Science of the Total Environment 619–620 (2018) 28–41

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Spatial and temporal distribution of rainfall and drought characteristics across the Pearl River basin

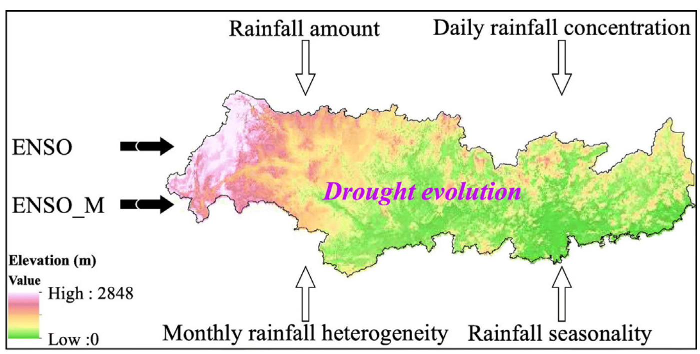
Shulin Deng [a,b,c], Tan Chen [b,c], Ni Yang [d], Lean Qu [b,c,e], Manchun Li [a,b,c,*], Dong Chen [b,c]

[a] *Collaborative Innovation Center of South China Sea Studies, Nanjing University, Nanjing 210093, China*
[b] *Jiangsu Provincial Key Laboratory of Geographic Information Science and Technology, Nanjing University, Nanjing 210023, China*
[c] *Geographic and Oceangraphic Sciences, Nanjing University, Nanjing 210023, China*
[d] *School of Management Science and Engineering, Guangxi University of Finance and Economics, Nanning 530003, China*
[e] *College of Territorial Resources and Tourism, Anhui Normal University, Wuhu 241002, China*

HIGHLIGHTS

- The rainfall and drought characteristics were systematically investigated based on CI, PCI, SI, and SPEI.
- The trends were analyzed using Sen's trend test, Sen's slope, and segmented models.
- ENSO and El Nino Modoki events had different impacts on seasonal drought across the Pearl River Basin.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 July 2017
Received in revised form 29 October 2017
Accepted 31 October 2017
Available online xxxx

Editor: R. Ludwig

Keywords:
Rainfall
Drought
ENSO
El Nino Modoki
Pearl River Basin

ABSTRACT

Understanding rainfall trends as well as drought characteristics plays a key role in watershed development and management. In this study, the spatial and temporal characteristics of rainfall and drought based on temperature and precipitation data observed in 48 meteorological stations from 1959 to 2012 across the Pearl River Basin in China were analyzed. The possible influence of El Nino-Southern Oscillation (ENSO) and El Nino Modoki (ENSO_M) events on seasonal drought based on the Standardized Precipitation-evapotranspiration Index (SPEI) were also investigated. The results show that annual and seasonal rainfall decreased slightly in most areas, annual and seasonal daily precipitation concentration decreased in a few areas, monthly rainfall had an irregular distribution but with no significant trend detected, and rainfall seasonality increased in most areas. Drought tended to worsen during recent years, especially in the upper reaches, and seasonal drought also tended to become serious or occurred frequently across the Pearl River Basin. The drought patterns are not only related to the decreasing trends in rainfall but also to changes in the daily rainfall concentration, monthly rainfall heterogeneity, and rainfall seasonality. Both ENSO and ENSO_M events had an influence on summer drought in the middle-upper reaches. The ENSO events dominated the patterns of autumn drought in the Pearl River Delta, and the ENSO_M events strongly affected the changing patterns of autumn drought in the middle-upper reaches and northern parts of the middle-lower reaches.

* Corresponding author at: Collaborative Innovation Center of South China Sea Studies, Nanjing University, Nanjing 210093, China.
E-mail address: limanchun@nju.edu.cn (M. Li).

https://doi.org/10.1016/j.scitotenv.2017.10.339
0048-9697/

1. Introduction

Climate change has altered rainfall structures, such as rainfall amount, rainfall extremes, rainfall seasonality, and further affected drought characteristics (Feng et al., 2013; Kumar, 2013; Trenberth et al., 2013). A warmer atmosphere can hold more vapor, and as a result, rainfall tends to be more intense. Extreme rainfall events can further affect the mean annual rainfall or rainfall seasonality (Kumar, 2013). Furthermore, the rising temperature intensifies evaporation and transpiration on the earth's surface, likely resulting in droughts that are longer and more severe (Milly and Dunne, 2016). Global climate change is anticipated to lead to greater uncertainties in spatial and temporal variability of precipitation, including unexpected changes in the timing and characteristics of rainfall, which plays a key role in the occurrence and propagation of droughts (Mishra et al., 2015). Therefore, it is important to analyze rainfall trends as well as drought characteristics for water resource management and agricultural production.

Many studies have focused on the changes in annual and seasonal rainfall (Ramu et al., 2017; Poulidis and Takemi, 2017; Machiwal et al., 2017; Li et al., 2017; Latif et al., 2017; He et al., 2017; García-Barrón et al., 2015; Huang et al., 2013; Brunetti et al., 2012; Wang et al., 2011; Lebel and Ali, 2009). Similarly, the spatial and temporal characteristics of daily and monthly rainfall concentration have been studied in various parts of the world (Yesilirmak and Atatanir, 2016; Voskresenskaya and Vyshkvarkova, 2016; Shi et al., 2015; Huang et al., 2015; Benhamrouche et al., 2015; Shi et al., 2014; Huang et al., 2014; Shi et al., 2013; Suhaila and Jemain, 2012; Coscarelli and Caloiero, 2012; Cortesi et al., 2012; Li et al., 2011). Moreover, a new rainfall seasonality index was developed by Feng et al. (2013). Unlike the traditional seasonality index proposed by Walsh and Lawer (1981), this index rests on information theory, and can describe the annual distribution of rainfall and the timing and duration of the wet season based on information theory indicators (the demodulated amplitude, the demodulated phase, and the entropic spread). Rainfall seasonality was analyzed in the tropics (Feng et al., 2013), and the inter-annual variability of seasonality increased in many parts of the dry tropics, implying increasing uncertainty in the intensity, arrival and duration of seasonal rainfall. In the Pearl River Basin, annual and seasonal rainfall showed no significant changes (Liu et al., 2016a). Daily rainfall concentration was low and decreased in the southwestern and northeastern areas, and was high and increased in the northwestern and southern areas from 1960 to 2005 (Zhang et al., 2009).

