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Performance Evaluating of Combination Techniques for Enhancing Water Requirement Estimation of Saffron (Crocus Sativus L.) in Iran

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Abstract

An accurate estimation of the water requirement of saffron, as the most strategic product in the eastern regions of Iran, is inevitable. Considering the field limitations in measuring the water requirement, applying empirical models has always been of interest. However, since each estimation model has unique strengths and weaknesses, relying only on an experimental model cannot obtain a reliable estimate for water requirements. This study intends to evaluate different combined methods' ability to merge the saffron water requirements simulations and obtain an improved output. Six empirical models and four other combination techniques were applied to get some skilful simulations about saffron water requirements in arid regions. Results indicate that the evapotranspiration prediction under the Abtew method (ABM) has more proficiency, such that its RMSE was 0.13 mm. Also, the different comparative tests show that the outputs of combined techniques such as Multi Model Super Ensemble 'MMSE' and Modified MMSE 'M3SE' outperform others.

Keywords: Empirical Evapotranspiration Models, Ensemble Modeling, Multi- Collinearity, Post Processing.

1. Introduction

Accurate estimation of crops' water requirements and evapotranspiration can improve the management of water consumption in the agriculture section. Because enhancing water productivity is one of the ways to manage water consumption in the agricultural sector and increase its efficiency (Kouzegaran et al., 2020). The importance of this issue for strategic agricultural products is more than others. With the scientific name Crocus sativus L, Saffron is a strategic product in many aspects in the east of Iran. This plant creates jobs and high income for many rural areas (Dessein et al., 2015), and people have used saffron as an additive and flavoring spice long ago (Rimani et al., 2019; Stelluti et al., 2021; Cid-Pérez et al., 2021). Also, saffron can be considered a medicinal plant with a special place in traditional medicine (Abu-Izneid et al., 2020; Lu et al., 2021).

Iran is currently the world's largest producer of saffron, and the largest cultivated area of this crop belongs to Iran (Shahnoushi et al., 2020). Almost 90% of saffron production and more than 84% of its vastitude in the world belongs to Iran (Ramezani et al., 2022). The farmland area of this plant in Iran in 2013 was 72,162 hectares, of which two provinces of Razavi and Southern Khorasan farmed more than 70,000 hectares (57,000 hectares to Razavi Khorasan and 13,000 hectares to South Khorasan) (Azgomi et al., 2021). Therefore, it is necessary to keep this strategic product's position in the region's development by adjusting water consumption management. Since the incorrect estimation of water requirements will lead to wrong planning and consequently cause the waste of water resources, accurate estimation is the starting point in this direction. Considering the substantial cultivated area of this product in the eastern parts, researchers have to make a diligent effort to improve the saffron water requirement modelling.

Literature indicates that the pioneers of the evaluation of saffron's water requirements (SWR) are Iranian academic scholars and the background of these studies goes back to the late 1370s when Alizadeh and his colleagues conducted the first studies on the water requirement of saffron in Khorasan province (Alizadeh et al., 1999; Alizadeh, 2006). Also, Sepaskhah and his colleagues, a few years later, started new studies focusing on the SWR in Shiraz state (Shirmohammadi Aliakbarkhani et al., 2006; Azizi-Zohan et al., 2008; Sepaskhah and Yarami, 2009; Yarami et al., 2011). They measured the SWR on a local scale by implementing lysimetric laboratories based on the water balance content. For example, Azizi-Zhohan et al. (2008) study focused on investigating the effect of irrigation method and interval on saffron yield. In another study, Sepaskhah and Kamgar Haghighi (2009) investigated the characteristics of saffron irrigation and its water requirement. After the initial research, more recent studies, practically after 2010, examined other aspects related to saffron irrigation (Maleki et al., 2011; Yarami and Sepaskhah, 2015; Jafarzadeh et al., 2015; Shamsabadi et al., 2016; Yarami and Sepaskhah, 2016; Fallahi and Mahmoodi, 2018; Koocheki et al., 2016; Koocheki et al., 2020).

Hagan et al. (1967) believe that potential evapotranspiration should be measured directly (like the above studies) or estimated using physical or empirical process. In the physical ones, the scientific understanding of the evapotranspiration process is described via mass conservation and energy balance. The most well-known and widely used methods in this category are Penman, Penman-Montieth, FAO Penman-Montieth (FPM), and Priestly-Taylor Method (PTM). While empirical models are based on the inferred relationships in which local climate variables play a crucial role. The water requirement and crop coefficients of saffron for regions with no lysimetric facilities cannot be directly measured, and in these conditions, the physical or empirical models are alternatives to estimate the water requirement. For the first time, in 1948, Thornthwaite presented an empirical equation describing the reference evapotranspiration based on the temperature and day length. The historical path of the most improvement of potential evapotranspiration was presented in Table 1.

On the other hand, Penman (1948) presented the radiation-aerodynamic equation to explain physical evapotranspiration (Penman, 1948). In those years, other relationships were also presented. For example, Blaney Criddle and Turc equations were introduced in 1950 and 1961 (Blaney and Criddle, 1950); later, Jensen and Haise (1963) presented a relationship for calculating evapotranspiration based on daily temperature and solar radiation. Due to solar radiation, this method is expected to work better than temperature-based methods (Jensen and Haise, 1963). Monteith revised the Penman equation in 1965 and introduced the Penman-Monteith equation (Monteith, 1965). Also, Priestley and Taylor developed the Penman-Monteith equation to simplify its applicability by removing the aerodynamic terms and adjusting a constant factor. Further, Hargreaves and Allen (1998) presented a simple equation based on temperature and solar radiation (Hargreaves and Allen, 2003). Finally, by reviewing the existing equation, FAO Irrigation and Drainage added aerodynamic conditions and surface resistance into the Penman-Monteith equation and provided a standard method (Allen et al., 1998). In recent years, many diligent efforts have also been made to provide new methods for estimating potential evapotranspiration (Carlson and Petropoulos, 2019; Allies et al., 2020; Delogu et al., 2021; de Souza et al., 2022). However, applying the physical and empirical methods is always accompanied by uncertainties due to some simplifying assumptions.

