Modelling Evapotranspiration to Increase the Accuracy of the Estimations Based on the Climatic Parameters

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Abstract The potential evapotranspiration was estimated using different mass transfer-based models and was compared with the Food and Agriculture Organization Penman–Monteith model. The results showed that the Albrecht model estimates the potential evapotranspiration better than the other models in the most provinces of Iran (23 provinces). The best values of R^2 were 0.9854 and 0.9826 for the Brockamp–Wenner and Albrecht models in Bushehr (BU) and Tehran provinces, respectively. Finally, a list of the best performance of each model has been presented. The best weather conditions (not only for Iran but also for all countries) to use mass transfer-based equations are 23.6–24.6 MJ m⁻² day⁻¹, 12–26 °C, 18–30 °C, 5–21 °C, and 2.50–3.25 m s⁻¹ (with the exception of Penman) for solar radiation, mean temperature, maximum temperature, minimum temperature, and wind speed, respectively. The results are also useful for selecting the best model when researchers must apply mass transfer (humidity)-based models on the basis of available data. In addition, the designed maps and categories are applicable for considering the role of climatic parameters in architectural evaluations over Iran.

Keywords Architecture · Evapotranspiration · FAO Penman–Monteith · Humidity · Iran · Linear regression · Mass transfer · Optimum design · Prevailing wind

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Introduction

The best estimations of actual evapotranspiration are obtained by using a lysimeter or imaging techniques, the costs of which are very high [1–7]. Thus, the Food and Agriculture Organization (FAO) Penman–Monteith model [8] has become one modelling approach to estimate the potential evapotranspiration [9–14]. Although the FAO Penman–Monteith (FPM) model has been applied in various regions of the world [15–24], its application requires many parameters which are often difficult to obtain. To this end, experimental models have been developed for estimation of the potential evapotranspiration using limited data. They include mass transfer, radiation, temperature, and pan evaporation-based models. The mass transfer-based model is one of the most widely used models to estimate potential evapotranspiration. The common mass transfer-based models include Papadakis, Rohwer, Dalton, Ivanov, Meyer, Trabert, and World Meteorological Organization (WMO) [25–35].

Azhar and Perera [36] calibrated the Meyer model as well as nine other (temperature and radiation-based) models under Southeast Australian Conditions successfully. Acheampong [2] considered the Penman, Thornthwaite, and Papadakis models for the estimation of the potential evapotranspiration for Ghana. Under the varying weather and climatic conditions over the country, the modified Penman method was found to be most suitable for estimating the potential evapotranspiration for Ghana. More examination of the performance resulted in the following rank of preciseness as compared with the FPM estimates: Priestley–Taylor, Makkink, Hargreaves, Blaney–Criddle, and Rohwer [37]. The adjusted Dalton model gives the better estimation of the potential evapotranspiration compared with the adjusted Penman–Monteith model for the Kendall subwatershed located in Tucson, Arizona [38]. The top six methods obtained for the average as well as for central Saudi Arabia ratings are ranked in the following order of merit: Jensen–Haise, class A

pan, Ivanov, adjusted class A pan, Behnke–Maxey, and Stephens–Stewart [39]. Hargreaves [40] calibrated the Hargreaves, Makkink, Turc, Priestley–Taylor, Jensen–Haise, Doorenbos–Pruitt, Abtew, McGuinness–Bordne, Rohwer, and Blaney–Criddle models. It can be concluded that calibration can be used to modify the potential evapotranspiration equations with multi-station data to improve the preciseness of the potential evapotranspiration estimates in Northwest China. Singh and Xu [51] evaluated the Meyer, Dalton, and Rohwer models for determining free water evaporation at four climatological stations in Northwestern Ontario, Canada. The results of the comparison showed that all equations were in reasonable agreement with observed evaporation. Jakimavicius et al. [41] compared the Dalton, Trabert, Meyer, WMO, Mahringer, Thornthwaite, Schendel, Hargreaves–Samani, Irmak, and Kay–Davies models. The study revealed that the Thornthwaite and Schendel models gave the most precise assessment in estimating the evaporation from the Curonian Lagoon, Baltic. Bormann [34] compared the Dalton, Trabert, Meyer, WMO, and Mahringer models with some of other temperature and radiation-based models to analyse climatic change in Germany. He showed significant difference between performances of all models.

