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Selecting the best model to estimate potential evapotranspiration with respect to climate change and magnitudes of extreme events

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ABSTRACT

There are a lot of investigations to select the best model to estimate potential evapotranspiration (ET_o) in a certain climate or region. In this paper, the types of climate include arid, semiarid, Mediterranean, and very humid. A spatial and temporal study of the ET_o is the aim of this paper, according to the peak and low events (extreme events) and climate change alarms. For this purpose, 50 years (1961–2010) monthly meteorological data of 18 regions in Iran, with various climates, were collected. For estimating the ET_o, 5 temperature–based, 5 radiation–based, and 5 mass transfer–based models, were selected with respect to better performance of them in different climates on the basis of past investigations. The results will especially be useful in the regions where the monthly (rather than daily) meteorological data are available. The results appear that the Blaney–Criddle (BC) (root mean square error (RMSE) = 1.32 mm day^{-1}) and Abtew (Ab) (RMSE = 0.83 mm day^{-1}) are the best models for estimating the ET_o in the arid and semiarid regions, respectively. While, modified Hargreaves–Samani 2 (MHS2) represents the best performance in the Mediterranean and very humid regions (RMSE = 0.30 mm day^{-1} & 0.68 mm day^{-1}, respectively). In addition, radiation—and mass transfer–based models are proper tools to estimate the ET_o in warm and cold seasons on the basis of improving values of evaluation indices in 40% and 70% of the study area, respectively. Increasing air temperature and decreasing minimum relative humidity for best performance of most models alarms a climate change in most regions of Iran. As a result, the radiation–based models were adapted with climate change better than the temperature–based and particularly mass transfer–based models. Finally, a step by step flowchart was presented for selecting the best model to estimate the ET_o in each climate.

1. Introduction

There have been many studies into the estimation of ET_o around the world. Although there are some advancements in each study, one or more limitation also leads to decreasing reliability of the models those were introduced by researchers as the best for the estimating the ET_o. It can be observed using an overview on the literature.

Ngongondo et al. (2013) claimed that the PT and HS methods underestimate the ET_o by using a 37–year data in an arid environment, in Malawi. However, there are also some investigations in which overestimation of the HS were reported (Azhar and Perera, 2011; Ashraf et al., 2014; Patel et al., 2015). Ahmadi and Fooladmand (2008) indicated advantages of Thornthwaite's equation, in southern Iran, by using 20–year data (average data). In the other studies, the researchers focused on importance of water management which indicates the role of accurate estimation of evapotranspiration to deal with water crisis (Valipour, 2012a,b,c,d,e; Valipour, 2014; Valipour, 2015e,f,g; Valipour, 2016a,b). Shiri et al. (2014) revealed the superiority of the HS compared to the Mk, Turc, and PT by using a 9–year period data.

An overview on the mentioned above indicates that anyone of the previous investigations suffers one or more the sources of uncertainty. One of them is lack of sufficient data which not only leads to reduction of reliability for the results but also leads to inapplicability for studying the role of climate variability and/or climate change on the accuracy of the models. In addition, the main part of the reported errors related to the peak and low events which occurred in warm and cold seasons, respectively, that has not been evaluated separately. Moreover, the efficiency of the Food and Agriculture Organization of the United Nation (FAO)–Penamn–Monteith (FPM), as the base model, has not been characterized. There are also some other sources of uncertainty

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such as lack of proper selection of temperature−, radiation−, and mass transfer−based models for accurate estimating the ET_o with respect to the climate of the region.

In the other hand, some studies tried to reflect the peak and low errors. For instance, Caporusso and Rolim (2015) compared 18 different models to estimate the ET_o in a humid region of Brazil using only 6−year meteorological data. The results indicated that Presley−Taylor (PT) and Thornthwaite (Th) estimate the ET_o in warm and cold seasons, respectively, better than other models against the FPM.

In the other hand, climate change impacts on the different parameters applied for various models to estimate the ET_o (Table 2). Therefore, accurate analysis of climate change is very important to find the best model which has more adaptation with the variations of meteorological data in future. There are many investigations to deal with climate change in Iran. For example, Ashraf et al. (2014) showed that the most significant increasing temperature occurred at the beginning of 21 century in all locations of Iran during a 48−year period of 1961–2008. According to precipitation anomalies, all locations experienced dry and wet periods, but generally dry periods occurred more often especially in the beginning of 21 century.