Table 1. Background of historical development of potential evapotranspiration models by pioneers

Items	Author	Year	Advancement
1	Penman	1948	Provided a radiation-aerodynamic equation to explain physical evapotranspiration
2	Blaney and Criddle	1950	Introduced new equation based on climate features such as temperature and rainfall
3	Turc	1961	Present a new energy-based equation through radian and temperature
4	Jensen and Haise	1963	Presented a relationship for calculating evapotranspiration based on daily temperature and solar radiation
5	Monteith	1965	Revised the Penman equation and introduced the Penman-Monteith equation
6	Priestley and Taylor,	1972	Developed the Penman-Monteith equation to simplify its applicability by removing the aerodynamic terms and adjusting a constant factor
7	Hargreaves and Allen	1985	Presented a simple equation based on temperature and solar radiation
8	FAO	1988	The aerodynamic conditions and surface resistance were included into the Penman-Monteith equation (reported in Allen et al., 1998)

Despite all efforts and valuable advancements in the estimation of potential evapotranspiration and water requirements, it should be stated that each of the mentioned models has its strengths and weaknesses, and this issue highly influences their final outputs. Indeed, due to the above limitations, achieving a reliable prediction by relying on a single model is impossible (Duan et al., 2007; Wang et al., 2015; Huang et al., 2022). Hence, in recent decades, researchers have recommended combining several models rather than a single model to obtain a more reliable output in water engineering studies. Ensemble modeling is a new debate that is currently expanding rapidly in various sciences, and its application to improve results has received much attention (Zhou, 2019; Afan et al., 2021). Conceptually, ensemble modeling can contain techniques in which several samples are generated from simulations and combined with each other to produce a boosted output (e.g., Boosting and BAGGING). Also, in complex methods, the outputs of several simulator models are combined to produce an improved simulation (combination methods). In combination techniques, the researcher can simultaneously use the output of the simulator models from machine learning, conceptual, analytical, and semi- or fully-distributed models. From the perspective of theory, these methods are divided into Simple Model Averaging (SMA) and Weighted Averaging Modeling (WAM) methods. However, in recent years, new methods have been introduced, including Bayesian Model Averaging (BMA) and Multi Models Super Ensemble (MMSE). Although the good performance of these methods in surface water (Ajami et al., 2006; Duan et al., 2007; Pourreza Bilondi et al., 2019; Samadi et al., 2020), groundwater modeling (Jafarzadeh et al., 2021, 2022), and infiltration (Abdalla et al., 2020) has been reported frequently, studies focusing on the examination of combination techniques' ability in improving the physical and empirical models outputs of the SWR received less attention.

By appropriately implementing ensemble modeling, the advantages of this approach can be harnessed in field studies. For instance, instead of using a single ETO model in isolation, multiple models can be employed simultaneously through combination methods, yielding a significantly improved output.

The review of performed studies clarifies some research deficiencies in SWR's studies: first: the studies focusing on applying combination techniques (SMA, WAM, MMSE, and M3SE) in improving water requirement are minimal. Second, paying attention to saffron, the main strategic product in the eastern regions of Iran, is one of the most crucial research necessities in this field. Third: considering some different combination techniques simultaneously for enhancing water requirement simulation was performed in the fewer studies. Therefore, the motivation of this study is to examine the effectiveness of the different approaches of combination techniques in improving the SWR. Further, an open-source framework coded in Python was presented that can be used as a practical tool and a guideline for related future studies.

2. Materials and Methods

This section describes the strategy used to predict water requirement and to perform ensemble modeling. The applied steps and performed methods are explained in detail.

2.1. Study Area and Data

Birjand plain is located in the east of Iran, where annual rainfall is low (<100 mm), and its climate pattern is considered an arid region (Jafarzadeh et al., 2019, see Figure 1). This study followed Khashei-Siuki et al. (2020) and Ghavamsaeidi Noghbi et al. (2020) and builds the proposed research plan through their findings.

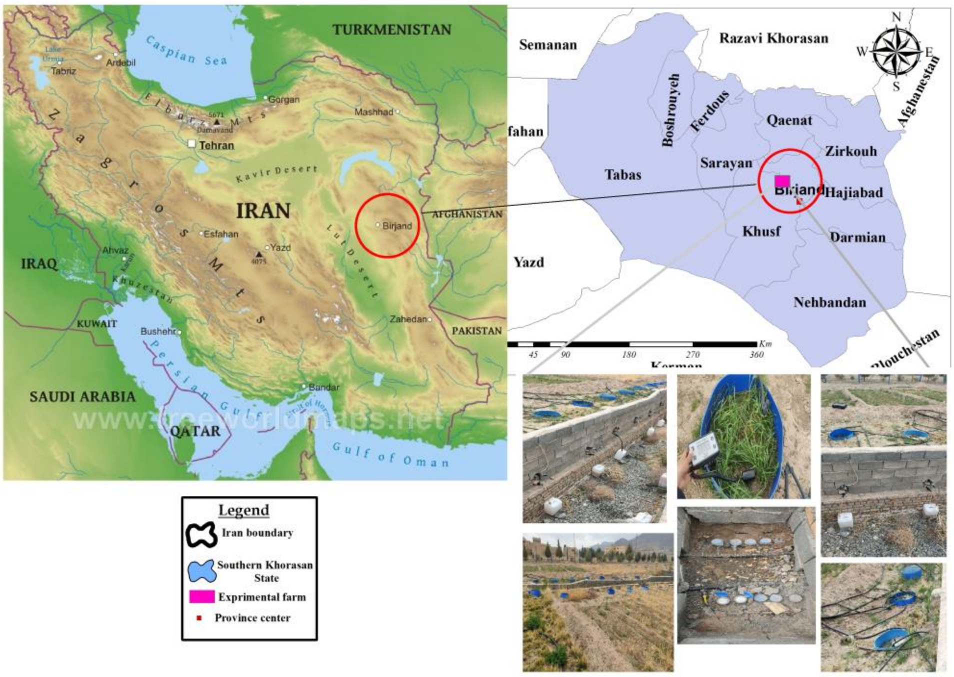

Fig. 1. Map showing the location of study area in Birjand state: right-above illustrating international geographical map of IRAN, left-above demonstrating the Southern Khorasan and its state, and down picture represents the lysimeter lab facilities used in this study.