In the previous studies, one or more of the mass transfer-based models have been compared with temperature, radiation, or pan evaporation-based models and, in the most of the cases, other models (temperature, radiation, or pan evaporation-based models) estimated the potential evapotranspiration better than the mass transfer-based models. The previous studies focus on specific (humid, arid, semi-arid, etc.) weather conditions (that they are not suitable for applying the mass transfer-based model) and/or did not consider many methods of mass transfer-based models. Moreover, the results of previous studies are not useable for estimation of the potential evapotranspiration in other regions. Because they were recommended for one or more climatic conditions, there was a climatic condition that contains a wide range of magnitude of each weather parameter (e.g. temperature, relative humidity, wind speed, and solar radiation) and the results of each research (for a region with specific weather variations) are not applicable to other regions without determining specified ranges of each weather parameter even if climatic conditions (e.g. humid, arid, semi-arid, and temperate) are identical for both regions. In addition, the governments cannot schedule for irrigation and agricultural water management when the potential evapotranspiration is estimated for a basin, wetland, watershed, or catchment instead a state or province (different parts of them are located in more than one state or province) and/or the number of weather station used is low (increasing uncertainty). This study aims to estimate the potential evapotranspiration for 31 provinces of Iran (considering various weather conditions and being useful for long-term and macroeconomic policies of governments) using the average data of 181 synoptic stations (decreasing uncertainty) and by 11 mass transfer-based models to determine the best model based on the weather conditions of each province (for

which ranges of weather parameters have been determined to use other regions and next researches).

Material and Methods

In this study, weather information (from 1986 to 2005) has been gathered from 181 synoptic stations of 31 provinces of Iran (without data gaps). Table 1 shows the position of each province and the number of stations.

In each station, the average of weather data in years measured has been considered as the value of that weather parameter in each month (e.g. the value of relative humidity in July for North Khorasan (NK) is an average of 20 data gathered). Finally, the average of data in all stations has been considered as the value of that weather parameter in each month for provinces with more than one station (e.g. the value of relative humidity in July for Khuzestan (KH) is an average of $20 \times 14 = 280$ data gathered). All of the data mentioned have been used to estimate the potential evapotranspiration using 11 mass transfer-based models and were compared with the FPM model to determine the best model based on the weather conditions of each province (Table 2).

The best model for each province and the best performance of each model were determined using the coefficient of determination

$$R^2 = 1 - \frac{\sum (ET_{FPM_i} - ET_{m_i})^2}{\sum \left(ET_{FPM_i} - \frac{\sum ET_{FPM_i}}{12} \right)^2} \quad (1)$$

where i indicates the month, ET_{FPM} indicates the potential evapotranspiration calculated for FPM model, and ET_m indicates the potential evapotranspiration calculated for mass transfer-based models.

Finally, a map of the annual average of solar radiation, mean temperature, maximum temperature, minimum temperature, relative humidity, and wind speed was provided and the best performance of each model based on these values was determined. Furthermore, the map of the best model for each province and the map of the error calculated for each province have been presented.

Results and Discussion

Estimating the Potential Evapotranspiration for 31 Provinces of Iran

Table 3 shows the errors for each model and province.

According to the R^2 values, each model estimates the potential evapotranspiration for only one or few

