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Research papers

Evaluation of six potential evapotranspiration models for estimating crop potential and actual evapotranspiration in arid regions

Sien Li [a,*], Shaozhong Kang [a], Lu Zhang [b], Jianhua Zhang [c], Taisheng Du [a], Ling Tong [a], Risheng Ding [a]

[a] Center for Agricultural Water Research in China, China Agricultural University, Beijing 100083, China
[b] CSIRO Land and Water, GPO Box 1666, Canberra, ACT 2601, Australia
[c] School of Life Sciences and State Key Laboratory of Agrobiotechnology, The Chinese University of Hong Kong, Hong Kong

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ABSTRACT

Using potential evapotranspiration (PET) to estimate crop actual evapotranspiration (AET) is a critical approach in hydrological models. However, which PET model performs best and can be used to predict crop AET over the entire growth season in arid regions still remains unclear. The six frequently-used PET models, i.e. Blaney-Criddle (BC), Hargreaves (HA), Priestley-Taylor (PT), Dalton (DA), Penman (PE) and Shuttleworth (SW) models were considered and evaluated in the study. Five-year eddy covariance data over the maize field and vineyard in arid northwest China were used to examine the accuracy of PET models in estimating daily crop AET.

Results indicate that the PE, SW and PT models underestimated daily ET by less than 6% with RMSE lower than 35 W m^{-2} during the four years, while the BC, HA and DA models under-predicted daily ET approximately by 10% with RMSE higher than 40 W m^{-2}. Compared to BC, HA and DA models, PE, SW and PT models were more reliable and accurate for estimating crop PET and AET in arid regions. Thus the PE, SW and PT models were recommended for predicting crop evapotranspiration in hydrological models in arid regions.

1. Introduction

The potential evapotranspiration (PET) can be defined as the rate at which evapotranspiration (ET) would occur from a large area completely and uniformly covered with growing vegetation which has access to unlimited water supply, and without advection or heating effects, while the actual ET (AET) is the actual evapotranspiration of the land surface (McVicar et al., 2012; McMahon et al., 2013). PET rather than AET is a common input for hydrological models, such as HYDRUS, SWAP, SWAT, MODFLOW-2000. PET provides the upper limit of land surface ET, while the estimation of AET in hydrological models is generally based on PET and crop coefficient (Douglas et al., 2009). PET models can be grouped into four categories: (1) combination (Penman, 1948; Shuttleworth, 1993); (2) radiation (Priestley and Taylor, 1972); (3) temperature-based (Blaney and Criddle, 1950); (4) mass-transfer (Dalton, 1802; Xu and Singh, 2002). How to choose the appropriate PET model to estimate land AET is critical for determining the watershed ET.

Until recently, several cross comparisons between these PET models in estimating PET under different climate conditions and underlying surface types, have been conducted by scientists (see Table 1), such as McKenney and Rosenberg (1993), Xu and Singh (2002), Lu et al. (2005), Sumner and Jacobs (2005), Douglas et al. (2009), Donohue et al. (2010), Bormann (2011), Fisher et al. (2011) and Tabari et al. (2013). Most of these studies concluded that the fully-physically based combination models are most optimal, and the radiation-based PET models usually performed better than the temperature-based and mass transfer-based models. Additionally, many studies also suggested that the PET models should be recalibrated using the local data to improve accuracy, and model improvement was still required.

However, the PET is not identical to the reference crop water requirement (ET_0). Many studies used the ET_0 estimated by FAO-56 PM model to evaluate the reliability of PET models, which is not appropriate and should be corrected. These issue has been clarified in McMahon et al. (2013). A lot of studies took the Penman method as the standard method to evaluate the reliability of other PET methods for the lack of the measured AET data (see Table 1). The Penman model is an estimating method but not a measuring approach for PET. Thus these comparisons were not entirely reliable. Furthermore, the previous studies mainly focused on

* Corresponding author.
E-mail addresses: lisien@163.com, lisien@cau.edu.cn (S. Li).

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Table 1
A review of studies on the reliability of PET models at different climate conditions and regions.