A scientific and realistic experiment contained the six lysimeters (three for saffron and the remainder for reference-crop of grass) was executed on a farm-based investigation at the University of Birjand ($32^\circ\,53'N, 59^\circ\,7'E, 1480\,msl$) to measure the saffron water requirement and its crop coefficient. Description of key features of this site are presented here. The circle-polymer lysimeters with diameters and heights of 0.9 and 1 m were installed into the ground with an interval distance of 1 m (see Figure. 1). The last 15 cm of each lysimeter has a slope of 6.7 % and it was filled with more coarse-grained gravel to provide drainage facilities. Also, to record the drained water a piping system leads the output water to a small tank in the bottom.

The operator of the digging returned the excavated soil to its initial position. Also, the analysis of taken samples from different parts indicates that the major structure of the soil in this farm was loam. Tables 2 and 3 represent the chemo-physical contents of the derived samples.

The process of planting was accomplished on 15 September 2018 at a depth of 17-25 cm and a density of 6 for each lysimeter. Just one month later, the saffron corms were watered and 10 days later their flowering were started and took 25 days. The irrigation was performed at intervals of seven days through the basin method and a piping system equipped with a water meter. The growing season of saffron and irrigation planning was from 8-Nov-2020 to 18 May 2021 in the second year (180 days) in which four rainfall events (21.3 mm) occurred. Also, a portable potentiometer (TDR 150 Spectrum) measures the soil-water content (see Figure 1) at before and after any irrigation.

Table 2. Physical and chemical components of soil in the Birjand investigation site

Depth	Texture	Bulk density	θ_{FC}	θ_{PWP}	Ec	pH	Organic carbon
cm	-	$g.cm^{-3}$	%	%	$ds.m^{-1}$	-	%
0-30	Loam	1.4	17.9	11.8	8.12	7.8	0.49

Table 3. Chemical components of used water in Birjand investigation site

Component	unit	magnitude
Ec	$ds.m^{-1}$	1.4
pH	-	8
SAR	%	7.5
Ca^{++}	$meq.lit^{-1}$	3.5
Mg^{++}	$meq.lit^{-1}$	2.7
Na^{+}	$meq.lit^{-1}$	13.3
K^{+}	$meq.lit^{-1}$	0.08
Cl^{-1}	$meq.lit^{-1}$	8.8
$Hcom_3^{-1}$	$meq.lit^{-1}$	4.9
Com_3^{-2}	$meq.lit^{-1}$	0
So_4^{-2}	$meq.lit^{-1}$	6.4

The second-year water requirement of saffron was gained based on the moisture balance equation as following:

$$ETc = I + P - D \pm \Delta s \quad (1)$$

Where ETc indicates actual water requirement (mm), I denotes the volume of irrigation (mm), P represents rainfall (mm). Also, D and Δs indicate, respectively, drained water and variation of moisture content (mm). Finally, Khashei-Siuki et al. (2020) computed the daily average of 10 days-water requirements in each lysimeter. Figure 2 gives derived temporal variability of potential evpotranspiration of reference crop (ETo) next to saffron’ potential evpotranspiration (ETc) and its crop coefficients for second-year. The value of ETo and saffron ETc during growing season were respectively 543 and 365 mm.

Further, the required considerations about pre-process practices, including missing values, outliers’ elimination, and stationary assumptions, were addressed and confirmed.

2.2. Evapotranspiration Models

Six experimental models (ETo models) were hired to evaluate daily potential evapotranspiration. The estimated SWR was then derived concerning saffron crop coefficients (see Figure. 2). The required explanation of these methods formulation is presented here.

2.2.1. FAO Penman-Montieth (FPM)

The FPM, a deep-rooted method, is formulated based on energy balance and aerodynamic ingredients. Compared to other empirical models, it requires more climate features resulting in intensive calculation. FPM formulation can be expressed as followings:

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\left[\frac{900}{T+273}\right]U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad (2)$$

where ET_O, R_n, T, U_2, e_s, and e_a denote, respectively, potential evapotranspiration ($mm.day^{-1}$), net radiation ($MJ^{-2}.day^{-1}$), average of air temperature (C°), wind speed ($m.s^{-1}$), saturation vapor pressure (kPa), actual vapor pressure (kPa), while Δ, γ and G represent, respectively, slope of the vapor pressure curve ($kPa.C^{-1}$), Psychrometric constant ($kPa.C^{-1}$), and soil heat flux density ($MJ^{-2}.day^{-1}$). Based on the FAO-paper 56, Δ is computed through average temperature and Psychrometric constant is earned based on the sea level elevation. Also, R_n is calculated by shortwave and longwave radian. A detailed description about FPM structure and computation steps is presented in the reference text especially FAO-paper 56.

