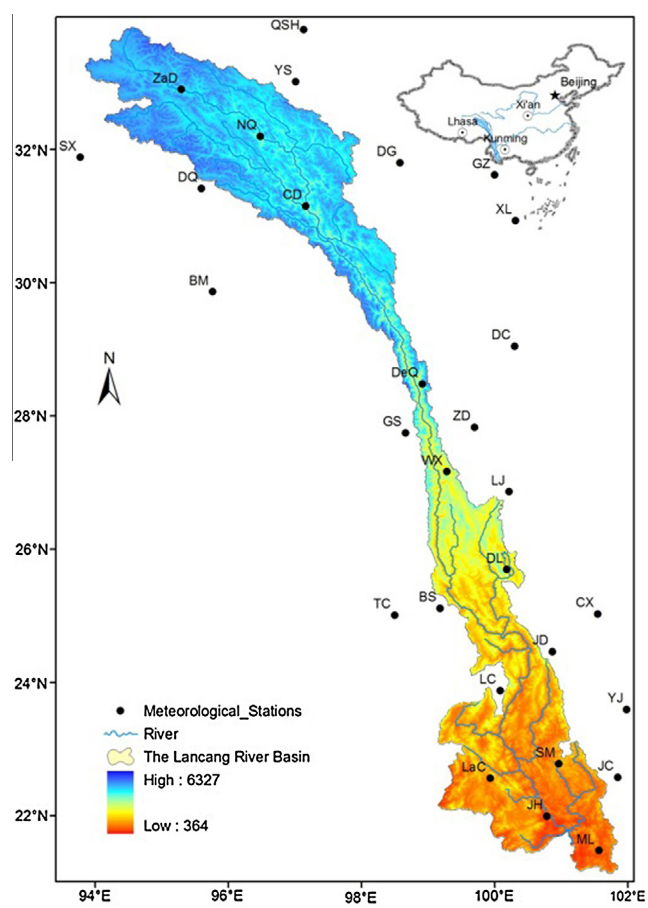

Fig. 1. Location of the Lancang River basin and rain gauge stations in China.