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Evaluation of random forests and generalized regression neural networks for daily reference evapotranspiration modelling

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ABSTRACT

Accurate estimation of reference evapotranspiration (ET_0) is of importance for regional water resource management. The present study proposed two artificial intelligence models, random forests (RF) and generalized regression neural networks (GRNN), for daily ET_0 estimation. Meteorological data including maximum/minimum air temperature, solar radiation, relative humidity, and wind speed during 2009 ~ 2014 from two stations in southwest China were used to train and test the RF and GRNN models by using two input combinations, including complete data and only temperature and extraterrestrial radiation (R_a) data. The k-fold test was adopted to test the performance of models according to temporal and spatial criteria and data set scanning procedures. The results indicated that both local and external RF and GRNN models performed well for estimating daily ET_0, and RF was slightly better than GRNN generally. The high fluctuations in the accuracy ranges justify the importance of applying k-fold test for assessing the model performance, which could avoid drawing partially valid conclusions from model assessments based on simple data set assignment. Overall, both temperature-based RF and GRNN models can accurately estimate daily ET_0, which is helpful for irrigation scheduling in southwest China.

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1. Introduction

Evapotranspiration (ET) is an important parameter in the interactions among soil, vegetation, and atmosphere, and is a central part of surface energy and water budgets (Liu et al., 2013). Accurate estimation of ET has great importance for hydrologic water balance, design and management of irrigation system, crop yield simulation, planning and management of water resources (Kisi, 2016).

There are different terms to describe the ET, and it is of importance to clarify them. Actual evapotranspiration (ET_a) is the actual liquid water transformed into vapor from the soil surface by evaporation and from the crop by transpiration. It is driven by meteorological factors, mediated by soil and vegetation characteristics, and constrained by the amount of available water (Amell and Liu, 2001). Reference evapotranspiration (ET_0) is defined as "the rate of ET 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 ET from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground" (Allen et al., 1998). Since ET_0 is only affected by metrological variables, it can be computed from meteorological data, and the FAO-56 Penman-Monteith (PM) model is recommended as the sole standard method for the definition and computation of the ET_0 (Allen et al., 1998). The FAO-56 PM model can be used in a great variety of environments and climate conditions without any local calibrations due to its physical basis, and is a well-documented method which has been validated using lysimeters under a wide range of climate conditions (Landeras et al., 2008). However, application of this method requires a lot of meteorological data, including solar radiation, relative humidity, wind speed, and maximum/minimum air temperature, which could be a real hindrance (Abdullah et al., 2015).

In the past decades, artificial intelligence (AI) models have been successfully implemented for modeling ET_0 around the world. The implementation of AI models in ET_0 estimation was first investigated by Kumar et al. (2002) using artificial neural networks (ANN). After that, ANN models have been extensively applied in modeling ET_0 (Trajkovic et al., 2003; Kisi, 2006; Kisi, 2008; Zanetti et al., 2007; Kim and Kim, 2008; Landeras et al., 2008; Traore et al., 2010; Martí et al., 2011a). Kisi (2008) investigated the potential of three different ANN models, the multi-layer perceptions (MLPs), radial

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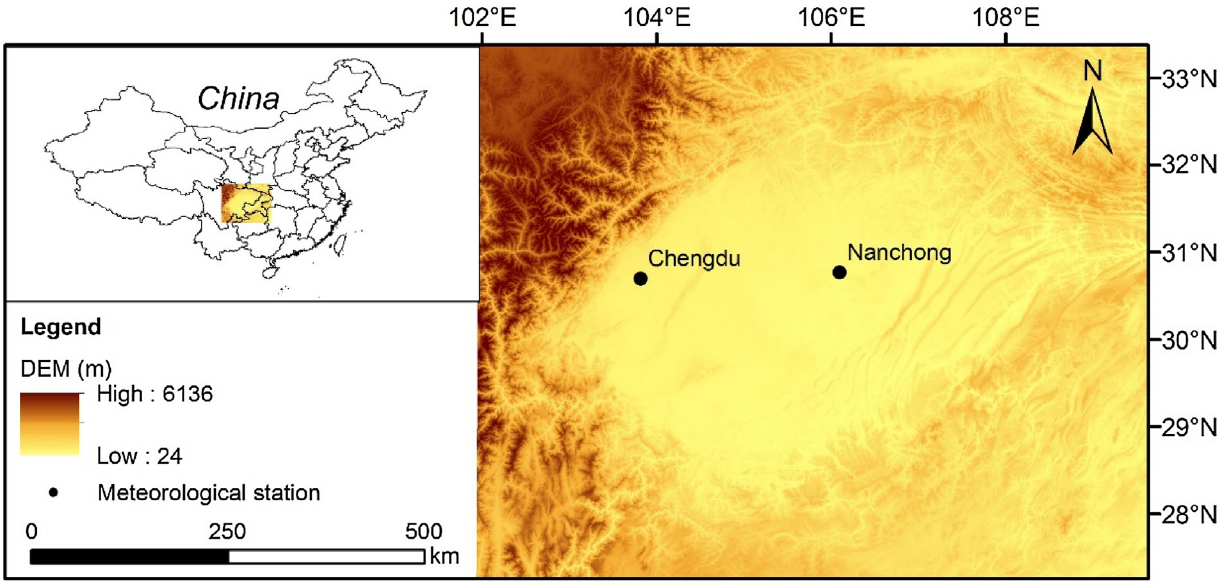

