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Independent testing for assessing the calibration of the Hargreaves–Samani equation: New heuristic alternatives for Iran

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ABSTRACT

There is multitude of models for estimating daily reference evapotranspiration (ET_0) using meteorological parameters. Among others, the temperature-based Hargreaves–Samani (HS) model is one of the frequently applied models for estimating ET_0 when meteorological parameters in the studied station are limited. However, this method tends to require a preliminary local calibration. Most calibration procedures usually apply the same data sets for calibrating and testing. At the most, some studies reserve an independent test set for evaluating the calibrated model, but considering a single data set assignment. In the present study, the HS model and its calibrated version were assessed using meteorological parameters from 29 weather stations in Iran, through complete temporal and spatial data scanning, using a k-fold testing approach. A similar procedure was also repeated using the Gene Expression Programming (GEP) technique relying on the same input variables of the HS model. The results showed the importance of adopting k-fold based independent testing approach in order to avoid problems related to the influence of selected test period on the performance of the GEP models.

1. Introduction

There are mainly five evapotranspiration (ET) model categories, namely, water budget, mass transfer, combination, temperature-, and radiation-based methods (Xu and Singh, 2002). Among others, the Penman–Monteith (PM) model adopted by the Food and Agriculture Organization (FAO) [which will be referred to as FAO56-PM] has been accepted as the standard model for calculating reference evapotranspiration (ET_0) and calibrating other equations (Allen et al., 1998). FAO56-PM model has been validated using lysimeters under a wide range of climatic contexts and can be applied in a great variety of environments and climate scenarios without local calibration (Landeras et al., 2008). However, the need of a large number of meteorological parameters (i.e. air temperature, relative humidity, solar radiation and wind speed) is a major disadvantage of this model, especially in developing countries and regions which suffer from lack of instruments and sensors. Therefore, calibration and validation of models relying on fewer input parameters is a key issue in such regions.

According to Allen et al. (1998), the temperature-based Hargreaves–Samani model (HS) (Hargreaves and Samani, 1985) might be considered as an alternative to the FAO56-PM model when only air temperature records are available. Although some studies have recommended the application of HS for 10-day or monthly periods (e.g. Henggeler et al., 1996; Jensen et al., 1990; Shuttleworth, 1993), its applicability has been approved for daily scales, too (Hargreaves and Allen, 2003; Gavilan et al., 2006). Nevertheless, numerous studies have shown that this model overestimates ET_0 values in humid regions and at low ET rates, and underestimates in dry regions and at high ET rates (e.g. Droogers and Allen, 2002; Xu and Singh, 2002). Consequently, the HS model should be calibrated locally/regionally for improving its performance in different climatic contexts. Some studies have proposed local values for the adjusted Hargreaves coefficient (AHC) worldwide, considering calculated (Table 1) or experimental benchmarks. Other studies have even proposed new parametric expressions for the calculated AHCs (e.g. Samani, 2000; Vanderlinden et al., 2004; Lee, 2010; Mendicino and Senatore, 2013; Maestre-Valero et al., 2013; Shahidian et al., 2013).

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Table 1
Data management scenarios for HS model calibration in literature.

No.	Reference	Location	Station studied	Calibration criterion	Independent test	Calibration patterns (per station)	Test patterns	Kind of calibration
1	Martinez Cob and Tejero-Juste (2004)	Spain	9	Local	Yes	4 years	–	Linear regression
2	Stockle et al. (2004)	World wide	5	Local	Yes	5 years	2 years	Linear regression
3	Vanderlinden et al. (2004)	Spain	16	Local/regional	No	38 years	–	Relating HS adjusting coefficient to temperature variations
4	Gavilan et al. (2006)	Spain	86	Regional	Yes	2–3 years	14 years	Linear regression
5	Trajkovic (2007)	Western Balkan	10	Local	Yes	7–8 years	7–8 years	Regression analysis
6	Lee (2010)	South Korea	21	Local	No	10 years	–	Linear regression, one parameter, and three parameter
7	Tabari and Talaee (2011)	Iran	12	Local	No	12 years	–	Ratio of FAO56-PM ET_0 to HS ET_0
8	Ravazzani et al. (2012)	Italy	51	Local	Yes	9 years	9 years	Correction factor based on station elevation
9	Bachour et al. (2013)	Lebanon	1	Local	No	16 years	–	Linear regression
10	Long et al. (2013)	China	811	Local/regional	No	30 years	–	ET_0 ratios
11	Mendicino and Senatore (2013)	Italy	137	Local	Yes	18 years	–	Regression analysis
12	Maestre-Valero et al. (2013)	Spain	66	Local/regional	Yes	8 years	12 years	Regression analysis
13	Berti et al. (2014)	Italy	35	Regional	Yes	13 years	13 years	Regression analysis