Authors	Climate	Location	Validation methods	PET models	Conclusions
McKenney and Rosenberg (1993)		North American Great Plains, USA	Eight alternative PET estimation methods	Thornthwaite, Blaney-Criddle, Hargreaves, Samani-Hargreaves, Jensen-Haise, PT, Penman	The PET methods differed in their sensitivities to temperature and other climate inputs. The degree of agreement among the methods was affected by location and by time of year
Abtew (1996)	Humid	Florida, USA	PET models *VS* lysimeters measurements	The Turc method, PT and Penman methods	The PM method was well suited to estimate ET from cattails, marsh, and an open water/algae system, but that calibrated radiation-based models also provided reasonable estimates
Federer et al., 1996		USA	Five PET models *VS* Four AET approaches	Thornthwaite, Hamon, Jensen-Haise, Turc, and Penman methods	No methods were consistently low or high. Use of 5-day or monthly input data did not greatly degrade results
Vörösmarty et al. (1998)		The conterminous US	Eleven PET models *VS* Watershed Water Balances	Thornthwaite, Hamon, Turc, Jensen and Haise, Penman PT, McNaughlon and Black, SW, SW day-night	Predictions made by macro-scale hydrology models can be sensitive to the specific PET method applied and this sensitivity results in bias relative to measured components of the terrestrial water cycle
Jacobs et al. (2004)	Humid	Central Florida, USA	PET models *VS* Eddy covariance measurements	The Turc method, Hargreaves and Makkink models	The calibrated PM model gave good results for PET, the PT and the PE models overestimated PET, and that the Turc and Makkink methods performed nearly as well as the PM method
Lu et al. (2005)	Humid	Southeastern United States	PET models *VS* Watershed Water Balances estimation	Thornthwaite, Hamon, and Hargreaves-Samani, Turc, Makkink, and PT methods	PT, Turc and Hamon methods performed better than the other PET methods
Oudin et al. (2005)	Different climates	France, USA and Australia	–	The Penman method	Temperature-based PET estimates perform as well as more physically-based PET methods
Sumner and Jacobs (2005)	Humid	Florida, USA	PET models *VS* Eddy covariance measurements	The modified PT, reference evapotranspiration and pan evaporation models	Both PM and a modified PT methods required seasonal calibration parameters
Zhou et al. (2006)		The Mekong River basin	PET models *VS* pan evaporation data	Shuttleworth–Wallace model	The PET and the reference evapotranspiration (RET) are vegetation-type-dependently correlated very well.
Weiß and Menzel (2008)	Different climates	Global scale	PET models *VS* pan evaporation data	Priestley Taylor, Kimberly Penman, and Hargreaves	The PT estimations were closest to available pan evaporation data
Douglas et al. (2009)	Different climates	Florida, American	PET models *VS* EC[a] or BREB[a] measurements	The Turc method and the Priestley–Taylor method	The PT performance appears to be superior to the other two methods for estimating PET for a variety of land covers in Florida at a daily scale
Donohue et al. (2010)	Typical arid climate	Australia	PET models vs pan evaporation dynamics	Penman, Priestley–Taylor, Morton point, Morton areal and Thornthwaite methods	The four-variable Penman formulation produced the most reasonable estimation of potential evaporation dynamics against PT, Morton point, Morton areal and Thornthwaite
Fisher et al. (2011)	–	Global scale	–		The choice of ET model and input data is likely to have a bearing on model fits and predictions when used in analyses of species richness and related phenomena at geographical scales of analysis
Our study	Typical arid climate	Arid northwest China	Six PET models *VS* Five-year EC[a] measurements	FAO-Blaney-Criddle, Hargreaves, Priestley-Taylor, Dalton, Penman and Shuttleworth models	The PE, SW and PT models combined with the dynamic coefficient equations are reliable to estimate daily crop ET, while the BC, HA and DA methods are not suitable in the arid regions

[a] EC represents eddy covariance, BREB means Bowen Ratio Energy Balance, PE represents Penman, PT means Priestley–Taylor, SW means Shuttleworth, BC means FAO-Blaney-Criddle, HA means Hargreaves, DA means Dalton.