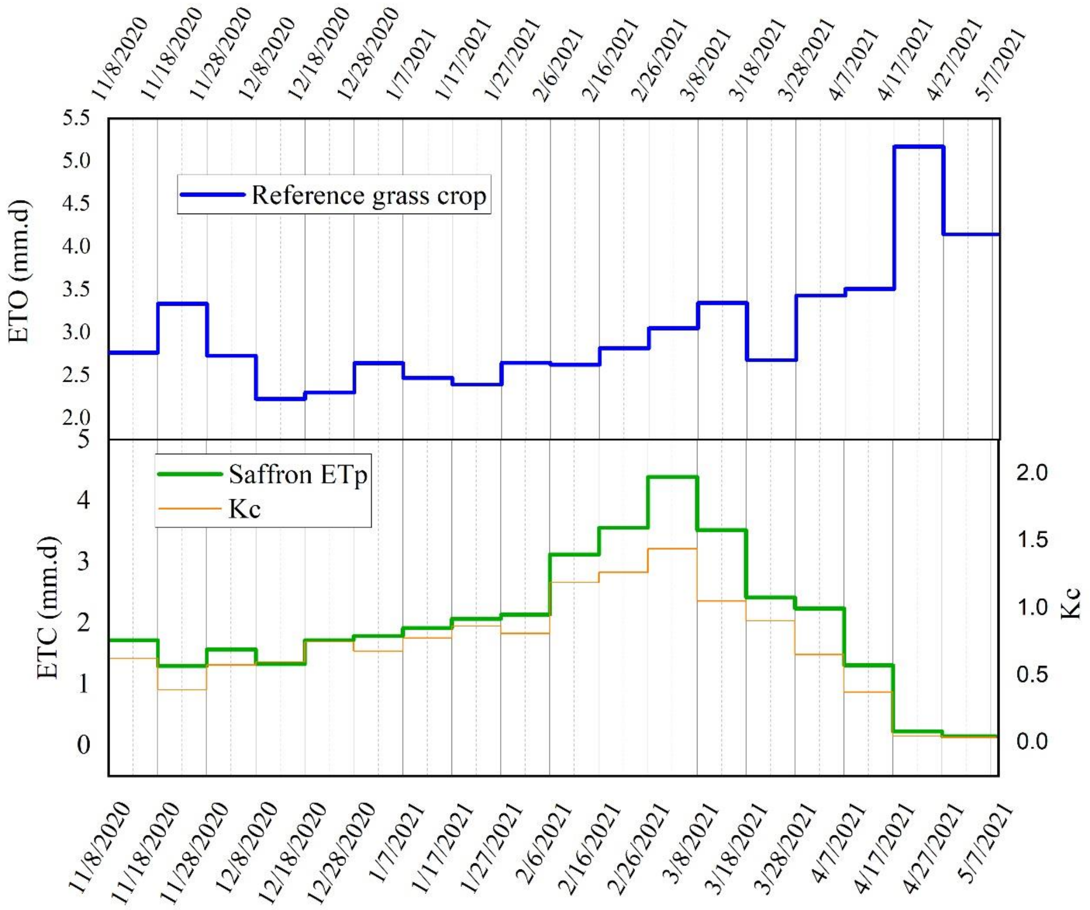

Fig. 2. A row-panel demonstrating: (first row) the potential evapotranspiration for reference grass crop and (second row) the potential evapotranspiration for saffron along with its crop coefficients

2.2.2. Priestley-Taylor Method (PTM)

PTM is a physically-based model that can be accounted for as a simplified version of FPM by eliminating the aerodynamic content. The formulation of PTM can be described as followings:

$$ET_O = \alpha \frac{\Delta(R_n - G)}{\Delta + \gamma} \tag{3}$$

Where α is a climate factor that give different values based on the climate type.

2.2.3. Hargraves Method (HM)

The HM is a temperature-based model formulated through mean temperature and extraterrestrial solar radiation (R_a). It may be written as:

$$ET_O = 0.0022 R_a * \sqrt{T_{\max} - T_{\min}} . (T + 17.8) \tag{4}$$

where $T_{\min}$ and $T_{\max}$ denote, respectively, minimum and maximum temperature (C°).

2.2.4. Turc Method (TUM)

TUM is an energy balance-based model utilizing relative humidity, mean temperature, and solar radiation and can be expressed as following:

$$\begin{aligned} & ET_O = 0.013\left(\frac{T}{T+15}\right).(23.9R_a + 50).\beta \\ & where, \\ & if\ \underline{T < 0}\ then \rightarrow \beta = 0 \\ & elseif\ \underline{T > 0\ and\ Rh > 50}\ then \rightarrow \beta = 1 \\ & elseif\ \underline{T > 0\ and\ Rh < 50}\ then \rightarrow \beta = \left(1 + \frac{50 - Rh}{70}\right) \end{aligned} \tag{5}$$

where Rh indicates the relative humidity (%).

2.2.5. Jensen Haise Method (JHM)

JHM Model gives an equation to determine ETo relying on daily temperature and solar radiation. Indeed, Jensen and Haise developed temperature-based models incorporating solar radiation content (Jensen and Haise, 1963). The following equation provides the JHM formula:

$$ET_O = \frac{(0.025T + 0.08)R_a}{\lambda} \qquad (6)$$

Where λ denotes the latent heat of vaporization (2.54 $MJ.kg^{-1}$).

2.2.6. Abtew Method (ABM)

ABM is a simplified energy-based model for the computation of ETo and an energy-based model including solar radiation content. The following equation can give its formula:

$$ET_O = 0.53\frac{R_a}{\lambda} \qquad (7)$$

2.3. Combination Techniques

After the above step, a set of participating models consisting of different simulations of SWR is constructed, and it is then used for ensemble modeling to perform post-processing. Indeed, ETO models are participating members in combining process to generate some developed simulation. Descriptin of these procedures are presented in proceed.

2.3.1. Simple Model Averaging (SMA)

This method, SMA utilized by Georgakakos et al. (2004), is the most straightforward approach in which the concept behind is supplanting of standard deviation of attendees with the original deviation as the following:

$$WR_{SMA}^{t} = \overline{WR}_m + \frac{\sum_{i=1}^{n} WR_{Sim}^{t,i} - \overline{WR}_{Sim}^{i}}{n} \qquad (8)$$

where WR_{SMA}^{t} is SMA outcome, n is total number of attendees (here six), $WR_{Sim}^{t,i}$ is the ETc considered for ith input model (i.e., FPM) at time t, $\overline{WR}_{Sim}^{i}$ is the mean of the simulated ETc, and $\overline{WR}_m$ denots the average value with respecy of saffron's ETc.

2.3.2. Weighted Average Method (WAM)

This technique, introduced by Shamseldin et al. (1997), produces a arithmetic mean in which the weight of each participating member is gotten relying on regression fit. WAM formulation can be given as follows:

$$WR_{WAM}^{t} = \sum_{i=1}^{m} x_i.WR_{Sim}^{t,i}$$

$$Z : \min(WR_m - \sum_{i=1}^{m} x_i.WR_{Sim}^{t,i})^2 \qquad (9)$$

$$s.t\begin{cases} x_i > 0 \\ \sum_{i=1}^{n} x_i = 1 \end{cases}$$

where WR_{WAM}^{t}, x_i, WR_m denote, respectively, ETc produced by WAM, weight, and saffron ETc.