Droughts occur in virtually all climatic zones as a result of abnormally dry weather that lasts long enough to produce a serious imbalance in the water cycle (Zhang et al., 2013). In recent years, droughts have been experienced with higher peaks and severity levels. The period between extreme events seems to have become shorter in certain regions (Mishra and Singh, 2010). Droughts are generally classified into four categories: meteorological drought, hydrological drought, agriculture drought, and ground water drought (Mishra and Singh, 2010). In this study, we focus on meteorological drought. A number of different indices, such as the Standardized Precipitation Index (SPI; Mckee et al., 1995) and Standardized Precipitation-evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010), have been developed to quantify meteorological drought. In the Pearl River Basin, recent years have witnessed serious droughts with high intensity and many prolonged water deficit periods, such as the severe drought in southern China in 2011 (Chen et al., 2016). The occurrence of short duration drought has also become more frequent, especially, in the Pearl River Delta (Zhang et al., 2012).

Droughts also have possible teleconnections with global climate indexes (Bazrkar and Eslamian, 2017). The teleconnection of El Nino-Southern Oscillation (ENSO) events and drought characteristics was studied in Ecuador (Vicente-Serrano et al., 2017), southern Africa (Meque and Abiodun, 2015), Northwest China (Liu et al., 2016b), Southern China (Zhang et al., 2014), United States (Mo et al., 2009; Mo and Schemm, 2008), Indonesia (Keil et al., 2008), Iran (Nazemosadat and Ghasemi, 2004), New Zealand (Fowler and Adams, 2004), and the Sahel (Janicot et al., 1996). Recently, a new global climate index, El Nino Modoki (ENSO_M), was proposed by Ashok and Yamagata (2009). ENSO_M is associated with strong anomalous warming in the central tropical Pacific and cooling in the eastern and western tropical Pacific, so ENSO_M is different from ENSO. The possible influence of ESNO_M on tropospheric aerosol concentrations (Feng et al., 2016), seasonal precipitation (Cordoba-Machado et al., 2015; Zhang et al., 2016; Salimun et al., 2014; Ratnam et al., 2014; Kim et al., 2012; Feng and Li, 2011), mid-lower stratospheric ozone (Xie et al., 2014), extremely-low discharge events (Sahu et al., 2014), Antarctic iceberg distribution (Romanov et al., 2014), tropical Atlantic sea surface temperature (Amaya and Foltz, 2014), and sea level (Behera and Yamagata, 2010; Chang et al., 2008) has been analyzed by many scholars, however, to our knowledge, no study has focused on the teleconnection of ENSO_M and drought. The mean extreme drought duration is highly affected by the warm or cool phases of ENSO across the Pearl River Basin (Xiao et al., 2016), which may be explained by the influence of ENSO on precipitation (Niu, 2013). However, the possible influences of ENSO_M events on drought evolution remain unclear in the Pearl River Basin.

Although rainfall and drought have been studied at different spatial and temporal scales, no research has focused on exploring the rainfall trends as well as the drought characteristics across the Pearl River Basin. Therefore, the objectives of this paper are to analyze: (1) the spatial and temporal patterns of daily, monthly, and seasonal rainfall; (2) the spatial and temporal characteristics of drought; and (3) the differential impacts of ENSO and ENSO_M events on seasonal drought across the Pearl River Basin. The paper is organized as follows. Section 2 presents the datasets, followed by a brief presentation of the methods in Section 3. The results and discussion are presented in Sections 4 and 5, respectively, and the main findings are summarized in Section 6.

2. Material

2.1. Study area

The Pearl River basin (Fig. 1) is located in the tropical and subtropical climate zones with annual mean temperature ranging from14 °Cto 22 °C and long-term annual average precipitation of 1525.1 mm (Zhang et al., 2012). The Pearl River basin consists of three major tributaries: the West River, the North River and the East River and the rivers within the Pearl River Delta (PRD). The PRD is the integrated delta composed of West River delta, North River delta, and East River delta (Niu, 2013). The area of PRD is about 9750 km^2.

2.2. Data

The daily precipitation and monthly temperature data observed at 48 meteorological stations from 1959 to 2012 was provided by the National Meteorological Information Center (NMIC) of the China Meteorological Administration, and was available at http://data.cma.cn/en. The data quality was strictly checked by NMIC before the dataset was released (Li et al., 2011). The homogeneity of the precipitation and temperature series was analyzed by calculating the cumulative deviation (Wang et al., 2011), and all stations used were homogeneous at the 95% confidence level. Fig. 1a shows the spatial distribution of the meteorological stations. The monthly precipitation was derived from the daily precipitation data.

The El Niño (ENSO) event can be measured by the Southern Oscillation Index (SOI), which is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia. The SOI is available at https://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/. El Niño Modoki is associated with strong anomalous warming in the central tropical Pacific and cooling in the eastern and western tropical Pacific, and is quite different from El Niño. Ashok and Yamagata (2009) applied the El Niño Modoki index (EMI) to define