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Temporal variations of reference evapotranspiration and its sensitivity to meteorological factors in Heihe River Basin, China

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Abstract

On the basis of daily meteorological data from 15 meteorological stations in the Heihe River Basin (HRB) during the period from 1959 to 2012, long-term trends of reference evapotranspiration (ET_0) and key meteorological factors that affect ET_0 were analyzed using the Mann-Kendall test. The evaporation paradox was also investigated at 15 meteorological stations. In order to explore the contribution of key meteorological factors to the temporal variation of ET_0, a sensitivity coefficient method was employed in this study. The results show that: (1) mean annual air temperature significantly increased at all 15 meteorological stations, while the mean annual ET_0 decreased at most of sites; (2) the evaporation paradox did exist in the HRB, while the evaporation paradox was not continuous in space and time; and (3) relative humidity was the most sensitive meteorological factor with regard to the temporal variation of ET_0 in the HRB, followed by wind speed, air temperature, and solar radiation. Air temperature and solar radiation contributed most to the temporal variation of ET_0 in the upper reaches; solar radiation and wind speed were the determining factors for the temporal variation of ET_0 in the middle-lower reaches.
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Keywords: Reference evapotranspiration; Evaporation paradox; Meteorological factor; Heihe River Basin

1. Introduction

Evapotranspiration plays an important role in the hydrological cycle as well as the global energy budget. It contributes 2/3 of annual precipitation and has an essential influence on the Earth's climate system (Jayawardena, 1989; Chahine, 1992; Zhan et al., 2011; Zuo et al., 2012; Duhan et al., 2013). In addition, evapotranspiration is a key input to hydrological models (Liang et al., 1994; Gerten et al., 2004; Zhao et al., 2013). Therefore, a comprehensive understanding of temporal trends and spatial distribution of evapotranspiration is highly significant to water resource management, especially in places where the water availability is limited.

Global warming has been one of the most concerning issues for governments. As reported in the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC), the surface temperature of the Earth has increased by about 0.13 °C per decade over the past 50 years (IPCC, 2007). This has significant impacts on environmental systems, by causing glaciers to melt, the sea level to rise, etc. Global warming also breaks the balance of eco-systems and threatens food supplies. Some studies on climate change have predicted that one of the phenomena that global warming will bring about is an increase in the rate of evaporation from terrestrial open water bodies, which will enhance the scarcity of water resources in arid regions (Jackson, 2001; Scheffer et al., 2001; Yang et al., 2009; Jayantha et al., 2011; Sjoegersten, 2013).

Observed pan evaporation data have revealed the fact that evaporation from open water bodies has been decreasing over the past several decades in different regions around the world

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(Brutsaert et al., 1998; Gao et al., 2012; Yesihrmak, 2013), including Australia (Roderick and Farquhar, 2004), Canada (Aziz and Burn, 2006), Eurasia (Velichko et al., 2008), China (Cong et al., 2009), and India (Rao and Wani, 2011). The contrast between the increase in air temperature and the decrease in observed pan evaporation rate is referred to as the evaporation paradox (Roderick and Farquhar, 2002). Furthermore, a similar decreasing trend of reference evapotranspiration (ET_0) was also found by Thomas (2000) and Roderick and Farquhar (2004).

In order to investigate the evaporation paradox, many studies have been carried out. Generally, these studies can be divided into two categories. One includes studies meant to determine the key factors that impact pan evaporation and ET_0 and analyze variations of these key factors so as to explain the reason why pan evaporation and ET_0 have decreased over the past several decades. The other includes studies that focus on determining whether decreasing pan evaporation or ET_0 definitely leads to the decrease in actual evapotranspiration. Studies concerning spatial and temporal variations in pan evaporation and ET_0 have been carried out by researchers worldwide. Gao et al. (2006) studied spatial and temporal variations in ET_0 at 580 stations in China during the period from 1956 to 2000, and, through a partial correlation analysis, the study determined that sunshine duration, wind speed, and relative humidity have a significant impact on ET_0. Wang et al. (2014) analyzed the relationship between the variations of ET_0 and each climatic variable at Linhe Station, a representative weather station in the Hetao Irrigation District of China, during the period from 1954 to 2012. The results showed that ET_0 in the Hetao Irrigation District is most sensitive to mean daily air temperature, followed by wind speed. Changes in sunshine duration had only a minor effect on ET_0 during the study period. Recent analysis from Wang et al. (2012) indicated that the aerodynamic component of ET_0 accounted for 86% of the long-term changes in global ET_0 from 1973 to 2008. However, Matsoukas et al. (2011) showed the opposite conclusion: trends in ET_0 more closely followed trends in energy availability than trends in atmospheric holding capability for vapor transfer.

