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A nonlinear mathematical modeling of daily pan evaporation based on conjugate gradient method

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ABSTRACT

The mathematical form to estimate the evaporation plays an important role in sustainable development and optimal water resources management of the countries facing water crisis. In this paper, a general regression analysis is proposed to estimate the daily pan evaporation with respect to input variables including the air temperature (T), relative humidity (R), wind speed (W) and sunshine hours (H) from two weather stations (i.e. Chahnimeh Zabol reservoirs and Iranshar station) in Iran. A conjugate gradient optimization method is used to calibrate the nonlinear mathematical function for accurate prediction of daily pan evaporation. Three mathematical functions with nonlinear forms are calibrated on data points of daily pan evaporation using proposed general regression analysis by proposed conjugate line search method. Then, the accuracies of three nonlinear models are compared with adaptive neuro-fuzzy inference system (ANFIS) and M5 Model Tree (M5Tree) models for two stations. Results indicated that that the conjugate gradient method was successfully applied to estimate the nonlinear models for predictions of daily pan evaporation with explicit mathematical function. The proposed mathematical models (RMSE of 4.14 mm for Chahnimeh and 1.94 mm for Iranshar) performed better than the ANFIS predictions for Iranshar (RMSE of 2.41 mm) and M5tree (RMSE of 4.31 mm for Chahnimeh and 2.19 mm for Iranshar).

1. Introduction

Evaporation from water resources is a major issue affecting agricultural regions of Iran and dry regions. Annual losses potentially exceed 40% of water resources (Prime et al., 2012). Loss of this water can lead to reduced agricultural productivity and can adversely affect the environment. Notwithstanding, there are numerous problems with them. Many factors can present errors in pan evaporation measurement, for example, debris in water, animal activity in and around the pan, pan size, materials utilized to construct the pan, exposure of the pan, strong winds, and measurement of water depth in the pan (Piri et al., 2009). The most widely recognized and imperative factors influencing evaporation are sunshine, air and soil temperature, relative humidity, vapor pressure deficit, atmospheric pressure, and wind speed. Empirical formulas are connected with different climate factors affecting evaporation. As the complexity of the empirical methods increases, data requirements to drive the equations often make them difficult to apply for field applications.

The mathematical models were typically developed based on a set of observed data points and curve fitting techniques using a mathematical function to achieve the prediction. The accuracy of mathematical models depends greatly on the set of evaporation data and the forms of mathematical functions which were involved the important input variables such as air temperature (T), relative humidity (R), wind speed (W) and sunshine hours (H). Despite of many attempts, there is a gap in the field in terms of using a general regression analysis on a large set of observed data points on the basis of nonlinear expression forms. Therefore, there is required to implement a general regression procedure applicable for nonlinear mathematical functions that it can be calibrated every mathematical function with unlimited coefficients. The calibration of nonlinear mathematical models is essential factor to achieve an accurate predictions. Thus, there is a need to establish an efficient iterative procedure to be able to find the unknown parameters of suitable nonlinear functions in calibrating process with a larger database.

In recent decades, the artificial intelligence methods (e.g., ANFIS and ANN) have been successfully applied in water resources

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(Terzi et al., 2006; Moghaddamnia et al., 2009; Shiri et al., 2011, 2014; Jahanbani and El-Shafie, 2011; Sanikhani et al., 2012; Kisi and Tombul, 2013; El-Shafie et al., 2013, 2014; Cobaner et al., 2014; Goyal et al., 2014; Kisi et al., 2015, 2016; Li et al., 2014, 2015). Terzi et al. (2006) applied ANFIS method to daily meteorology data from the Lake Egirdir region in the southwestern part of Turkey and they found acceptable results. Moghaddamnia et al. (2009) compared the accuracy of ANFIS and artificial neural network (ANN) in modeling pan evaporation and they found small difference between them. They reported that although ANN and ANFIS techniques seem to be powerful, their data input selection process is quite complicated. Shiri et al. (2011) estimated daily pan evaporation of the State of Illinois, USA using ANFIS and found good estimates especially when limited climatic parameters were used. Sanikhani et al. (2012) applied two different ANFIS techniques, ANFIS with grid partitioning (GP) and ANFIS with subtractive clustering (SC), in modeling daily pan evaporation based on air temperature, wind speed, solar radiation and relative humidity. They obtained similar accuracy from both ANFIS methods and their performances were better than the multivariate non-linear regression (MNLR), ANN, Stephens-Stewart (SS) and Penman models. Goyal et al. (2014) used ANFIS for estimating pan evaporation in sub-tropical climates, Karso watershed in India. As mentioned, the soft computing-based modeling were utilized in almost the new studies for predicting the pan daily evaporations due to more accuracy but these modeling approach were not provided an explicit function to simple predictions, and also these predictions-based soft-computing models can not available to apply an another user. The nonlinear mathematical modeling can be used to estimate the pan evaporation with an explicit function while has as accurate predictions as soft computing-based models.