Table 1 Position of all provinces and synoptic stations

Province	Latitude (N)	Longitude (E)	Number of station
Alborz (AL)	35° 55'	50° 54'	1
Ardabil (AR)	38° 15'	48° 17'	4
Bushehr (BU)	28° 59'	50° 50'	5
Chaharmahal and Bakhtiari (CB)	32° 17'	50° 51'	4
East Azerbaijan (EA)	38° 05'	46° 17'	10
Esfahan (ES)	32° 37'	51° 40'	12
Fars (FA)	29° 32'	52° 36'	9
Ghazvin (GH)	36° 15'	50° 03'	2
Gilan (GI)	37° 15'	49° 36'	4
Gorgan (GO)	36° 51'	54° 16'	3
Hamadan (HA)	34° 52'	48° 32'	4
Hormozgan (HO)	27° 13'	56° 22'	9
Ilam (IL)	33° 38'	46° 26'	3
Kohgiluyeh and Boyer-Ahmad (KB)	30° 50'	51° 41'	1
Kerman (KE)	30° 15'	56° 58'	8
Khuzestan (KH)	31° 20'	48° 40'	14
Kurdistan (KO)	35° 20'	47° 00'	7
Kermanshah (KS)	34° 21'	47° 09'	6
Loresstan (LO)	33° 26'	48° 17'	9
Markazi (MA)	34° 06'	49° 46'	4
Mazandaran (MZ)	36° 33'	53° 00'	7
North Khorasan (NK)	37° 28'	57° 16'	1
Qom (QO)	34° 42'	50° 51'	1
Razavi Khorasan (RK)	36° 16'	59° 38'	12
Sistan and Baluchestan (SB)	29° 28'	60° 05'	8
Semnan (SE)	35° 35'	53° 33'	4
South Khorasan (SK)	32° 52'	59° 12'	3
Tehran (TE)	35° 41'	51° 19'	8
West Azerbaijan (WA)	37° 32'	45° 05'	8
Yazd (YA)	31° 54'	54° 17'	6
Zanjan (ZA)	36° 41'	48° 29'	4

provinces with very high accuracy. In the other words, preciseness of estimation by mass transfer-based models

is very sensitive to variations of the parameters used in each model (Table 2).

Table 2 Model used and parameters applied in each model

Model	Reference(s)	Formula	Parameters
FAO Penman–Monteith	Allen et al. [8]	$ET_o = 0.408(R_n - G) \frac{+ \gamma \frac{900}{T + 273} u (e_s - e_a)}{\Delta + \gamma(1 + 0.34u)}$	$H, \varphi, T, T_{min}, T_{max}, RH, u, n$
Albrecht	Albrecht [3]	$ET_o = (1.005 + 2.97u)(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
Brockamp–Wenner	Brockamp and Wenner [25]	$ET_o = 5.43u^{0.456}(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
Dalton	Dalton [26]	$ET_o = (3.648 + 0.7223u)(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
Ivanov	Romanenko [31]	$ET_o = 0.00006(25 + T)^2(100 - RH)$	T, RH
Mahringer	Mahringer [27]	$ET_o = 2.8597u^{0.5}(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
Meyer	Meyer [28]	$ET_o = (3.75 + 0.5026u)(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
Papadakis	Papadakis [33]	$ET_o = 2.5(e_{ma} - e_a)$	T_{min}, T_{max}, RH
Penman	Penman [29]	$ET_o = (2.625 + 0.000479/u)(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
Rohwer	Rohwer [30]	$ET_o = (3.3 + 0.891u)(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
Trabert	Trabert [32]	$ET_o = 3.075u^{0.5}(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$
WMO	WMO [35]	$ET_o = (1.298 + 0.934u)(e_s - e_a)$	$T, T_{min}, T_{max}, RH, u$

ET_o is the reference crop evapotranspiration (mm day^{-1}). R_n is the net radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$). G is the soil heat flux ($\text{MJ m}^{-2} \text{ day}^{-1}$). γ is the psychrometric constant ($\text{kPa}/^\circ\text{C}$). e_s is the saturation vapour pressure (kPa). e_a is the actual vapour pressure (kPa). Δ is the slope of the saturation vapour pressure–temperature curve ($\text{kPa}/^\circ\text{C}$). T is the average daily air temperature ($^\circ\text{C}$). u is the mean daily wind speed at 2 m (m s^{-1}). H is the elevation (m). φ is the latitude (rad). T_{min} is the minimum air temperature ($^\circ\text{C}$). T_{max} is the maximum air temperature ($^\circ\text{C}$). RH is the average relative humidity (%). n is the actual duration of sunshine (h). R_s is the solar radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$). e_{ma} is the saturation vapour pressure at the monthly mean daily maximum temperature (kPa).