These studies have come to quite different conclusions in different regions, indicating a need for new methods to identify the most important meteorological factors in explaining changes in ET_0 at the regional level. Besides, most of these studies focused on the theoretical sensitivity of ET_0, which is the expected variation of ET_0 due to changes in variables under the assumption that only one variable changes while other variables remain the same. In fact, the theoretical sensitivity of ET_0 does not consider the actual changes in meteorological variables. However, the explanation of meteorological factors controlling changes in ET_0 must consider both the sensitivity of and long-term changes in the meteorological factors themselves.

In this study, overall analysis of the variation of ET_0 in the arid region in northwestern China was carried out. The study mainly focused on both the temporal trends of annual and seasonal ET_0 and quantitative analysis of the contributions of different meteorological variables to the variation of ET_0. The objectives of this study included: (1) to detect the long-term trends in ET_0 and air temperature using the Mann-Kendall (M-K) test; (2) to investigate the evaporation paradox at 15 stations by comparing the changing trends in annual ET_0 with the changing trends in air temperature, in order to compensate for the lack of pan evaporation data in the Heihe River Basin (HRB), because Zuo et al. (2010) found a linear relationship between pan evaporation and ET_0 in northwestern China and a coefficient of determination greater than 0.97, verifying the rationality of using the variation of ET_0 to reflect the variation of pan evaporation in this study; and (3) to quantify the contribution of key meteorological factors (air temperature, solar radiation, relative humidity, and wind speed) to the variation of ET_0 and explain the reason for the evaporation paradox using the sensitivity coefficient method.

2. Study area and data

2.1. Study area

The HRB, covering an area of approximately 134 000 km^2, is the second largest inland river basin in northwestern China and spans Qinghai and Gansu provinces as well as the Inner Mongolia Autonomous Region from upper reaches to lower reaches. The HRB is located between latitude 37.50°N and 42.40°N, and longitude 98°E and 102°E (Fig. 1).

The HRB is situated in the interior of the Eurasian continent and dominated by arid hydrological characteristics with a mean annual precipitation of approximately 400 mm and a mean annual ET_0 of approximately 1 600 mm. The precipitation, temperature, evaporation, and runoff in the HRB vary greatly at both spatial and temporal scales. The dominant land use types are desert land and grass land, occupying approximately 60% and 25% of the total area, respectively. Due to its important role in water resources management in northwestern China, the HRB has long been a focus of studies on inland rivers in arid regions.

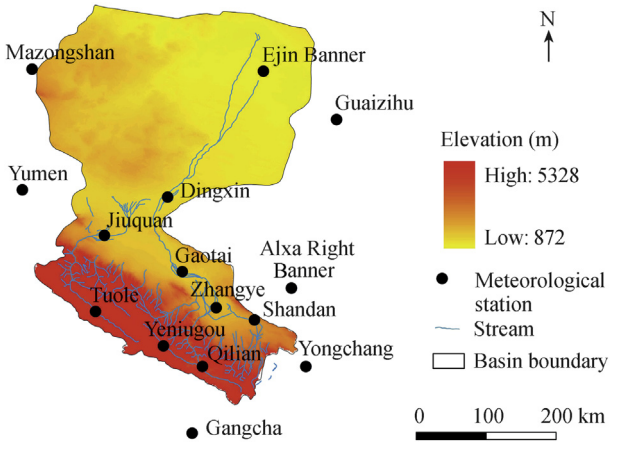

Fig. 1. Meteorological stations in and around HRB.

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