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Research papers

Projecting the potential evapotranspiration by coupling different formulations and input data reliabilities: The possible uncertainty source for climate change impacts on hydrological regime

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ABSTRACT

Representing atmospheric evaporating capability for a hypothetical reference surface, potential evapotranspiration (PET) determines the upper limit of actual evapotranspiration and is an important input to hydrological models. Due that present climate models do not give direct estimates of PET when simulating the hydrological response to future climate change, the PET must be estimated first and is subject to the uncertainty on account of many existing formulae and different input data reliabilities. Using four different PET estimation approaches, i.e., the more physically Penman (PN) equation with less reliable input variables, more empirical radiation-based Priestley-Taylor (PT) equation with relatively dependable downscaled data, the most simply temperature-based Hamon (HM) equation with the most reliable downscaled variable, and downscaling PET directly by the statistical downscaling model, this paper investigated the differences of runoff projection caused by the alternative PET methods by a well calibrated abcd monthly hydrological model. Three catchments, i.e., the Luanhe River Basin, the Source Region of the Yellow River and the Ganjiang River Basin, representing a large climatic diversity were chosen as examples to illustrate this issue. The results indicated that although similar monthly patterns of PET over the period 2021–2050 for each catchment were provided by the four methods, the magnitudes of PET were still slightly different, especially for spring and summer months in the Luanhe River Basin and the Source Region of the Yellow River with relatively dry climate feature. The apparent discrepancy in magnitude of change in future runoff and even the diverse change direction for summer months in the Luanhe River Basin and spring months in the Source Region of the Yellow River indicated that the PET method related uncertainty occurred, especially in the Luanhe River Basin and the Source Region of the Yellow River with smaller aridity index. Moreover, the possible reason of discrepancies in uncertainty between three catchments was quantitatively discussed by the contribution analysis based on climatic elasticity method. This study can provide beneficial reference to comprehensively understand the impacts of climate change on hydrological regime and thus improve the regional strategy for future water resource management.

1. Introduction

Evapotranspiration not only is an essential element of energy budget in the earth-atmosphere system, but also plays an important role in water resources (Wang et al., 2012b). Among different terms to describe the evapotranspiration, potential evapotranspiration (PET) was first introduced by Thornthwaite (1948) and formally defined by Penman (1956) as "the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile." As the indicator of evaporative power of atmosphere, PET determines the maximum possible water consumption from the land surface, and thus is the most excellent indicator for the changing behavior of climatic and hydrological regime. Due that PET is the important input for hydrological modelling, reliable estimation of PET constitutes the basis of evaluating climatic effect on hydrological processes, especially for future PET projection in

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the background that climate change become more pronounced (Bates et al., 2008].

More than 50 different methods with various complexities existed for the estimation of PET (Lu et al., 2005). Generally, in terms of the required inputs of meteorological variables, these methods can be roughly classified into three categories, i.e., temperature-based methods, radiation-based methods, and aerodynamic-and radiation-based methods. Among them, the Penman (PN) method, the aerodynamic-and radiation-based one, is always considered to the most reliable method for all climatic conditions due to its physically based characteristic, and is thus recommended as the single standard method for determining the PET by the Food and Agricultural Organization of the United Nations (FAO) (Xu et al., 2006). In many regions, however, the use of PN method is always prevented by the insufficient input data. The application of temperature-based methods and radiation-based methods requiring less meteorological data were thus compelled. For example, with only requiring air temperature as input, temperature-based methods were widely used in hydrological models (Bai et al., 2016), such as the early version of the Soil and Water Assessment Tool model (SWAT, Arnold et al., 1998) and the Hydro-Informatic Modeling System model (HIMS, Liu et al., 2008). Some works on intercomparisons of PET method suggested that less data-intensive methods can also give reliable approximation of PET in certain climatological condition if the simplified methods were sufficiently calibrated (e.g., Federer et al., 1996; Vorosmarty et al., 1998; Lu et al., 2005).