Table 1 presents various calibration procedures considering different calibration scenarios with and without independent test worldwide. The independent test involves that the testing patterns have not been previously used for calibrating. It can be observed from the sample studies that only few studies have attempted to carry out an independent test of the calibrated HS model, and they usually test the calibrated version using the same data used for calibrating. This might lead to partially valid results. Among the listed studies, Berti et al. (2014), Martinez Cob and Tejero-Juste (2004), Mendicino and Senatore (2013), Ravazzani et al. (2012), Stockle et al. (2004) and Trajkovic (2007) developed the calibrated HS models using a part of the available patterns, and tested with independent data. Nevertheless, these studies only considered a single data set assignment for calibrating and testing.

The application of Gene Expression Programming (GEP) (Ferreira, 2001) might be considered as an alternative to conventional models to estimate ET_0 values using limited input parameters. Detailed information about GEP modeling of ET_0 might be found e.g. in Shiri et al. (2012). Parasuraman et al. (2007) applied GP for modeling the dynamics of ET. Guven et al. (2008) used GEP for modeling ET_0 in USA. Shiri and Kisi (2011) applied soft computing techniques including GEP for modeling daily pan evaporation in Iran. Shiri et al. (2012) compared GP with neuro-fuzzy systems for modeling daily ET_0 values in the Basque Country, Spain. Shiri et al. (2014a) compared various heuristic models including GEP for estimating ET_0 in Iran. Kim et al. (2015) applied GEP and neural networks models for predicting daily pan evaporation values in Iran. However, these applications considered a single data set assignment. The literature survey by the authors showed that only few studies have reported the external application of GEP models, i.e. when the test patterns belong to a station not considered for training (e.g. Shiri et al. 2012, 2013). However, a complete testing scan (local and external) was not considered in these studies. Shiri et al. (2014b) compared local and external training procedures of GEP models for estimating pan evaporation values of six weather stations of the USA. Shiri et al. (2014c) evaluated the generalizability of GEP-based ET_0 estimation models in coastal regions of Iran. The obtained results revealed that the externally trained models might be a valid alternative to locally trained ones when relying on a suitable input selection. Martí et al. (2015a) assessed the implications derived from using calculated targets for training and testing GEP-based ET_0 models in Spain.

The present study aims at assessing the performance of temperature-based approaches at a wider range of climatic contexts in Iran using data set scanning procedures. First, a k-fold assessment of the calibrated HS equation was performed according to temporary and spatial criteria in coastal and inland regions of Iran. Similarly, GEP-based equations fed with the same inputs were assessed for the same scenarios. The evaluation of the calibration procedures according to k-fold test was also compared with the traditional evaluation procedure. Finally, new temperature-based expressions were provided for each station.

2. Methods

2.1. Study area

This study considers 8 coastal and 21 inland weather stations of Iran comprising a period of nine years (January 2000–December 2008). A brief characterization of the stations is presented in Table 2. The climate in the studied regions may be classified as humid, semi-arid, arid and hyper-arid. The altitude ranges between −8.6 m (costal region) to 2465 m (inland region) among the studied stations with a minimum annual ET_0 of 916 mm and a maximum value of 2124 mm, respectively. In the costal context, the mean relative humidity varies between 26.63% (Abadan) and 99% (Rasht), while it ranges between 59.57% (Zahedan) and 73.17% (Abali) for the inland context. Wind speed variations, which clearly affects the temperature difference, is similarly wide for both studied regions with variations between 1.56 m/s and 3.747 m/s (Rasht and Bandar-e-Abbas, respectively) in the coastal region and 1.826–4.73 m/s (Quazvin and Bam, respectively) in the inland region. The available data were thoroughly screened and checked for any inconsistency and removing meaningless as well as missing values.

2.2. Input variables and targets

Due to the absence of experimental ET_0 values, the FAO56-PM model was used for providing the targets for the empirical and heuristic models, which is an accepted and very common practice in this situation, in agreement with the FAO recommendation (Allen et al., 1998):

$$ET_0^{PM} = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T_{mean}+273}W_S(e_a - e_d)}{\Delta + \gamma(1 + 0.34W_S)} \quad (1)$$

where ET_0^{PM}: reference evapotranspiration (mm/day), Δ: slope of the saturation vapor pressure function (kPa/°C), γ: psychrometric constant (kPa/°C), R_n: net radiation (MJ/m^{2}day), G: Soil heat flux density