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Trends in reference evapotranspiration and their causative factors in the West Liao River basin, China

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ABSTRACT

In this study the daily reference evapotranspiration (ET_{ref}) was estimated through the Penman-Monteith method at 15 meteorological stations in the arid and semi-arid area of the West Liao River basin of China from 1960 to 2012. The characteristics of the seasonal and annual variation and the spatial distribution of ET_{ref} through the Cokriging (spherical) interpolation methods were analyzed. The trends of seasonal and annual ET_{ref} and meteorological factors were investigated using the Mann-Kendall test after eliminating the effect of significant lag-1 serial correlation by trend-free pre-whitening. Moreover, the major meteorological factors affecting ET_{ref} using stepwise regression and partial correlation analysis were investigated. Results showed that: (1) The decreasing degree of ET_{ref} at 46.7% stations is larger than the increasing degree of ET_{ref} at 53.3% stations, which resulted in the decreasing trends of ET_{ref} during the study period. The magnitude of the negative trend in annual average ET_{ref} was 0.28 mm yr^{-1}; (2) a significant overall increase in air temperature, a significant decrease in wind speed, solar radiation, sunshine duration, and relative humidity was observed; (3) ET_{ref} was larger for the plain area and gradually decreased toward the surrounding areas. It was smaller for the mountain area. ET_{ref} has obvious zonal effect; (4) There was a significant negative correlation between ET_{ref} and relative humidity while ET_{ref} has a significant positive correlation with other factors ($p < 0.05$). In annual time scale, solar radiation was found to be the most dominant variable influencing ET_{ref}, however, in seasonal time scale, average air temperature, maximum air temperature, relative humidity were the most dominant factors in spring, summer and winter, and autumn, respectively. Wind speed was the second most significant factor in all seasons. The results of this study support the conclusion that the evapotranspiration decreases over the West Liao River basin are controlled mainly by trends in the radiative component.

1. Introduction

Evapotranspiration is an important step and key variable in the hydrologic cycle process (Xu et al., 2006). It determines groundwater recharge, surface runoff, soil moisture and plant growth (Thomas, 2008), which is essential to the available water resources (Komatsu et al., 2008). Moreover, it is part of the water balance and surface heat balance, and ground heat and moisture balance which largely determine the weather and climate change, and the formation and evolution of the geographical environment. Reference evapotranspiration (ET_{ref}) is a type of potential evapotranspiration, defined as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground" (Allen et al., 1998). Many methods exist to estimate the ET_{ref} (Xu and Singh, 2001), including (1) water budget, (2) mass-transfer, (3) combination, (4) radiation, and (5) temperature-based. The more precise and more widely used method is the Penman-Monteith method (e.g., Goyal 2004; Dinpashoh et al., 2011; Jhajharia et al., 2014; Gao et al., 2015), as recommended by the Food and Agriculture Organization of the United Nations (Allen et al., 1998).

Research has shown that global warming occurred in the past one hundred years (IPCC, 1996; Barnett et al., 2005; Hansen et al., 2005). The global average surface temperature has increased by 0.74 °C (IPCC, 2007) and will increase by 1–5 °C in China by the end of the 21st century (Piao et al., 2010). The majority of evapotranspiration trends are decreasing despite globally rising temperatures (McVicar et al., 2012). Brutsaert and Parlange (1998) and Roderick and Farquhar (2002) named such phenomenon the "evaporation

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paradox" and it is a very important scientific problem. Studies have shown that in the past several decades pan evaporation (E_{pan}) and ET_{ref} decreased in many areas around the world (Golubev et al., 2001; Roderick and Farquhar, 2004; Irmak et al., 2012; Jhajharia et al., 2012). Similarly, evapotranspiration decreases in most places in China as well (Thomas, 2000; Gao et al., 2006; Huo et al., 2013). Other similar results were also reported for the Yangtze River basin, northern regions, and Tibetan Plateau of China (Xu et al., 2006; Zhang et al., 2007; Song et al., 2010). However, there are a few studies reported the increase of ET_{ref} in Asia (Sabziparvar et al., 2010; Tabari, 2010; Tabari et al., 2011; Wang and Wang, 2012; Tabari and Aghajanloo, 2013) and in Europe (Chaouche et al., 2010; Domenico et al., 2011).

Many investigators have also studied the reasons for the change in evapotranspiration across different regions of the world. Climate change was thought to be the major influencing factor in the past half century, but the effect on evapotranspiration due to different climate factors is very different (Zuo et al., 2005; Roderick et al., 2007; Liu et al., 2010; McVicar et al., 2012; Jhajharia et al., 2014). Especially Roderick et al. (2007), Vautard et al. (2010), McVicar et al. (2012) pointed out the factor of decreasing of land surface wind speed. On the other hand, the increase of the amount of cloudiness, which is caused by the decrease of global solar irradiance, urbanization and the increased air pollution and aerosols concentration are also factors that contribute the change in evapotranspiration (Peterson et al., 1995; Roderick and Farquhar, 2002; Roderick and Farquhar, 2004; Zhang et al., 2011a; Zhang et al., 2011b). But from a global perspective, the radiation decrease caused by the increase of cloudiness or aerosol is the main cause of the decrease of ET (McVicar et al., 2012).

