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Influence of climate change on reference evapotranspiration and aridity index and their temporal-spatial variations in the Yellow River Basin, China, from 1961 to 2012

Ke-xin Zhang [a], Shao-ming Pan [a,*], Wei Zhang [a], Yi-hong Xu [a,*], Li-guo Cao [a], Yong-pei Hao [a], Yun Wang [b]

[a] *Ministry of Education Key Laboratory for Coastal and Island Development, Nanjing University, Nanjing, Jiangsu, 210023, China*
[b] *Geography and Environment College, Northwest Normal University, Lanzhou, Gansu, 730070, China*

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ABSTRACT

The non-parametric Mann–Kendall method, wavelet transform and simple linear regression were applied in this study to investigate the temporal trends and spatial distributions for reference evapotranspiration and aridity index in the Yellow River Basin, China, from 1961 to 2012. The key meteorological factors for ET_0 and AI were also evaluated. The results showed that the annual mean ET_0 had a significant declining trend at the rate of 1.29 mm per year and AI also had a slightly decreasing trend of 0.001 per year from 1961 to 2012. The abrupt change used by the M–K method revealed that the year of abrupt change for ET_0 was in 1983 and 1993, but AI did not have abrupt change from 1961 to 2012. The spatial distributions of the average annual ET_0 exhibited a declining trend from northeast to southwest over the study region. The spatial change trends for AI were similar to ET_0, which the decreasing trends were located in the most parts of YRB. Furthermore, the correlation coefficient analysis indicated that the change of sunshine hours was the major factors influencing the variability of ET_0, followed by wind speed. However, the dominating factor of AI was relative humidity, followed by precipitation. The significant wavelet power spectra of ET_0 were 4–6 year and 12–15 year and there were obvious periodic oscillations of 4–6 year, 8–12 year and 18–22 year for AI. The periodic variation of ET_0 was similar in some degree with that of AI and both of them had the comparable main periods.

1. Introduction

Global climate changes and intensified human activities have induced significant impacts on ecological environments, such as the high frequency of drought disasters and drying-up in many river basins (Xu et al., 2007; Zhang et al., 2009a, b). Changes in climatic factors also affected all elements of hydrologic cycle, such as precipitation, evapotranspiration, runoff, and groundwater flow in a variety of ways. In addition to the effects on runoff through the changes of temperature and precipitation, climate change influences evaporation to a high degree (Zhang et al., 2011). Reference evapotranspiration (ET_0) is one of the key indicators of atmospheric evaporating capability over a hypothetical reference surface and it is the theoretical upper limit of actual evapotranspiration, which is usually the basis of the actual evapotranspiration (Zhang et al., 2009a, b). Additionally, ET_0 is also a factor determining climatic drought in some regions (Huo et al., 2013). Under the influences of average global temperature increases, it is universally accepted that the air near Earth's surface will become drier and evaporation from terrestrial open water bodies will increase. However, despite the observed increases in average temperature, observations indicated that the rate of pan evaporation has been steadily declined in most parts of the world in the past several decades (Peterson et al., 1995; Roderick and Farquhar, 2002). The phenomenon that the global temperature increases and ET_0 decreases take place simultaneously is called the pan evaporation paradox (Roderick and Farquhar, 2002). Numerous investigations have verified this paradox in many parts of the world (Peterson et al., 1995; Chattopadhyay et al., 1997; Garcia et al., 2004; Hobbins et al., 2004; Michael and Graham, 2004; Roderick and Farquhar, 2005; Zhang et al., 2009a, b; Yin et al., 2010; Liu et al., 2010a, b; Zhang et al., 2011; Irmak et al., 2012). However, ET_0 has increased in semi-arid Iran for the same period

* Corresponding authors.
E-mail addresses: span@nju.edu.cn (S.-m. Pan), yhxu@nju.edu.cn (Y.-h. Xu).

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(Tabari, 2010). On the basis of the supplementary theory, the decline in actual evapotranspiration will lead to the increase of ET_0. Many studies (Peterson et al., 1995; Cohen et al., 2002; Roderick and Farquhar, 2002; Zhang et al., 2009a, b; Irmak et al., 2012) indicated that the change of ET_0 in the context of climate change is based not only on temperature but also on relative humidity, solar radiation and wind speed in different regions of the world.

In recent years, extensive research has shown that global climate variation increases drought and changes rainfall patterns and hydrologic cycle (Zhang et al., 2008a, 2009a, b). These results will undoubtedly contribute to a better understanding of increasing flood and drought disasters over the world. ET_0 and precipitation largely determine annual evapotranspiration and runoff rates in a region (Arora, 2002). The aridity index (AI), which describes the evaporation ratio, can be used to estimate change in runoff given annual changes in precipitation and ET_0. Consequently, it is a scientific and practical advantage to understand changing characteristics of dry-wet variations for improving integrated water resource management and management of water-related natural hazards at the basin scale. Aridity-humidness variations were predicted for some areas in some models which estimated that drought would continue in critical agricultural regions. Although some significant evidence of extreme drought/wetness was found by extreme precipitation (Frich et al., 2002; Zhai and Pan, 2003; Li et al., 2012), these studies only considered the influence of temperature and precipitation variation on aridity-wetness, and could not show the influence of relative humidity, solar radiation and wind speed on drought, especially under global warming.

