Journal of Hydrology 524 (2015) 696–700

Contents lists available at ScienceDirect

Journal of Hydrology

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

Technical Note

How large are uncertainties in future projection of reference evapotranspiration through different approaches?

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ARTICLE INFO

Article history:
Received 7 January 2015
Received in revised form 12 March 2015
Accepted 14 March 2015
Available online 21 March 2015
This manuscript was handled by G. Syme, Editor-in-Chief

Keywords:
Reference evapotranspiration
Projection
Uncertainties

SUMMARY

As the indicator of atmospheric evaporative demand over a hypothetical reference surface, reference evapotranspiration (ET_0) is an important input to hydrological models. Future projections of ET_0 are of great importance in assessing the potential impacts of climate change on the hydrologic regime as well as water resources systems. Different estimating formulations and different input data reliabilities existing in practice determine there may be potential uncertainty in projection of future ET_0 change. Here we investigated the difference of future ET_0 response to climate change based on three approaches, i.e., more physically based Penman–Montieth equation with relatively uncertain downscaled data quality, more empirical temperature-based Hargreaves equation with more reliable downscaled input data, and statistical downscaling method with directly selecting ET_0 as predictands. The Hanjiang River Basin, a headwater source of famous South to North Water Diversion Project (SNWDP) in China was chosen as example to illustrate this issue. Although similar increase processes of ET_0 in the Hanjiang River Basin were suggested by three methods, the magnitude of ET_0 increase differs substantially, indicating that uncertainty still exist despite of approximate performance of these methods in simulating general trends. Whilst increasing aridity index and decreasing water surplus over the period of 2011–2099 would inevitably cause negative impacts on the implementation of the SNWDP and effective adapting measures are thus expected.

1. Introduction

As the only term connecting energy balance and water balance, evapotranspiration is the most excellent indicator for the changing behavior of climate and hydrological regime (Wang et al., 2012). Reference evapotranspiration (ET_0), defined as the evaporation occurring from a land surface with "reference crop (usually assumed as short, complete and green plant cover)" on soil condition with sufficient water available (Allen et al., 1998), is the important input within hydrological modeling. Consequently, reliable estimates of future ET_0 form the basis of assessing hydrological response to changing climate condition (Xu et al., 2006), especially in the background that the climate change effects become more pronounced (Bates et al., 2008). From the temperature-based formulation to the physically-based ones, there are numerous different methods with various complexities for the estimation of ET_0. Among them, the Penman–Monteith (PM) method is always considered to the most reliable one for various climatic conditions and recommended by the Food and Agricultural Organization of the United Nations (FAO) due to its physically based characteristic with incorporating both physiological and aerodynamic parameters (Xu et al., 2006).

However, the use of PM method was always limited due to insufficient meteorological data. Particularly, in the projection of future ET_0, not all the climatic variables required for the physically based equation are available from climate models including GCMs and RCMs. Therefore, simplified and empirical methods requiring less data are always compelled to employ in many insufficient data region and are proved to give reliable estimation of ET_0 in certain climatological condition (e.g., Federer et al., 1996; Lu et al., 2005). While physically-based methods are more reliable compared with temperature-based ones (Roderick et al., 2009), the GCM-simulated temperature was also widely considered to have relatively high confidence in comparison with vapour

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http://dx.doi.org/10.1016/j.jhydrol.2015.03.033
0022-1694/

pressure, wind speed and cloud cover (Randall et al., 2007), which are the basic factors for driving physically-based methods. In practice, we are in a dilemma on the ET_0 projection: should we use more reliable physically-based methods (e.g., Penman–Monteith) but with insufficient or uncertain data quality, or should we employ more empirical methods (e.g., temperature-based methods) with more reliable input data. In addition, the simulation of ET_0 using statistical downscaling method by establishing the "black box" relationship between ET_0 and large-scale atmospheric predictors is also an alternative. (e.g., Li et al., 2012; Wang et al., 2013). Future ET_0 projections are thus subject to the method selections. However, systematic investigations on the performance of different projection methods estimating future ET_0 are scarce. To address this research gap, this paper compared the change patterns of future ET_0 in the Hanjiang River Basin, a headwater source for the middle route of the well-known South-to-North Water Diversion Project (SNWDP) in China, calculated from three different approaches (i.e., more physically based PM equation with relatively uncertain downscaled data quality, more empirical temperature-based Hargreaves equation with more reliable downscaled input data, and statistical downscaling method with directly selecting ET_0 as predictands). Meanwhile, as the important implication of future ET_0 changes and significance to SNWDP, the future estimation of regional water resources is also performed by investigation of the aridity index and regional water surplus.