2.3.3. Multi Model Super Ensemble (MMSE)

This process, presented by Krishnamurti et al. (1999), is similar to SMA and displace the original deviation with a deviation of participating member. However, in MMSE the weights can take any rational value without a specified limit. The MMSE output can be received through followings:

$$WR_{MMSE}^{t} = \overline{WR}_m + \sum_{i=1}^{n} x_i.(WR_{Sim}^{t,i} - \overline{WR}_{Sim}^{i}) \qquad (10)$$

Where WR_{MMSE}^{t} is the water requirement produced by MMSE considered for t.

2.3.4. Modified MMSE (M3SE)

One of the last progress of the combination technique is M3SE method, introduced by Ajami et al. (2006). In this method, the bias error of any participatings' outputs is first corrected through frequency mapping technique, and a strategy similar to MMSE is then applied to produce M3SE. More details about combination techniques can be found in related studies (Jafarzadeh et al., 2021).

2.4. Model Development

The applied steps of this study are presented and explained here. First, we determined the 10-day water requirement of saffron for each lysimeter for the simulation period, and their average was then evaluated (i.e., 18 steps). Additionally, climate variables such as temperature, humidity, wind speed, and rainfall was collected from Birjand synoptic station for the simulation period. At the second step, the prediction of potential evapotranspiration was performed through six different models. At third step, the simulations of saffron water requirement were gained using these models and crop coefficients obtained from Khashei-Siuki et al. (2020) and Ghavamsaeidi Noghbi et al. (2020). The daily water requirement simulations for each model were converted to a 10-day scale similar to measured values. In fourth step, different combination techniques then captured the output of the evapotranspiration models to generate four new estimations. The ranking ability and performance comparison of evapotranspiration models and combination techniques were accomplished using comparative tests and quantitative criteria such as Root Mean Square Error (RMSE). Note that all the above-mentioned steps were coded in Python version 3.4, available in Visual Studio code editor version 1.72.

3. Results and Discussion

Here actual results received from different models and their estimations concerning the water requirement of saffron are presented. Also, the comparison between the outputs of the empirical models (evapotranspiration models) is brought up, along with the performance assessment of the different combination techniques. In addition, analyzing the derived results with findings of related studies has been discussed here.

3.1 Modeling Performance

This part handles the skill ranking of various evapotranspiration models in terms of the prediction of saffron water requirement. Figure 3 displays the time series of 10-day measured and predicted water requirements for the four best models (for brevity and better display). The derived results in this part disclosed that ABM outperformed others, PTM, and HM, respectively, are in second and third places, and Turk prediction is the worst. Besides the ABM model, there is no significant difference between the models (see Figure. 3). Also, Figure 4 delivers the ability of different models in terms of the RMSE index. The average simulated water requirement was obtained at 363.3 mm, while the measured water requirement of saffron in the second growing year was reported at 365 mm by Khashei-Siuki et al. (2020).

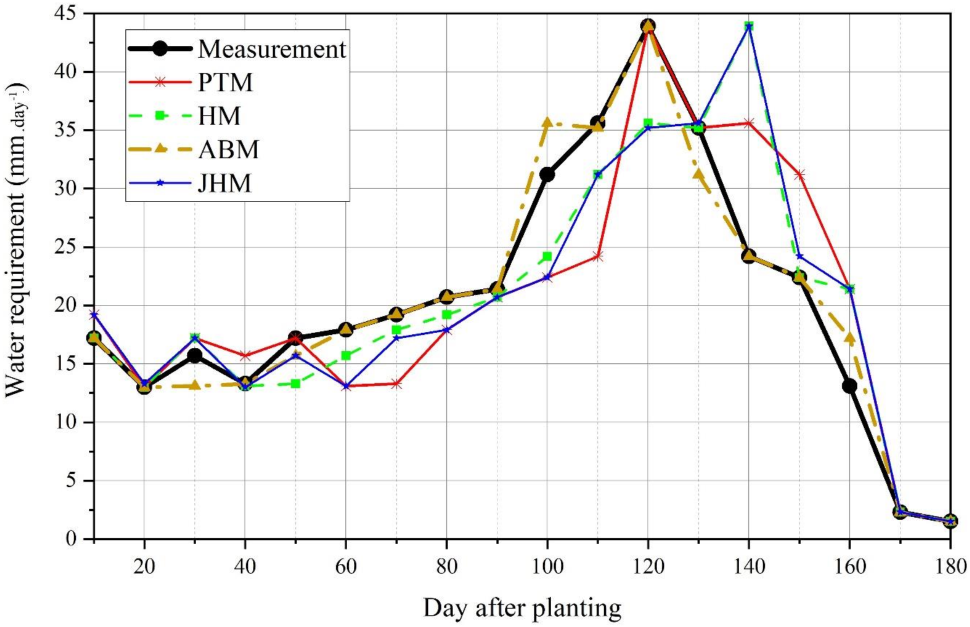

Fig. 3. Illustration the time series of the measured and simulated saffron water requirement.

3.2 Combination Techniques Application

The emphasis of this section is on coupled comparing various evapotranspiration models with the combination techniques. Table 4 represents the ability results in terms of the RMSE criterion of using combination techniques to produce the time series of saffron water requirements along with empirical models. The RMSE criterion confirmed the high ability of combination approaches for solving the existing biases and errors of prediction. From this perspective, the WAM, MMSE, and mainly the M3SE were superior models, while the SMA result was inferior. The more careful examination implies that the M3SE produced an enhanced simulation accurately compared to others.

The outputs of the different combination techniques and ABM model, as the best empirical model, was shown in Figure 5. Results suggested that the M3SE process is a professional simulator along with the ABM model and MMSE. In contrast, the output of WAM has less accuracy than those mentioned models. Also, SMA predicts the water requirement accompanied by over or underestimation during the simulation period. The derived results of this section are consistent with the findings of Ajami et al. (2006), Shamshirband et al. (2019), and Jafarzadeh et al. (2021). These studies firmly declared and confirmed that the ability of more sophisticated combination techniques such as M3SE is more pleasing than other methods. The probable reason for superiority of M3SE may be related to some incorporated process in this method such as frequency mapping replacing values with same frequency resulting more accurate prediction.

Other tests have been scheduled to compare the performance of combination techniques better. In this section, the accomplished absolute error during the simulation was shown and compared simultaneously through a heat map (Figure 6) for all combination techniques and empirical models.