The Yellow River Basin (YRB) is not only the important source for water supply in Northern China but also an area of shortage of water resources. Evaporation has a significant impact on availability of water resources in the YRB. The changes of spatial and temporal distribution of ET_0 and AI will further alter the water resources in the YRB. Therefore, to investigate and assess the influence on the climate change about ET_0 and AI will help understand the relationships between climate and hydrological processes and provide reasonable water regulation and management-options to maintain the eco-hydrological system in the YRB.

The key purpose of this study was to identify the changes of spatial and temporal variations in ET_0 and AI in the YRB from 1961 to 2012 using simple linear regression, Mann–Kendall test, and Wavelet transform, and to provide a framework assessing the relative contributions of climatic factors for ET_0 and AI over the study area. This can provide valuable information to policymakers and researchers and play an important role in assessing and predicting the influence of dryness-humidness in the YRB.

2. Study area and methods

2.1. Study area and data

The Yellow River (32°10′–41°50′ N; 95°53′E–119°5′E), which has a length of 5464 km with a basin area of 752,443 km^2, is the second largest river in China and the fifth largest river in the world, mainly flowing through arid or semi-arid regions (Zhang et al., 2008b). The Yellow River, beginning in the Tibetan Plateau, flows through the Loess Plateau and North China Plain, finally reaching the Bohai Sea (Fig. 1). The YRB shows various features of geological and climate characteristics. From northwest to southeast, the basin is characterized by the Tibet Plateau with elevations from 2000 to 5, 000 m, the Loess Plateau with elevations from 500 to 2000 m and the alluvial plain (McVicar et al., 2007; Wang et al., 2013). The average annual temperature and precipitation ranges from 4 to 14 °C and is about 466 mm, respectively. The Yellow River is well known not only for its history and large drainage area but also for its severe soil erosion, frequent floods, and serious droughts. In recent years, the Yellow River has become a seasonal river with frequent occurrence of drying up. The most serious drought happened in 1997 with drying up for more than 226 days over the section close to the sea (Cong et al., 2009). The eco-environment and hydrological processes have worsened as result of the climatic change and human activities. In order to restore the vegetation cover and reduce the soil erosion, several projects have been implemented in the YRB (Liu et al., 2010b), which also changed the eco-hydrological processes.

In this paper, data for the 1961 to 2012 period are provided by the National Meteorological Information Center of China Meteorological Administration (available at www. nmic.gov.cn/). According to the standards whereby observed data are continuous and data series are as long as possible, 65 meteorological stations have been collected in the YRB. Seven meteorological variables were recorded including daily mean wind speed at 2 m, air temperature, maximum and minimum air temperature, relative humidity, precipitation, and sunshine hours. The ET_0 and AI of the regional annual series calculated as the arithmetic mean at 65 stations over the YRB. These data are used for calculating ET_0 and AI, analyzing the trends and impacts of climate factors on AI as well.

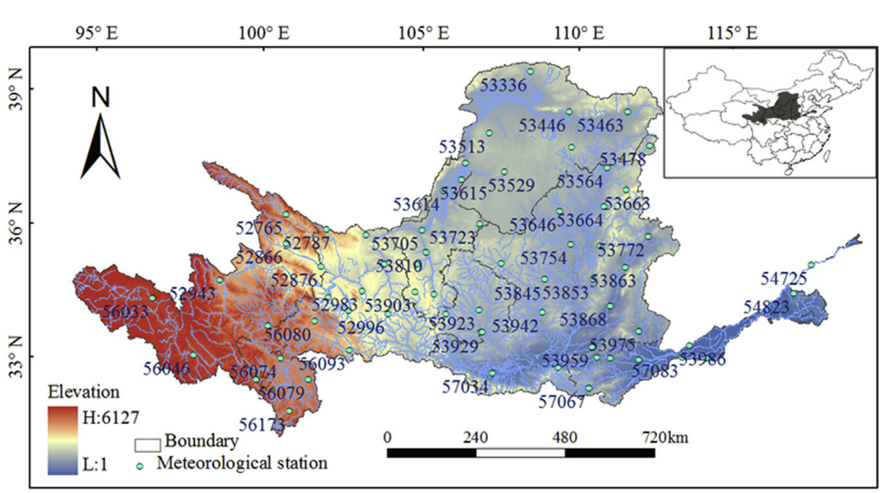

Fig. 1. DEM and location of meteorological stations in the YRB.