Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Influences of removing linear and nonlinear trends from climatic variables on temporal variations of annual reference crop evapotranspiration in Xinjiang, China

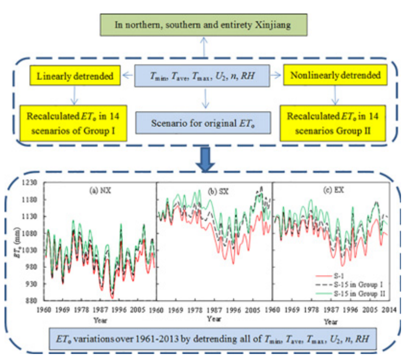
Yi Li [a,*], Ning Yao [a], Henry Wai Chau [b]

[a] College of Water Resources and Architecture Engineering, Northwest Agriculture and Forestry University, Yangling, Shaanxi 712100, China
[b] Department of Soil and Physical Sciences, Faculty of Agriculture and Life Science, Lincoln University, Lincoln, Canterbury 7647, New Zealand

HIGHLIGHTS

- Removing climatic variable trends increased reference crop evapotranspiration (ET_o).
- ET_o changes were more convincible when climatic variables were nonlinearly detrended.
- ET_o obtained from the detrended CVs caused different variations of drought severity.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 October 2016
Received in revised form 7 February 2017
Accepted 24 February 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Reference crop evapotranspiration
Temporal variation
Climatic scenario
Detrended climatic variable
Xinjiang

ABSTRACT

Reference crop evapotranspiration (ET_o) is a key parameter in field irrigation scheduling, drought assessment and climate change research. ET_o uses key prescribed (or fixed or reference) land surface parameters for crops. The linear and nonlinear trends in different climatic variables (CVs) affect ET_o change. This research aims to reveal how ET_o responds after the related CVs were linearly and nonlinearly detrended over 1961–2013 in Xinjiang, China. The ET_o-related CVs included minimum (T_{min}), average (T_{ave}), and maximum air temperatures (T_{max}), wind speed at 2 m (U_2), relative humidity (RH) and sunshine hour (n). ET_o was calculated using the Penman-Monteith equation. A total of 29 ET_o scenarios, including the original scenario, 14 scenarios in Group I (ET_o was recalculated after removing linear trends from single or more CVs) and 14 scenarios in Group II (ET_o was recalculated after removing nonlinear trends from the CVs), were generated. The influence of U_2 was stronger than influences of the other CVs on ET_o for both Groups I and II either in northern, southern or the entirety of Xinjiang. The weak influences of increased T_{min}, T_{ave} and T_{max} on increasing ET_o were masked by the strong effects of decreased U_2 & n and increased RH on decreasing ET_o. The effects of the trends in CVs, especially U_2, on changing ET_o were clearly shown. Without the general decreases of U_2, ET_o would have increased in the past 53 years.

Abbreviations: CV, climatic variable; ET_o, reference crop evapotranspiration; T, air temperature; T_{min}, minimum T; T_{ave}, mean T; T_{max}, maximum T; U, wind speed; U_2, U at 2 m; RH, relative humidity; n, sunshine hour; P, precipitation; NX, northern Xinjiang; SX, southern Xinjiang; EX, entire Xinjiang; EEMD, ensemble empirical mode decomposition; MK, Mann-Kendall; MMK, modified MK; Z, MK statistic; Z_m, MMK statistic; SQMK, sequential Mann-Kendall; S, scenario; b, Sen's slope; RS, regression slope; Y_{AC}, year with an abrupt change; P_{sl}, significant level; G, soil heat flux; e_a, actual vapor pressure; e_s, saturation vapor pressure; Δ, slope of vapor pressure curve; γ, psychrometric constant; R_n, net radiation; SD, standard error, RMSE-root mean square error.

* Corresponding author.
E-mail address: liyikitty@126.com (Y. Li).

http://dx.doi.org/10.1016/j.scitotenv.2017.02.196

Due to the non-monotone variations of the CVs and ET_o, the results of nonlinearly detrending CVs on changing ET_o in Group II should be more plausible than the results of linearly detrending CVs in Group I. The decreasing ET_o led to a general relief in drought, which was indicated by the recalculated aridity index. Therefore, there would be a slightly lower risk of water utilization in Xinjiang, China.

1. Introduction

The global average land surface temperature increased by 0.85 °C in the period from 1880 to 2012 (IPCC, 2013). Faced with the challenges of global warming, it is crucial to know how the water availability and the agricultural water demands change, as a function of reference crop evapotranspiration (ET_o) variation (Espadafor et al., 2011). ET_o is widely used for water scheduling of irrigation areas and uses key prescribed (or fixed or reference) land surface parameters for crops. Accurate estimation of ET_o is needed for field irrigation scheduling (Allen et al., 1998), drought assessment (Budyko, 1974) and climate change research (Tabari and Hosseinzadeh Talaee, 2014). The available models for estimating ET_o include temperature-based approaches (Blaney and Criddle, 1952; Hargreaves and Samani, 1985; Thornthwaite, 1948), radiation-based approaches (Slatyer and McIlroy, 1961) and combination approaches (Allen et al., 1998; Priestley and Taylor, 1972). Following an extensive analysis of different ET_o methods in many world-wide locations, the Penman-Monteith (PM) approach was unanimously accepted as a standardized approach endorsed by the Food and Agricultural Organization (Allen et al., 1998; McVicar et al., 2007).