Table 4. The RMSE values (mm) for different combination techniques in generating saffron water requirement.

Method	RMSE (mm)	Method	RMSE (mm)
PTM	0.559	JHM	0.613
FPM	0.676	SMA	0.754
HM	0.587	WAM	0.429
TUM	0.740	MMSE	0.225
ABM	0.185	M3SE	0.136

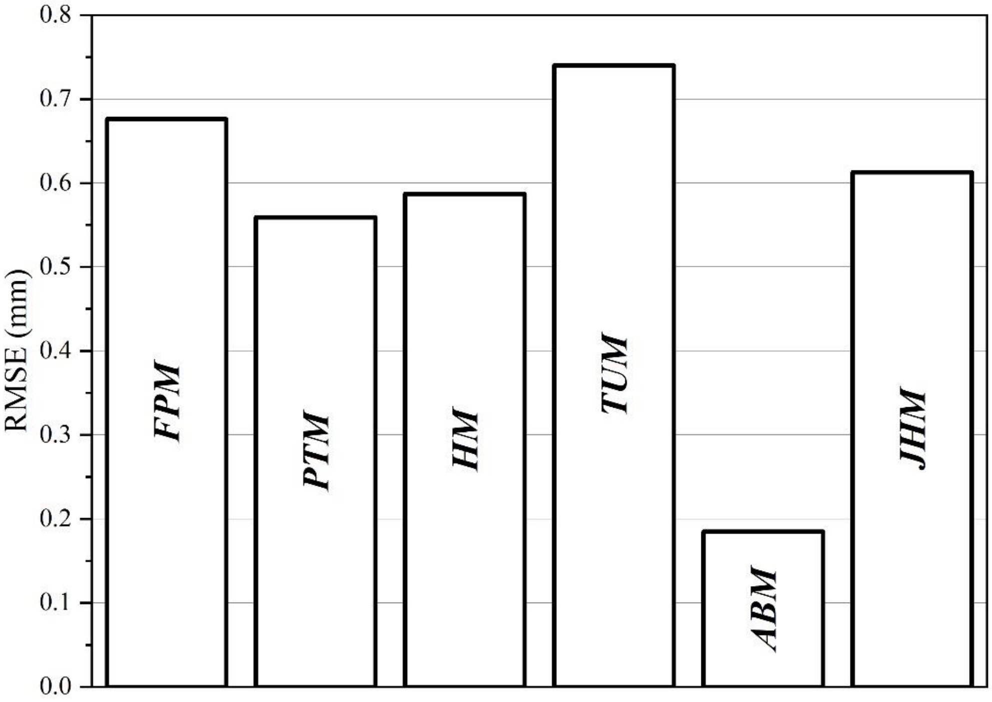

Fig. 4. RMSE values (mm) for the empirical evapotranspiration model in estimating water requirement. Good performances are bolded.

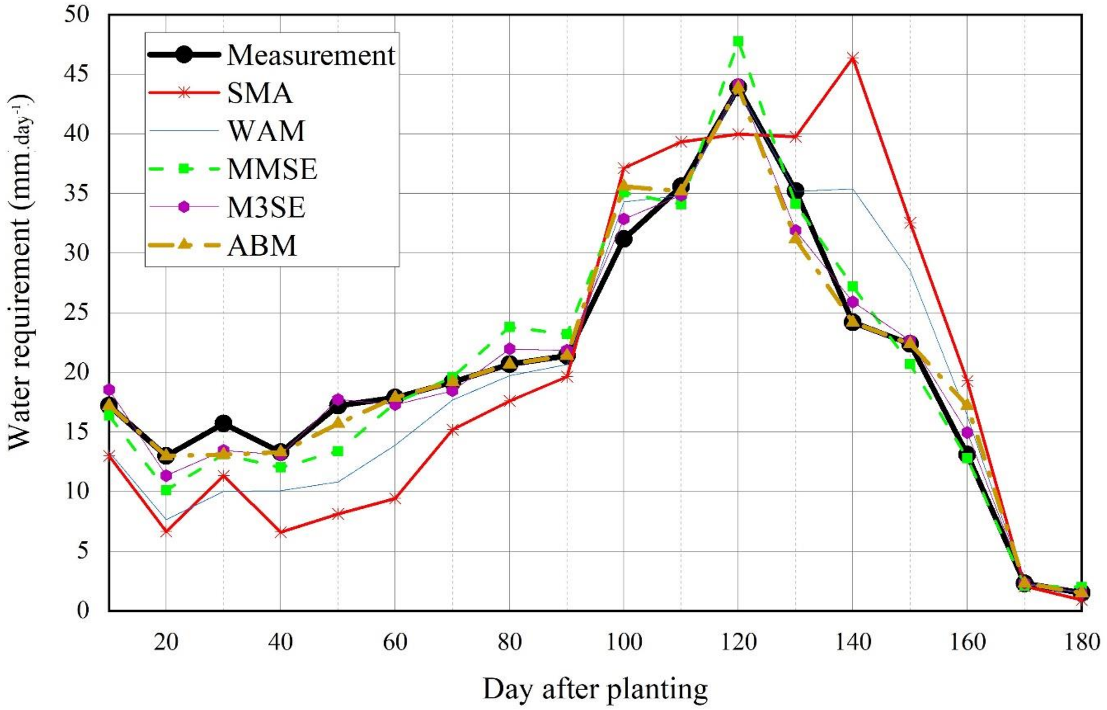

Fig. 5. Time series of water requirement of saffron showing a comparison among measured and simulated values

This figure indicated that the color of the absolute error in more sophisticated combination techniques, MMSE and specially M3SE, is lighter than that for other models. Similar to the previous experiment, someone can tell that the M3SE, ABM, and MMSE accomplish more promising than others, especially in the last simulation steps when a large portion of error has arisen.