2. Materials and methods

The Hanjiang River, the biggest tributary of the Yangtze River with a drainage area of 170,400 km^2, is the source of water for the middle route of the SNWDP, which aims to mitigating the water crisis in North China due to rapid development of the economy and the explosion of the city population by long distance transferring water from the south to the north (Stone and Jia, 2006; Chen et al., 2007). It is therefore of great importance to investigate the future water surplus in relation to the climate variability in this region. Time series of the daily records for air maximum temperature, minimum temperature, mean temperature, relative humidity, sunshine duration, wind speed, precipitation at 15 stations covering 1961–2001 provided by the National Climatic Centre (NCC) of the China Meteorological Administration (CMA) were used in this study (see Fig. S1 of the auxiliary material). The reanalysis dataset of NCEP/NCAR including twenty-six different large-scale atmospheric variables (detailed see Wilby et al., 2002) from 1961 to 2001 at a spatial scale of $2.5° \times 2.5°$ derived from the National Center for Environmental Prediction covering the whole Hanjiang basin were used to calibrate and validate the SDSM model. In this study, GCM outputs dataset derived from high greenhouse gases emission scenarios (A2 scenarios) of the Hadley Center Couple Model version 3 (HadCM3) at a resolution of $3.75° \times 2.5°$ for 1961–2099 including the same atmospheric variables as NCEP data were also used in this study. Transformed NCEP data keeping the same resolution as GCM data under scenarios A2 of HadCM3 model were download freely from the internet site: http://www.cics.uvic.ca/scenarios/sdsm/select.cgi.

Three different methods for projecting future ET_0 in regional scale are illustrated here (see Fig. 1): Penman–Monteith (Physically-based method) with complicated downscaling input (including mean air temperature, sunshine duration, wind speed and relative humidity) based on SDSM (for the brevity, we call it SD-PM method after here), Hargreaves equation (temperature-based method) with relatively simple downscaling input (including mean, minimum and maximum temperature and extra-terrestrial solar radiation) based on SDSM (SD-HG method), and downscaling directly from HadCM3 outputs by SDSM with estimated ET_0 using Penman–Montieth equation as the observation (PM-SD method). The schematic diagram explained three methods were illustrated in Fig. 1. As the physically based one with explicitly incorporating both radiative and aerodynamic parameters (Xu et al., 2006), the Penman–Montieth equation has been recommended by the Food and Agricultural Organization (FAO) as the best method to determine ET_0 (Allen et al., 1998) due to its good performance when compared with other methods in different climatic regions (Wang et al., 2012). However, in reality, lack of reliable meteorological data lead to the development of simpler ET_0 estimation equations. Consequently, as an alternative ET_0 estimation equation, Hargreaves equation (Hargreaves and Samani, 1985) become the method recommended by FAO when lacking of sufficient meteorological data to drive Penman–Monteith equation with only air temperature being available. Moreover, projection future ET_0 and climatic variables involves two steps, i.e., establishing the empirical relationships between ET_0 and climatic variables of each station (predictand) and large-scale variables of regional weather (predictor) obtained from the NCEP reanalysis climate data during 1961–2001 (fulfilled by calibrating and validating of SDSM based on two segmentation data, namely 1961–1990 and 1991–2001 for calibration and validation, respectively), and applying these relationships to downscale ensembles of the same local variables provided by HadCM3 under

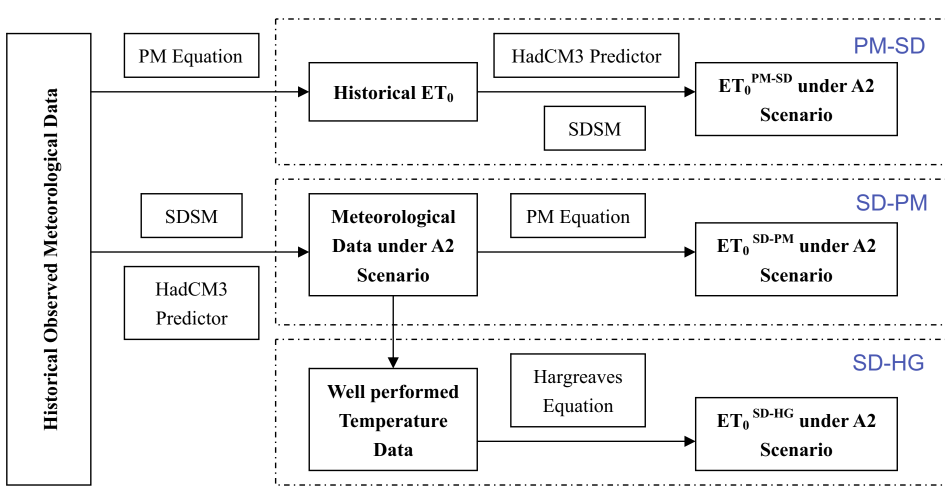

Fig. 1. The schematic diagram explained three methods for projecting future ET_0.