However, for the estimation of PET in global change study, the abilities of less data-intensive methods, particularly the temperature-based methods, to describe PET temporal variability have recently been questioned in the context of climate change. For example, compared with the more physically based one, the temperature-based version of the Palmer Drought Severity Index (PDSI) overestimated the recent trend of the global drought (Sheffield et al., 2012). Generally, physically based methods, e.g., PN method, are considered more competent in historical climate change assessment than temperature based ones (Roderick et al., 2009) due that changes in other atmospheric variables (e.g., wind speed and relative humidity) other than temperature are proved to have dominant effect on overall change in PET (e.g., Xu et al., 2006; McVicar et al., 2012; Wang et al., 2012b). However, as for future projection study, the issues become more complicated. Although PN method is more reliable compared with temperature-based or radiation-based one, more confidences are always found in downscaling GCMs-derived temperature and radiation data than that of relative humidity and wind speed data (Randall et al., 2007; Wang et al., 2015), which are the indispensable input data of the PN method. This thus leaves us in a dilemma in practice with respect to future PET projection: should we use more reliable methods (e.g., PN method) with uncertain data quality, or more empirical methods (e.g., temperature-based methods) with more reliable input data (Kingston et al., 2009). Recently, Wang et al. (2015) investigated the performance of different project approaches for future reference evapotranspiration (RET), a more narrowly defined term of PET with clearer vegetation type definition, by combination between RET estimating method and input data reliabilities and found uncertainties still lied in estimating how much the RET changed.

Apart from the most excellent indicator for the activity of climate change, PET is still the important input data to hydrological models of water balance study, especially under changing climate conditions (Hobbins et al., 2001; Xu and Singh, 2005). However, evidence from many studies suggested that the PET estimation is not critical for the performance of hydrological model in runoff simulation (Bai et al., 2016). For example, using 27 different PET estimation methods, Oudin et al. (2005) compared the performance of four conceptual rainfall-runoff models for 308 catchments and found simplistic (e.g., temperature-based methods) performed similarly (even better sometimes) compared with complex PET estimation methods. Similarly, Kannan et al. (2007) concluded that the temperature-based Hargreaves method appears to be at least as good as the more complex Penman-Montieth method in SWAT distributed hydrological model run for a small catchment in Southeastern regions of the United Kingdom. More recently, Bai et al. (2016) investigated the sensitivities of monthly hydrological models to different PET across 37 catchments in China under different climatic conditions and found different PET inputs can produce similar runoff in both non-humid and humid regions.

However, for the studies on the impact climate change on water availability though hydrological models, the issue may not be that simple, especially in the context of more pronounced climatic effect in the future (Bates et al., 2008; Wang et al., 2013a, 2015; Yang et al., 2015). The choice of PET method for the hydrological modelling should be restricted by more factors. On the one hand, PET changes are proved to more sensitive to changes in relative humidity and wind speed than air temperature, which is particularly true in China (Xing et al., 2017). On the other hand, data availability may have important influence for climate change impact assessments since less confidence is proved in GCM-derived vapor pressure, cloud cover, wind speed and net radiation compared with temperature (Randall et al., 2007; Haddeland et al., 2011). The choice of PET method used in the hydrological model may thus be a specific source of uncertainty in future projection of runoff. However, systematic investigation on the impact of applying different PET estimation approaches in hydrological model on prediction of future runoff is scare. Moreover, the influences of PET on AET and hydrological modeling are considered to be different in energy-limited region and water-limited regions (Donohue et al., 2007; Roderick et al., 2009; Wang et al., 2012b, 2016a). The diverse PET estimation approaches may thus give rise to different uncertainty of runoff projections between various climatic regions.

Therefore, to address these research gap, this paper further extends our previous study of Wang et al. (2015) by comprehensively investigating PET methods dependence for future runoff projections for three catchments in China representing a large geographic and climatic diversity. Four different PET projection approaches include more physically based Penman (PN) equation with relatively uncertain downscaled data, more empirical radiation-based Priestley-Taylor (PT) equation with more reliable downscaled data, the simplest and temperature-based Hamon (HM) equation with the most reliable downscaled temperature data, and statistical downscaling method with directly selecting PET as predictand. The abcd model was used to achieve the uncertainty analysis.

2. Study areas and data descriptions

This study was conducted for the three catchments, i.e., the Luanhe River Basin, the Source Region of the Yellow River and the Ganjiang River Basin, representing a large climatic diversity. The locations and the aridity index from geo-spatial datasets (UNEP, 1997) of the three catchments are shown in Fig. 1a. The Luanhe River Basin, located in the northeastern part of the Haihe River Basin with a drainage area of 44,900 km^2, is characterized by the temperate continental monsoon climate type (Fig. 1b). The average temperature is between −0.3 and 11 °C, gradually decreasing from the lower basin to the upper basin. With strong interannual and intra-annual variability, precipitation of the Luanhe River Basin has the multi-year average value of 560 mm, which mostly occurs in summer, especially in July and August. Located in 95.5–103.5°E and 32–36.5°N, the Source Region of the Yellow