Table 3 Error of the model calculated for each province

	Al.	BW	Da.	Iv.	Ma.	Me.	Pa.	Pe.	Ro.	Tr.	WMO
CB	0.9671	0.9251	0.8806	0.8586	0.9319	0.8696	0.8192	0.839	0.8911	0.9319	0.9295
EA	0.9397	0.9567	0.9555	0.9601	0.9557	0.9571	<i>0.9596</i>	0.9575	0.9537	0.9557	0.9468
WA	0.962	0.94	0.9221	0.9167	0.9431	0.9168	0.8926	0.9012	0.9271	0.9431	0.9443
AR	0.9487	0.9601	0.9599	0.9568	0.9596	0.9603	0.9415	0.956	0.9592	0.9596	0.9547
ES	0.978	0.9424	0.9218	0.8907	0.9477	0.9096	0.8464	0.8663	0.9321	0.9477	0.9604
IL	0.943	0.9345	0.9295	0.9271	0.9358	0.9267	0.9222	0.9166	0.9318	0.9358	0.9382
BU	0.961	0.9854	0.9837	0.9684	<i>0.9852</i>	<i>0.9802</i>	0.8932	0.95	0.9849	<i>0.9852</i>	<i>0.9783</i>
TE	0.9826	0.9506	0.9403	0.9075	0.9551	0.9297	0.8969	0.8879	0.9488	0.9551	0.9702
AL	0.9687	0.9519	0.942	0.9164	0.9545	0.9357	0.9165	0.9115	0.9471	0.9545	0.9606
SK	0.9564	0.9716	<i>0.9694</i>	0.9453	0.9711	0.9689	0.9258	0.9576	0.9691	0.9711	0.9643
RK	0.9585	0.9597	0.9566	0.9473	0.9601	0.9552	0.941	0.9486	0.9576	0.9601	0.9592
NK	0.9479	0.9537	0.9491	0.9309	0.9541	0.9468	0.9289	0.9321	0.9505	0.9541	0.9512
KH	0.9683	0.9673	0.9634	0.9497	0.9684	0.9597	0.919	0.9399	0.9658	0.9684	0.9695
ZA	0.945	0.9333	0.9251	0.9163	0.935	0.9215	0.9066	0.9097	0.9282	0.935	0.9376
SE	0.9553	0.9447	0.9323	0.9337	0.9466	0.9285	0.9219	0.9161	0.9357	0.9466	0.9463
SB	0.9766	0.9692	0.9655	0.9228	0.9714	0.9589	0.8846	0.925	<i>0.97</i>	0.9714	0.9775
FA	0.9681	0.9439	0.9334	0.9138	0.9471	0.9262	0.8944	0.9001	0.9394	0.9471	0.9562
QO	0.9595	0.9498	0.9384	0.914	0.9519	0.9319	0.8929	0.9055	0.9433	0.9519	0.9549
GH	0.9558	0.9437	0.936	0.9253	0.9454	0.9321	0.9177	0.9183	0.9393	0.9454	0.9487
KO	0.9388	0.9209	0.9123	0.9094	0.9231	0.9081	0.8968	0.8946	0.9161	0.9231	0.928
KE	0.9779	0.9677	0.9636	0.9353	0.9696	0.9582	0.897	0.9309	0.9675	0.9696	0.9752
KS	0.9438	0.9287	0.9237	0.9136	0.9304	0.9202	0.9175	0.908	0.9268	0.9304	0.936
KB	0.9178	0.9059	0.8895	0.8758	0.9082	0.8849	0.8731	0.8707	0.8937	0.9082	0.907
GO	0.9555	0.9452	0.9229	0.9066	0.9475	0.9175	0.9007	0.9009	0.9277	0.9475	0.9432
GI	0.971	0.9683	0.9633	<i>0.9689</i>	0.9689	0.9622	0.9251	<i>0.9592</i>	0.9643	0.9689	0.9679
LO	0.9234	0.9059	0.8959	0.893	0.9081	0.8925	0.8869	0.8825	0.8991	0.9081	0.9106
MZ	0.964	0.9344	0.9178	0.9191	0.9383	0.9101	0.8617	0.8853	0.9245	0.9383	0.9459
MA	0.9548	0.9236	0.9003	0.8867	0.9279	0.8924	0.8632	0.8689	0.9074	0.9279	0.9317
HO	0.9742	0.9558	0.947	0.8083	0.959	0.9381	0.8165	0.8954	0.9535	0.959	0.9676
HA	0.9687	0.9292	0.9003	0.8767	0.9351	0.8893	0.834	0.8566	0.9101	0.9351	0.9425
YA	0.9639	0.9524	0.9468	0.9289	0.9542	0.942	0.912	0.9219	0.9505	0.9542	0.9594