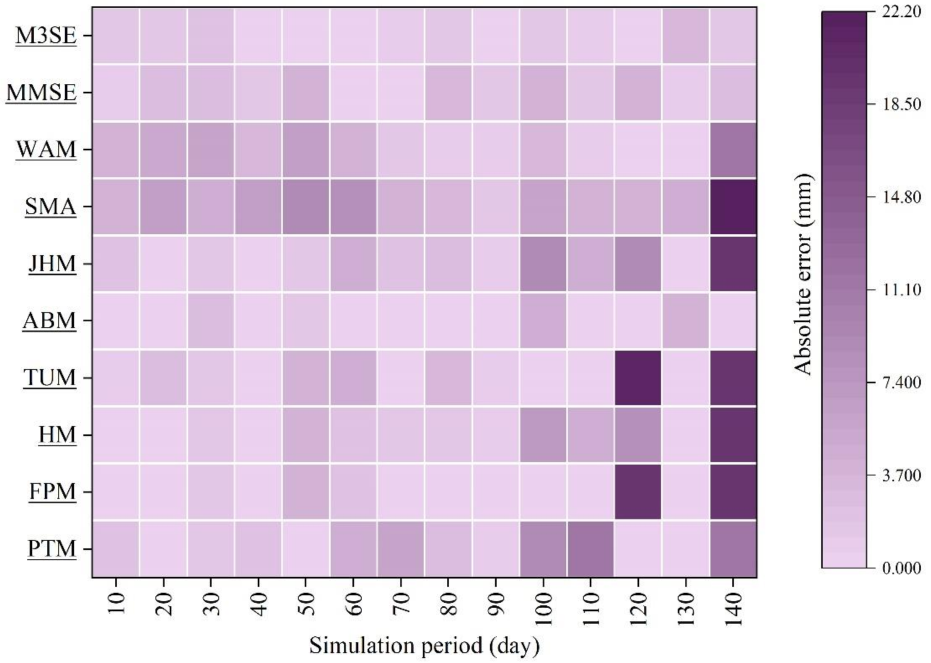

Fig. 6. Color map illustrating the absolute error variations during simulation period for all models

Figure 7 pictures the violin plots of measured versus simulated water requirements. A violin plot identifies the frequency thickness along with and box plot. The grey boxes and white circles in this plot display a 95 percent band and the average saffron water requirement. Also, the colorful two-sided distribution denotes the Kernel density of samples (black circle into violin). This diagram appropriately calls to mind the distinction of M3SE to other models, even the ABM model, because the violin plot acquired by M3SE is more relative to measurement ones.

In addition, to more precise Arbitration between different models, the estimates of the various combination techniques, along with ABM and PTM models, are exhibited in the form of a scatter plot to deal with the prediction status in terms of over and underestimation (Figure 8). As this figure shows, the outcome of saffron water requirement in MMSE and M3SE has more precision than other combination procedures.

Different comparative investigations in this section substantiated that the combination techniques could make the water requirement simulations of saffron more desirable efficiently. Also, derived results announced that M3SE offers the best performance across the combination techniques and can significantly decline total uncertainty.

Following the acquisition of the results mentioned above, it is reasonable to expect that these techniques will prove valuable in practical field investigations. By employing the M3SE approach, we can generate a composite output from a set of ETO models, rather than depending on a single model. This shift guarantees a notably enhanced level of accuracy compared to previous simulations.

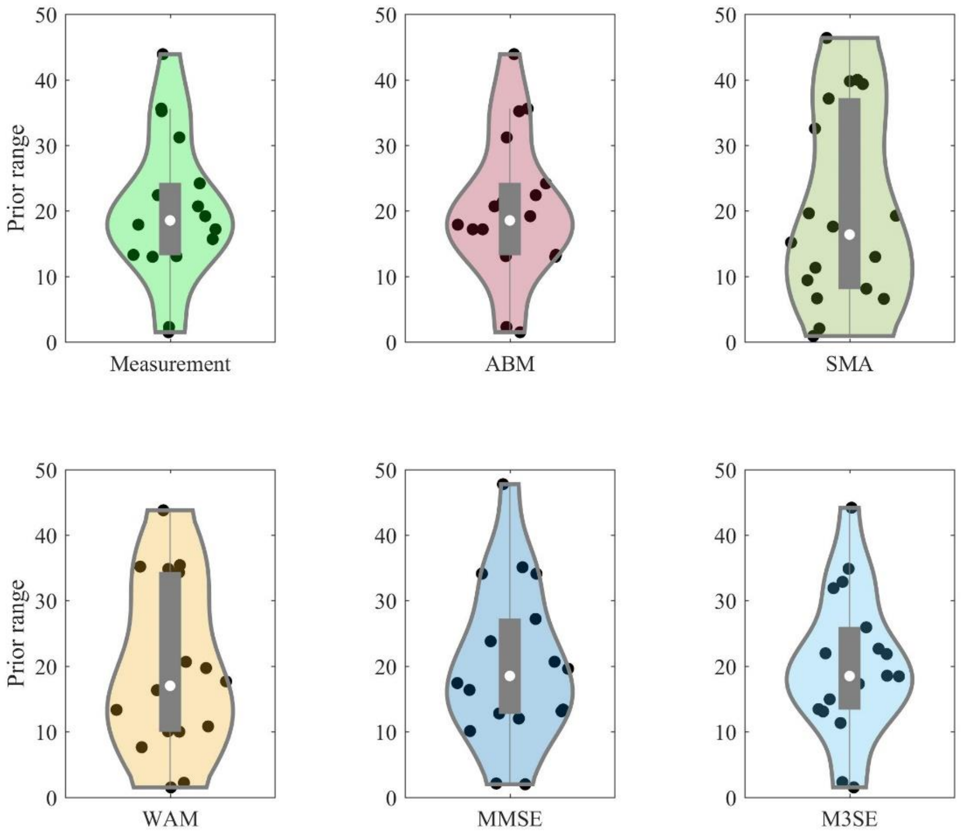

Fig. 7. A schematic view of violin plot illustrating the comparison of measured and evaluated water requirements of saffron