In the context of global warming, the trend of ET_o was found to have increased or decreased in different regions of the world. Increasing trends of ET_o were observed in Iran (Tabari et al., 2011, 2012) and southern Spain (Espadafor et al., 2011). However, a decreasing ET_o trend was reported for India (Chattopadhyay and Hulme, 1997). ET_o at many places in China have decreased (see detail in Table 6 from McVicar et al., 2007). Trends in ET_o have decreased in northwest and southeast regions (Thomas, 2000), the Yangtze River Basin (Xu et al., 2006), part of the Yellow River Basin (Liu and Yang, 2010), Tibet Plateau (Liu et al., 2011), and the Haihe River Basin (Tang et al., 2011). The increase or decrease of ET_o were mainly caused by the increase or decrease of climatic variables (CVs), which are necessary for estimating ET_o. These variables include air temperature (T), wind speed (U), relative humidity (RH), and radiation or sunshine hour (n) in the absence of radiation. The influences of CVs on ET_o, which also potentially reflect the effects of climatic change on ET_o, have been investigated regionally or globally (McVicar et al., 2012; Xu et al., 2006).

There are different ways for assessing the influences of CVs on ET_o. One way is to conduct a sensitivity analysis. This is done by determining the corresponding changes of ET_o after adding different percentages of the CVs or by calculating the sensitivity coefficient (Goyal, 2004; Lenhart et al., 2002; McKenney and Rosenberg, 1993). Because ET_o is a multi-factor parameter, its sensitivity varies with various CVs. Moreover, other factors, such as geological locations and the calculation models, also affect its sensitivity. Another way is to analyze the ET_o series re-estimated by the detrended CVs such as previous studies investigating the influences of detrended CVs on ET_o in the Changjiang River Catchment during 1970–2000 (Xu et al., 2006) and in northwestern China (Huo et al., 2013). However, their results only showed the influences of single CV on ET_o, not the simultaneous influences of multiple variables on ET_o. Because CVs change simultaneously, even the minimum, mean and maximum T (T_{min}, T_{ave} and T_{max}) increased with different patterns, not to mention the other CVs. It is not sufficient to only know the influences of single CV on ET_o. Previous research has not distinguished the ability of various Ts (T_{min}, T_{ave} and T_{max}) on influencing ET_o. Moreover, not only removing linear trends from CVs is executable and referable, but also removing nonlinear trends in CVs is necessary because most CVs vary nonlinearly with time. There is limited research that compares the influences of removing linear trends and nonlinear trends from various CVs on ET_o.

The effects of climate change on ET_o in northwestern China have been studied by Huo et al. (2013) using data obtained from 23 weather stations. The linear trends of T, RH, solar radiation and U were removed, and the detrended CVs were used for re-estimating ET_o. Their results showed that the contribution of the decline in U to the decrease in ET_o is larger than that of other meteorological variables. This study investigates the effects of removing linear and nonlinear trends from the annual CVs (including T_{min}, T_{ave}, T_{max}, RH, U and n) on the temporal variations of annual ET_o in Xinjiang, China. Our aims are to: i) assess the importance of each CV to ET_o for northern (NX), southern (SX) and the entirety of Xinjiang (EX); ii) to compare the differences in removing the trends from single, double and multi-CVs in various scenarios for each sub-region, and to distinguish the influences of various T-factors (T_{min}, T_{ave} and T_{max}) and non-T-factors (U_2, RH and n) on changing ET_o; and iii) to clearly show how the CVs affect ET_o in Xinjiang by comparing the original and recalculated ET_o series using the linear and nonlinear detrended CVs.

2. Data and methodology

2.1. The study sites and the data sets

The Xinjiang Uygur Autonomous Region is located in inland area of northwestern China. Xinjiang is surrounded on three sides by mountains and is distant from any sea (Li et al., 2016). The multiyear mean ratio of precipitation (P) (147 mm) to ET_o (1512 mm) is 0.1 (Li and Sun, 2016); therefore, the region was classified as an arid zone according to Erinç (1965). A total of 53 weather stations in Xinjiang, China were selected as study sites (Fig. 1). The observed monthly weather data were collected from the Meteorological Data Sharing Service Network in China, with strict quality control. Elevations of the selected sites ranged between 30 and 3095 m. The data duration was from 1961 to 2013 with the completeness larger than 99.7%. Missing data were interpolated linearly with the neighboring months. The belt along Tuergate – Aheqi – Bayinbuluke – Urumqi – Qitai – Qijiaojing – Balikun – Zhuomaohu, which belongs to NX, was set as the border of NX and SX. There were 27 sites in NX and 26 sites in SX, respectively.

2.2. Estimation of reference crop evapotranspiration

The Penman-Monteith equation (Allen et al., 1998) is used here for estimating ET_o (mm):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{ave} + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where G is soil heat flux (MJ m^{-2} day^{-1}), T_{ave} is for 2 m (°C), U_2 is U at 2 m (m/s), e_s is saturation vapor pressure (kPa), $e_s - e_a$ is saturation vapor pressure deficit (kPa), Δ is slope of vapor pressure curve (kPa $°C^{-1}$), γ is psychrometric constant (kPa $°C^{-1}$), R_n is net radiation (MJ m^{-2} day^{-1}) and calculated with n following Allen et al. (1998). Monthly G is estimated by

$$G_M = 0.07(T_{M+1} - T_{M-1}) \quad (2)$$

Please cite this article as: Li, Y., et al., Influences of removing linear and nonlinear trends from climatic variables on temporal variations of annual reference crop evapotr..., Sci Total Environ (2017), http://dx.doi.org/10.1016/j.scitotenv.2017.02.196