The values in italics show the best value of each method, and the values in bold show the best value of each province

Al. Albrecht, BW Brockamp–Wenner, Da. Dalton, Iv. Ivanov, Ma. Mahringer, Me. Meyer, Pa. Papadakis, Pe. Penman, Ro. Rohwer, Tr. Trabert

Comparison of the Best Models for Each Province

Figure 1 compares the potential evapotranspiration using the FPM model with values estimated using the best method (based on Table 3) for each province.

According to Fig. 1, the Brockamp–Wenner model for Bushehr (BU) ($R^2 = 0.9854$) yielded the best the potential evapotranspiration as compared to that from the FPM model. However, the Albrecht model has been introduced as the best model in the most of the provinces (23 provinces). In general, mass transfer-based models are more suitable (R^2 more than 0.97) for BU, Hormozgan (HO) (near the Persian Gulf), South Khorasan (SK), Kerman (KE), and Sistan and Baluchestan (SB) (south-east of Iran) and for Tehran (TE), Gilan (GI), and Esfahan (ES)

(south of Iran). However, according to Table 3, variations of the errors (the worst and best R^2) for different models are too high in all provinces, e.g. Chaharmahal and Bakhtiari (CB) (0.839 and 0.9671 for the Penman and Albrecht models, respectively), BU (0.8932 and 0.9854 for the Papadakis and Albrecht models, respectively), SB (0.8846 and 0.9775 for the Papadakis and WMO models, respectively), and HO (0.8083 and 0.9742 for the Ivanov and Albrecht models, respectively). These values indicate very different performances of the mass transfer-based models for a specific weather condition in each province. For instance, the Ivanov model estimates the potential evapotranspiration with the least R^2 for HO and the greatest R^2 for East Azerbaijan (EA) than the other models. However, according to Table 2, the Ivanov model is a function of mean temperature and relative

Fig. 1 Comparison of the evapotranspiration (mm day⁻¹) calculated using the FAO Penman-Monteith (FPM) model with the best model for each province. The vertical axis indicates the FAO Penman-Monteith (mm day⁻¹) model, and the horizontal axis indicates the best method (mm day⁻¹)

humidity, the Papadakis model is a function of minimum and maximum temperatures and relative humidity, and the other models are a function of mean, minimum, and maximum

temperatures; relative humidity; and wind speed. In addition, the only difference among the Albrecht, Dalton, Meyer, Rohwer, and WMO models is coefficients used in each model

Fig. 1 (continued)

(Table 2) and the only difference among the Brockamp–Wenner, Mahringer, and Trabert models is also coefficients used in each model (Table 2). Thus, we must use them according to their best weather conditions (with the most accuracy).

Distinguishing Various Regions Based on Weather Conditions

The maps of the annual average of the weather parameters have been provided to detect the best conditions (range of

weather parameters) that each model estimates the potential evapotranspiration with maximum preciseness (Figs. 2 and 3).