In the present study, an iterative algorithm-based a conjugate gradient optimization method is introduced to calibrate the nonlinear mathematical models for estimating the daily pan evaporation. A limited conjugate scalar factor is defined to control stability of conjugate gradient line search. A step size is proposed to achieve stabilization of the least squared error function based on the new and previous results. Three nonlinear mathematical functions for daily pan evaporation are fitted on the 2076 experimental weather station data of Chahnimeh Zabol reservoirs and Iranshar station in Iran. Then, the predictions data of these three nonlinear models are compared with ANFIS and M5Tree models based on several comparative statistics. Four applications are used to estimate the pan evaporation for each station. In first stage, the predictions based on input data of *T*, *W*, *R*, and *H* are compared. In the second to forth stages, the pane evaporations estimated based on the input data of *T* and *W* for second application, *T* and *H* for third application, and *T*, *R* for forth application. Unlike the ANFIS and M5tree models, these mathematical models can be provided an accurate estimation with a simple nonlinear function. The proposed nonlinear mathematical functions can be used for predicting the evaporations of the studied station, directly.

2. Experiment data

The study areas are the Chahnime Station of Zabol (61°35′ E and 30°47′ N) and city of Iranshahr Station (latitude 58°38′ E and 61°25′ N) in Sistan and Baluchestan province in southeastern Iran. Chahnemeh that included four natural water hole is located 35 km from city Zabol. The Chahnime located in Sistan delta has a very hot and dry climate which its temperature surpasses 50 °C in summer. Precipitation is around 60 mm/year and happens just in autumn and winter. Open water evaporation is high and is evaluated to be 3200 mm/year. Strong winds in the district are quite unique and are critical contributing factor for the high evaporation. The Iranshahr is located the eastern region Jazmoryan marshes make up the North West and South where the elevation is limited in terms of topography that the locations of these region are shown in Fig. 1.

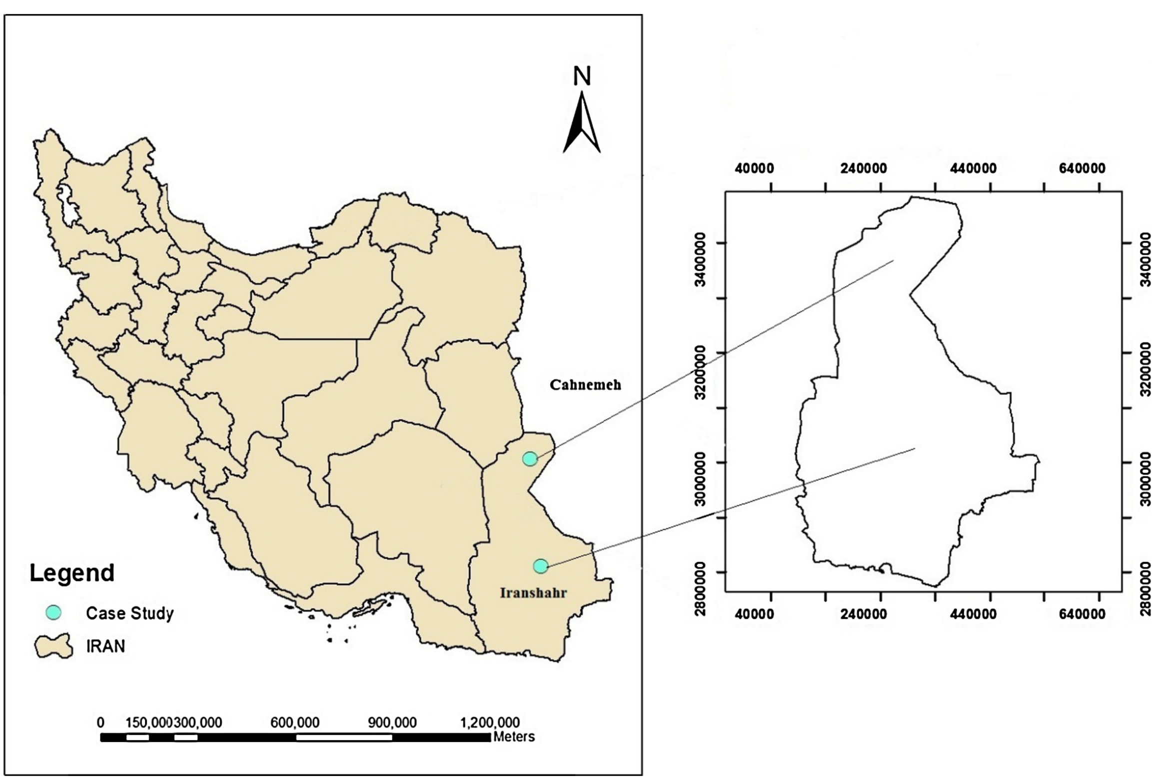

Fig. 1. The Sistan and Baluchestan plain and location of the Chahnime and Iranshar.