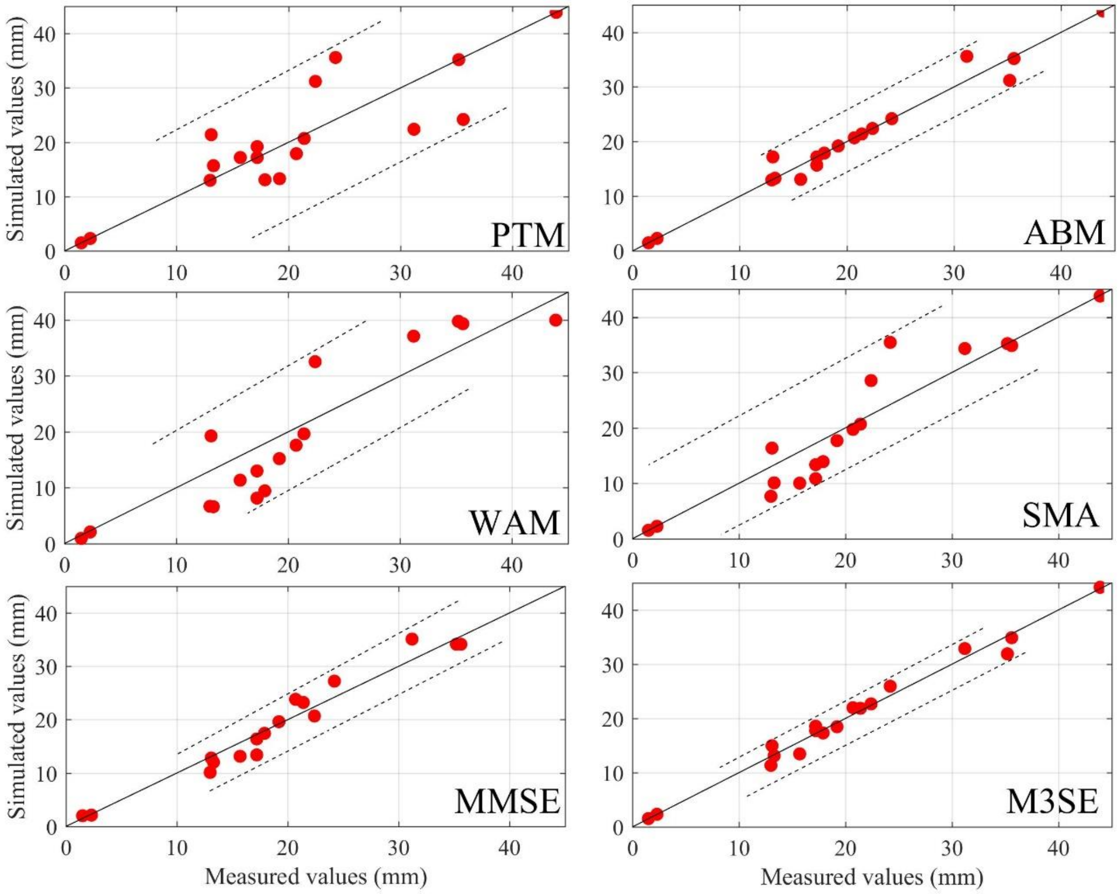

Fig. 8. Comparison of saffron water requirement prediction from different combination techniques and ABM model with measured values.

3.3 Estimated Weights Results

The discussion of this section is to address the weights estimated by different combination techniques. Indeed, the fact that each combination technique how generates a weighted average of water requirement simulation is assessed here. Table 5 represents the weights calculated by combination techniques. As seen, the SMA thought an identical weight for evapotranspiration models and failed their superiority. Also, the WAM eliminates the contribution of some participatings, such as FPM, HM, TUM, and JHM, so the assigned weights for these models were extremely low.

Further, the corresponding weights estimated by MMSE and M3SE do not relate to the performance of attendees. For example, the most weight in MMSE processes is given to the HM model, while the performance of the ABM and PTM is more pleasing than HM (see previous test, especially Table 3). This result, previously reported in hydrology and groundwater context (Raftery et al., 2003; Ajami et al., 2006; Shamshirband et al., 2019; Jafarzadeh et al., 2021), is related to multi-collinearity arising when the similarity and dependence between input models are significant.

This subject confuses the interpretations of combination techniques' applicability. However, it is inferred from the received results about estimated weights that the weights calculated by M3SE are accompanied by a more identical distribution.

Table 5. Empirical models weights estimated through combination techniques

ETo	Weights			
Models	SMA	WAM	MMSE	M3SE
PTM	1	0.33	-0.447	-0.009
FPM	1	6.67e-15	0.234	0.741
HM	1	0	141.849	-0.844
TUM	1	3.05e-14	-1.600	-0.750
ABM	1	0.67	-57.222	0.914
JHM	1	1.30e-14	-78.448	0.946

4. Conclusion

A practical framework for attaining a skillful prediction about saffron water requirements in eastern regions of Iran was introduced and reviewed here. To create an improved saffron water requirement, we compared the capability of combining approaches, including SMA, WAM, MMSE, and M3SE. The six empirical evapotranspiration models were hired to predict the potential ETo and the saffron water requirement in the Birjand investigation site. The relevance of different combination techniques was investigated through various comparative experiments to show how much the accuracy of combining methods contrasts among different models.

This study's findings revealed that the ABM model performs better than others in predicting saffron water requirements. The measured saffron water requirement was equal to 365 mm, while the value predicted by the ABM model was 364.1 mm. Obtained results from different tests confirmed that MMSE and especially M3SE work better than others. Therefore, these models can be accounted for by integrating available predictions and generating an enhanced simulation of saffron water requirement (strategic production in the eastern regions of Iran).

There seems to be a general conformity for devoting ensemble modeling as a post-processing stage to generate skillful prediction. There are many possible fields in which it will be felt that future studies are essential. The recommendations of this study for employing combining methods in water requirements are listed.

Despite the robust ability of some combination techniques, MMSE and M3SE, the interpretation of weights estimated by these methods due to existing multi-collinearity can be severing complicated. Therefore, it would be helpful to simulate the water requirement with more reliable ensemble modeling, such as Bayesian Model Averaging (BMA) and more advanced BMA proposed by Jafarzadeh et al. (2021b).

The findings of this study are specified to limited datasets and case studies. Hence, testing the proposed framework on other sites with different conditions is worth testing.

The application of these methods has only been considered in the studies of rainfall-runoff, groundwater, and water requirement, and their evaluation in other sectors of water resources has not been given serious attention yet.

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No potential conflict of interest was reported by the authors.

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