Fig. 1. Geographic location of the meteorological stations in Sichuan basin.

basis neural networks (RBNNs) and generalized regression neural networks (GRNN), in modeling ET_0. Kumar et al. (2011) discussed architecture, development, selection of training algorithm and performance criteria of ANN models for ET_0 estimation. However, ANN models are easily getting stuck in a local minimum, thus some studies proposed new AI models for ET_0 modeling.

Kisi and Cimen (2009) investigated the accuracy of support vector machines (SVM) in modeling ET_0, and found SVM could be employed successfully in modeling ET_0 process. Tabari et al. (2012) evaluated the performances of SVM, adaptive neuro-fuzzy inference system (ANFIS), multiple linear regression, multiple non-linear regression, four temperature-based, and eight radiation-based ET_0 models for estimating ET_0 in a semi-arid highland environment in Iran, and the results obtained with the SVM and ANFIS models for ET_0 estimation were better than those achieved using the regression and climate based models. Shiri et al. (2012) tested the applicability of Gene Expression Programming (GEP), ANFIS, Priestley-Taylor and Hargreaves-Samani models for ET_0 estimation in four meteorological stations in Basque Country of Northern Spain, and the GEP model was found performing better than the ANFIS, Priestley-Taylor, and Hargreaves-Samani models. Abdullah et al. (2015) investigated the efficiency of extreme learning machines (ELM) algorithm for predicting ET_0 for three meteorological stations, located at the northern, middle, and southern part of Iraq, and proved that the ELM model was efficient and simple in application of high speed, and had very good generalization performance. Kisi (2016) investigated the ability of least square support vector regression, multivariate adaptive regression splines and M5 Model Tree in modeling ET_0. Feng et al. (2016) developed three AI models to estimate ET_0, including ELM, backpropagation neural networks optimized by genetic algorithm (GANN) and wavelet neural networks (WNN), and found the GANN and ELM performed much better than WNN.

The present study proposed two AI models, the random forests (RF) and generalized regression neural networks (GRNN), in modeling daily ET_0 in Sichuan basin of southwest China, where droughts happen frequently under the impact of climate changes and strong human activities. The performances of the RF were evaluated through k-fold test. The main objective of this study is to propose two AI models for modeling daily ET_0 locally and externally using only air temperature and extraterrestrial radiation data as input. The temperature-based models could be applied for ET_0 forecasting using forecasted temperatures data, which is very helpful for farmers or irrigation system operators for improving their irrigation scheduling (Luo et al., 2015).

2. Materials and methods

2.1. Study area and data

The study area is located in Sichuan basin of southwest China, with an area about 0.26 million km^2 and a population of 90 million. The well-known Dujiangyan Irrigation Project is located in the center of Sichuan basin, supplying irrigation water for 6953 km^2 irrigated farmland. Daily meteorological variables, including maximum (T_{max})/minimum (T_{min}) air temperature at 2 m height, mean relative humidity (RH), wind speed at 10 m height (U_{10}), and sunshine duration, were obtained at 2 meteorological stations in Sichuan basin (Fig. 1) during 2009 ~ 2014. The data were obtained from the National Climatic Centre of the China Meteorological Administration with satisfactory reliability. For the calculation of ET_0, wind speed measured at 2 m above the surface (U_2) and solar radiation data are required, and these two parameters were estimated from U_{10} and sunshine duration data using wind profile relationship and Angstrom formula, respectively (Allen et al., 1998). Mean air temperature (T_{mean}) were estimated by averaging T_{max} and T_{min}.

Monthly and inter-annual variation of meteorological variables in the two stations are presented in Fig. 2 and Fig. 3, respectively. The studied area has a humid and warm climate, with average daily precipitation, relative humidity and air temperature of 2.6 mm/d, 77% and 17 °C in Chengdu, 2.9 mm/d, 77% and 19 °C in Nanchong, respectively. The low solar radiation (with average daily solar radiation of 11 MJ/m^2 d and 12 MJ/m^2 d in the two stations, respectively) results in low ET_0 rate (Feng et al., 2014), with average daily ET_0 of 1.9 and 2.1 mm/d, respectively.

2.2. FAO-56 Penman-Monteith model

Experimental ET_0 data were unavailable at the study area. Therefore, ET_0 values estimated by FAO-56 PM model were considered as the targets for RF and GRNN, which is an acceptable and common practice in this situation (Allen et al., 1998; Shiri et al.,

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