There are three sources of uncertainty that they are more considerable in the previous studies including decreasing accuracy of the selected models in the estimation of peak and low values occurred in warm and cold seasons, respectively, lack of considering the role of climate change to select the superior model, and/or lack of validation of the base method (i.e. the FPM in most cases). Thus, the literature review shows that there are considerable sources of uncertainty in the past studies which need to a comprehensive work to reduce the mentioned limitations and to improve reliability of the introduced models for estimating the ET_o in each climate. This study aims to estimate the ET_o by selecting 15 more recommended models (based on their performance in the previous investigations) with respect to values of the cold and warm seasons and climate change alarms in 18 regions of Iran, with various climates, during a 50−year period from 1961 to 2010.

2. Materials and methods

The monthly averages of meteorological data were collocated from Islamic Republic of Iran Meteorological Organization (IRIMO) (http://irimo.ir/eng/index.php). These data contain mean, minimum, and maximum daily air temperature (°C), mean and minimum relative humidity (%), wind speed (m s^{-1}), rainfall (mm $month^{-1}$), and sunshine (hr $month^{-1}$). Table 1 shows the position of all 18 synoptic stations and their climates.

Among all stations, there is 50−year period information for 16 regions. In addition, there is 27−year and 21−year period information for Moghan and Jiroft, respectively, that they were also added to other 16 regions (with 50−year data).

Although the FPM model has been applied in various regions (e.g. Rahimi et al., 2015; Valipour, 2013a,b,c; Valipour, 2015a; Yannopoulos et al., 2015), it needs too many parameters to estimate the ET_o. In most regions (without synoptic stations and/or with un−gauged stations), meteorological data are limited and researchers cannot use the FPM model. To this end, empirical methods have been developed for the estimation of the ET_o using limited data.

Among numerous empirical methods to estimate the ET_o, 5 temperature−based (HS, modified Hargreaves−Samani 1 (MHS1), MHS2, Th, and BC), 5 radiation−based (JH, PT, Mk, Ab, and Tu), and 5 mass transfer−based models (Penman (Pe), Ivanov (Iv), Mahringer (Ma), Trabert (Tr), and WMO), were selected with respect to better performance of them in different climates on the basis of the past investigations (e.g. Tabari et al., 2013; Valipour, 2015b; Valipour and Eslamian, 2014) and the results were compared with the FPM. Table 2 shows the selected models with their References

It should be noted that the definition and use of the term "reference evapotranspiration" was developed in the 1970s (Wright and Jensen, 1972; Doorenbos and Pruitt, 1977) to resolve ambiguities involved in the definition and interpretation of "potential evaporation"; the "reference" descriptor points to the use of a specific type of vegetation or specific definition of vegetation properties to represent the evaporative index.

Although there are a lot of studies in which the empirical methods (15 selected equations) have been compared with the FPM (e.g. Ahmadi and Fooladmand, 2008; Tabari et al., 2013; Valipour, 2015c), the ET_o from different equations may has different definitions which most of the mentioned investigations have neglected this. The different definitions of empirical models related to initial conditions for which these models have been extracted (See Table 2). The FPM equation refers to the potential evapotranspiration of a grass surface, but other equations might consider the ET_o as the evaporation from an open water surface. Table 2 compares also the different definitions of all models used in this paper.

To evaluate the accuracy of the models four indices were used as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{n}} \quad (1)$$

$$PVC = \frac{\sqrt[4]{\sum_{i=1}^{N_p}(X_i - Y_i)^2 \times (X_i)^2}}{\sqrt{\sum_{i=1}^{N_p}(X_i)^2}} \quad (2)$$

$$LVC = \frac{\sqrt[4]{\sum_{i=1}^{N_l}(X_i - Y_i)^2 \times (X_i)^2}}{\sqrt{\sum_{i=1}^{N_l}(X_i)^2}} \quad (3)$$

$$Student'st - test = \frac{\bar{X} - \bar{Y}}{\sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2 + \sum_{i=1}^{n}(Y_i - \bar{Y})^2}{n(n-1)}}} \quad (4)$$

where, *PVC* and *LVC* reflect the peak and low errors occur in the warm (June–September) and cold (November–February) seasons (El-Shafie et al., 2009; El-Shafie et al., 2014), respectively, X_i and Y_i are the calculated ET_o using the FPM and estimated ET_o using 15 empirical equations, respectively; $\overline{X}$ and $\overline{Y}$ are the average of X_i and Y_i, N_p is number of peak evapotranspiration greater than one−third of the mean peak ET_o observed, N_l is number of low ET_o lower than one−third of the mean low evapotranspiration observed and n is the total numbers of data. First, the average of extreme events (ET_o in June to September) was obtained. Then, this value was dived to 3 and extreme events were compared to this value to determine N_p. Similar method (ET_o in November to February) was employed to characterize N_l. This approach has already been applied in the previous investigations (El-Shafie et al., 2009; El-Shafie et al., 2014).

The following has been prepared in the different parts for better understanding readers. First, the more accurate model was charac-