Figure 2 shows the annual average of solar radiation and mean, maximum, and minimum temperatures in all 31 provinces of Iran, and Fig. 3 shows the annual average of relative humidity and wind speed in all 31 provinces of Iran. As shown, the value of solar radiation is more than $25.0 \text{ MJ m}^{-2} \text{ day}^{-1}$ for the south of Iran, it is from 24.0 to $25.0 \text{ MJ m}^{-2} \text{ day}^{-1}$ for the centre of Iran, and it ranges less than $24.0 \text{ MJ m}^{-2} \text{ day}^{-1}$ for the north of Iran. The mean temperature is less than 14°C for the north-west of Iran, it is more

Fig. 2 Average annual variations of solar radiation, mean temperature, maximum temperature, and minimum temperature in Iran

Fig. 3 Average annual variations of relative humidity and wind speed in Iran

Table 4 The best range to use the models based on the results of the current study

Model	T	$T_{\max}$	$T_{\min}$	RH	u	R^2
Albrecht	16–18	22.5–24.0	11–13	40–45	2.50–2.75	0.9826
Brockamp–Wenner	24–26	28.5–30	19–21	65–70	3.00–3.25	0.9854
Dalton	16–18	24.0–25.5	7–9	35–40	2.50–2.75	0.9694
Ivanov	14–16	–	–	>80	–	0.9689
Mahringer	24–26	28.5–30	19–21	65–70	3.00–3.25	0.9852
Meyer	24–26	28.5–30	19–21	65–70	3.00–3.25	0.9802
Papadakis	12–14	18.0–19.5	5–7	50–55	3.00–3.25	0.9596
Penman	14–16	19.5–21.0	11–13	>80	1.25–1.50	0.9592
Rohwer	18–20	25.5–27.0	9–11	<35	3.25–3.50	0.97
Trabert	24–26	28.5–30	19–21	65–70	3.00–3.25	0.9852
WMO	24–26	28.5–30	19–21	65–70	3.00–3.25	0.9783

T is the average daily air temperature (°C), u is the mean daily wind speed at 2 m (m s^{-1}), $T_{\min}$ is the minimum air temperature (°C), $T_{\max}$ is the maximum air temperature (°C), and RH is the average relative humidity (%)

than 24 °C near the Persian Gulf, and it is from 14 to 24 °C for the other regions (with the exception of NK and CB). The maximum temperature is more than 28.5 °C near the Persian Gulf, it is from 25.5 to 27.0 °C for desert provinces, it is less than 19.5 °C for the north-west of Iran, and it is from 19.5 to 25.5 °C for the other regions. The minimum temperature is more than 17 °C near the Persian Gulf, it is less than 7 °C for the north-west of Iran, it is from 11 to 15 near the Caspian Sea, and it is from 7 to 13 °C for the other regions (with the exception of CB, NK, and KE). The relative humidity is from 65 to 70 % near the Persian Gulf (with the exception of KH), it is from 50 to 65 % in the north-west and north-east of Iran (with the exception of Ardabil (AR)), it is more than 70 % near the Caspian Sea, and it is less than 45 % for the other regions. The wind speed is from 2.50 to 3.50 m s^{-1} for the south-east of Iran and near the Persian Gulf, and it is from 1.25 to 2.75 m s^{-1} for the other regions (with the exception of EA, AR, Gorgan (GO), and CB). The wind speed plays an important role in architectural studies to design buildings and structures with respect to the prevailing wind. For instance, in Qazvin, prevailing wind is a south-eastern wind called Raz or Shareh [42, 43]. This wind comes from desert areas of central Iran and is very warm and dry; hence, it is reasonable that a reduction of the wind speed (WS) due to desertification approaches [44] leads to decreasing impacts of the mentioned climate and consequently reducing the ET_0 . Therefore, the WS may be introduced as the most influencing factor on variations of the ET_0 in Qazvin.

The mass transfer-based models estimated the potential evapotranspiration in the south (near the Persian Gulf) and south-east (annual relative humidity 65–70 and <35 %, respectively) of Iran better than in the other provinces (Fig. 1). Therefore, the provinces of Iran are divided into five categories (at least): (I) the provinces near the Persian Gulf (KH, BU, and HO), (II) the provinces near the Caspian Sea (GI,

Mazandaran (MZ), and GO), (III) the provinces of the north-east of Iran (West Azerbaijan (WA), EA, AR, and Zanjan (ZA)), (IV) CB (due to the different weather conditions than the near provinces), and (V) the other provinces. These categories are useful for future studies over Iran because these four parameters (light, temperature, wind, and humidity) can be employed to the optimum design in architectural investigations.