In summary, the ET_{ref} change is a combined result of a variety of factors. But the dominant factor is different in different regions and at different scales. Furthermore, few studies are available in the literature on the trend analysis of seasonal and annual ET_{ref} and the major meteorological factors affecting ET_{ref} in the farming-pastoral West Liao River basin of China. The important component of hydrologic cycle and the effect of climate change on ET_{ref} is unclear either. Therefore, a new approach to explain the influence of meteorological factors on the changes of ET_{ref} is needed. The purposes of this study are as follows: (1) to estimate ET_{ref} using the Penman-Monteith method at annual and seasonal time scales over the West Liao River basin under the arid and semi-arid climatic conditions from 1960 to 2012; (2) to analyze and discuss the changing characteristics of annual and seasonal ET_{ref} and its dependent meteorological factors using the Mann-Kendall nonparametric test after eliminating the influence of significant lag-1 serial correlation over the past 53 years; (3) to analyze the spatial distribution of ET_{ref} through data interpolation using Cokriging; and (4) to identify the most dominating meteorological variables affecting ET_{ref} using multiple stepwise linear regression and partial correlation analysis.

2. Material and methodology

2.1. Description of the study area and data processing

The West Liao River basin is in Northeast China and its specific geographic position is between 116°36′–124°34′E and 41°05′–45°12′N (Fig. 1) including part of Liaoning, Jilin, Hebei province, and Inner Mongolia. The West Liao River is one of the main tributaries of the Liao River and its drainage area is 1.36×10^5 km^2. The average annual precipitation is about 376 mm, concentrated in July and August. The spatial distribution of average annual precipitation is shown in Fig. 1, which reflects the combined effects of the climatic conditions and topographic characteristic across the West Liao River basin, but the precipitation is not evenly distributed within the year. It clearly shows that the precipitation decreases from the southeast to the northwest and low rainfall area occurs centering at the Kailu station. The climate is a temperate continental monsoon type with annual mean air temperature of 5.0 °C to 6.5 °C in the basin. The average air temperature in July and August is 22.8 °C and 21.1 °C (Gao et al., 2015), respectively. Meanwhile, this area is located on the world's three largest "golden maize belts" (Zhao et al., 2015), which is a high maize production zone. Therefore, the study of evapotranspiration in this region of important agricultural base will play an important role in corn production (Zhao et al., 2015).

In this study, the meteorological data were obtained from 15 stations from January 1960 to December 2012 in the West Liao River

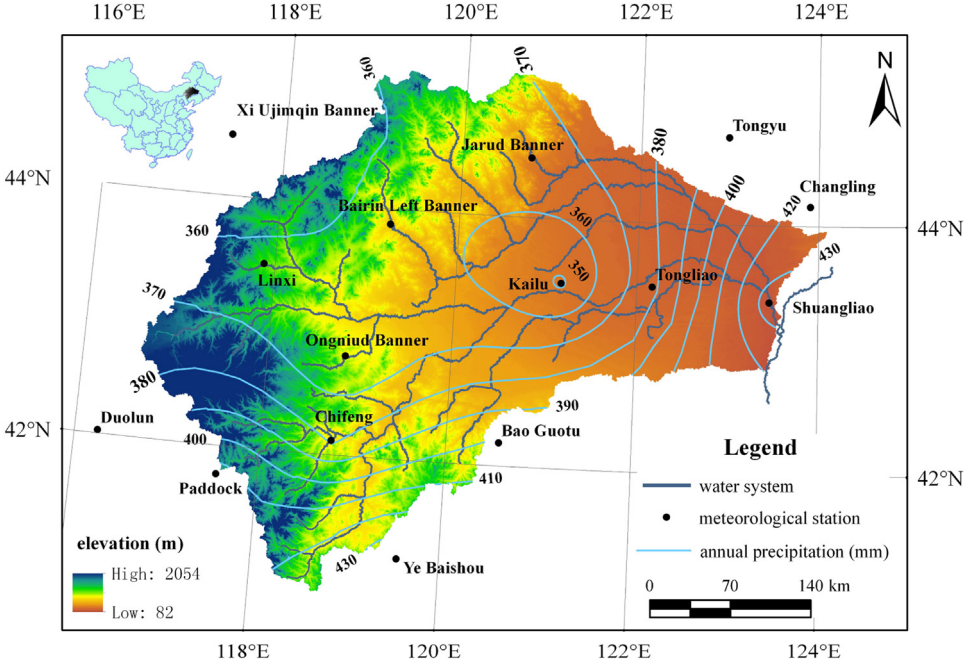

Fig. 1. The spatial distribution of digital elevation model, the meteorological stations and precipitation during 1960–2012 in the study.