Determining a Range of Weather Parameters for the Best Models

The maps of the annual average of weather parameters (Figs. 2 and 3) are useful not only for the mentioned categories but also for determining the range of each parameter for which the best preciseness of the mass transfer-based models is obtained (Table 4).

According to Table 4, the best performance of the Brockamp–Wenner, Mahringer, Meyer, Trabert, and WMO models is in similar weather conditions ($T = 24\text{--}26$ °C, $T_{\max} = 28.5\text{--}30.0$ °C, $T_{\min} = 19\text{--}21$ °C, RH = 65–70 %, and $u = 3.00\text{--}3.25$ m s^{-1}). However, their preciseness is different (e.g. 0.9783 and 0.9854 for the WMO and Brockamp–Wenner models, respectively). This underlines the important role of selection of the best model for specified weather conditions. Furthermore, we can see different ranges in the Albrecht, Dalton, Ivanov, Penman, Rohwer, and Papadakis models (Table 4). Therefore, we can use the mass transfer-based models for the other regions (in other countries) based on Table 4 with respect to their errors. The best weather conditions to use mass transfer-based equations are 23.6–24.6 $\text{MJ m}^{-2} \text{ day}^{-1}$, 12–26 °C, 18–30 °C, 5–21 °C, and 2.50–3.25 m s^{-1} (with the exception of the Penman model) for solar radiation, mean temperature, maximum temperature, minimum temperature, and wind speed, respectively. The

Fig. 4 The best model for each province and their error

results are also useful for selecting the best model when researchers must apply temperature-based models on the basis of available data.

Comparison of the Best Models with Their Errors for Each Province

Figure 4 is plotted to detect the best model for each province versus its error (after calibration).

First, although the Albrecht model is the most useful model for provinces of Iran (23 provinces), it is not suitable for two of the categories (near the Persian Gulf and the north-east of Iran) and the east of Iran (NK, RK, SK, and SB). This confirms that the categories are reliable and these two categories need more attention due to specific weather conditions. Moreover, the preciseness of the Albrecht model is less than 0.98 in 18 provinces of Iran. It reveals that the Albrecht model is a general model for estimating the potential evapotranspiration (high application and fair preciseness). Thus, we need

other temperature-, radiation-, and pan evaporation-based models to estimate the potential evapotranspiration in these 18 provinces. For instance, the values of solar radiation are more than $25.0 \text{ MJ m}^{-2} \text{ day}^{-1}$ for FA and KB; hence, the radiation-based models may be useful for these provinces [45–55]. It reveals that only if we use the mass transfer-based models for suitable (based on Table 4) and specific (based on Figs. 2 and 3) weather conditions, the highest preciseness of estimation will be obtained.

Conclusion

In this study, 11 mass transfer-based models were used to estimate the potential evapotranspiration in 31 provinces of Iran.

The preciseness of estimation by mass transfer-based models is very sensitive to variations of the parameters used in each model.

The best values of R^2 were 0.9854 and 0.9826 for the Brockamp–Wenner and Albrecht models in BU and TE provinces, respectively.

The provinces of Iran are divided into five categories (at least): the provinces near the Persian Gulf (KH, BU, and HO), the provinces near the Caspian Sea (GI, MZ, and GO), the provinces of the north-east of Iran (WA, EA, AR, and ZA), CB (due to the different weather conditions than the near provinces), and the other provinces. These categories are useful for future studies over Iran.

We can use the mass transfer-based models for the other regions (in other countries) based on ranges of each weather parameter for the best models with respect to their errors.

Only if we use the mass transfer-based models for suitable and specific weather conditions (based on weather conditions and the categories), the highest preciseness of estimation will be obtained.

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