Mapping reference evapotranspiration for Iraq using FAO Penman-Monteith method

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Abstract: Reference evapotranspiration (ETo) and other climatological elements are prerequisite needs in applications to irrigation planning and crop water management. They are crucial aspects for sustainable water resources management. In this article, data from 23 weather stations for 31 years were used to estimate the monthly reference evapotranspiration using FAO Penman–Monteith procedure. Based on the average monthly ETo values, the map of Iraq was divided into three main zones: northern, intermediate, and southern zone in the order of minimum, medium, and maximum values of ETo, respectively. The estimated values of reference evapotranspiration were then generalized on the whole area of Iraq using interpolation and then a contour map of evapotranspiration was provided. This map is necessary in providing approximate values for evapotranspiration in some regions where there are no climatological stations. The interpolation was conducted *via* two ways. The first way was done by interpolating the factors that included in FAO Penman–Monteith procedure and then calculating the ETo from the resulted data. The second way was conducted by interpolating the ETo values of the recommended 23 available stations. It was found that the resulted values of ETo from the second way was slightly higher than those of the first way. Consequently, the second way is more reliable for design purposes. It was concluded that the maximum ETo occurred on July while minimum occurred on January. The results showed that the most affecting climatological factor on ETo in Iraq based on FAO-Penman-Monteith procedure was the air temperature.

Keywords: climatological factors, contour map, interpolation, air temperature, ETo zones of Iraq

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1 Introduction

Evaporation is a basic component of the hydrologic cycle in the natural environment. Evapotranspiration (ET) is the total vaporization resulted from the combined processes of evaporation and transpiration (Running et al., 2017). Evaporation and transpiration occur concurrently and it is not easy to distinguish between the two processes (Allen et al., 1998; Ding et al., 2013; Jensen and Allen, 2016). One of the most important factors considered in applications such as irrigation design, irrigation scheduling, water resource management, and hydrology and cropping systems modeling is determination of evapotranspiration. Evapotranspiration can be calculated directly using lysimeters or a water balance in a controlled crop area but this method is difficult, expensive and time-consuming. Alternatively, evapotranspiration can be determined indirectly using some mathematical models as estimators (Gavilán et al., 2007; Yassin et al., 2016; Kisi and Alizamir, 2018). Researchers have developed many procedures over the last five decades for predicting the reference evapotranspiration based on climatic factors such as temperature, humidity, wind speed and radiation. The most accurate method for estimating evapotranspiration is the FAO Penman–Monteith that can

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be considered as a generalized approach to predict the reference evapotranspiration in agricultural and environmental studies. The main disadvantage of this method is that it needs a high number of climatic data, which may be unavailable or missing in some locations especially in developing countries (Allen et al., 1998). Singh et al. (2018) proposed a fairly robust and simplified framework to standardize less data-intensive (temperature-based) reference evapotranspiration (ETo) methods, viz, Hargreaves-Samani (HS) and Penman Monteith Temperature (PMT) against the standard FAO Penman–Monteith method. They adjusted the daily and monthly biases of these two methods utilizing the weather data of 14 stations for 1979-2003 period. They used salient statistical and graphical indicators to validate the performance of the standardized less data-intensive methods depending on 2004-2013 period. The results showed that the HS and PMT methods underestimated ETo on a monthly time step by 9.62% and 14.77%, respectively. Nevertheless, the performances of these methods considerably improved after the standardization and found to be in good agreement with the performance of the standard FAO-PM method. Maček et al. (2018) evaluated potential temporal changes of the daily ETo data of 55 years (1961 – 2016) calculated using the Penman Monteith method. The data were collected from 18 climatological stations situated in three different climate types in Slovenia. The trends in different samples defined based on ETo data were detected using Mann-Kendall test. The effects of changes in atmospheric conditions and their contributions to the trend of ETo were also assessed as using the generalized boosted regression trees model. The calculated trends were mostly increasing and statistically significant while no consistent trend was detected for all 18 stations. The results of the generalized boosted regression trees model showed that solar radiation had the largest effect on the ETo values, generally followed by air temperature, saturation vapor pressure deficit and wind speed. Sanford and Selnick (2013) predicted the actual ET across the conterminous United States (U.S.) by combining a water-balance method with a climate and land-cover regression equation. They obtained long-term estimates of actual ET by compiling the records of precipitation (P) and streamflow for 838 watersheds for 1971-2000 across U.S. They developed a regression equation that related the ratio ET/P to climate and land-cover variables within those watersheds. The results revealed that ET could be predicted satisfactorily at a county or watershed scale with readily available climate variables alone, and that land-cover data can also improve those predictions. Maps showing estimates of ET and ET/P for the entire conterminous U.S. were produced by averaging the climate and land-cover data at an 800-m scale to the county scale. They concluded that such maps could also be made using the regression equation for more detailed state coverages, or for other regions of the world of abundant climate and land-cover data. Elnmer et al. (2019) used remote sensing techniques to estimate the daily and seasonally ET over the Nile delta. To assess the performance of remote sensing methods, they used FAO Penman-Monteith method under the same conditions based on some statistical criteria. It was concluded that the remote sensing approaches provided good prediction of the spatial and temporal distributions of ET over the Nile delta (R^2 = 0.9783 and root mean square error (RMSE) = 0.469 mm day^{-1}). Alaa (2013) conducted a comparative study to assess the performance of some methods that used to estimate reference evapotranspiration. Alaa (2013) concluded that the easiest and most suitable method was Class A Pan Evaporation method as its estimations were the closest to the FAO 56 Penman–Monteith procedure for Mosul data. Investigation on an accurate value of ETo is very important in design, planning and management of strategic irrigation projects. This is essential to accomplish a successful irrigation and fulfill the plant requirements by giving adequate depths of water to the root zone depth. The good designer does not have to disparage the value of ETo even it is small because 1 mm depth of water is equal to 10 m^3 of water per 1 ha. For instance, the total area of Northern Al-jazeera Irrigation Project (in Ninawa province/ Iraq) is 60,000 ha which means a volume of 600,000 m^3 of water is required to apply 1 mm depth of water on the entire area of the project. This is a huge amount of water, which is equal to volume of the reservoir of the Mosul Dam. The objective of the current study is to prepare an evapotranspiration map for Iraq, which helps a lot in estimating ET in some regions where there are no climatological stations. Providing average, maximum or minimum ETo maps of Iraq is crucial in preliminary studies and planning of irrigation and drainage projects. Many studies have focused on studying ETo for specified regions of Iraq or just considering some climatological parameters (Tadros et. al., 2014; Saeed, 2012; Atiaa and Abdul-Qadir, 2012). In addition, some researchers considered shorter periods to study climatological parameters (Ali and Faraj, 2017). Therefore, ETo maps were provided for the whole map of Iraq and for long period. Furthermore, this study aims to investigate the most affecting climatological factors on ET in Iraq based on FAO Penman-Monteith procedure and to draw a contour map for minimum and maximum ET as well.

2 Materials and methods

2.1 Study area and data

In this study, the average monthly reference evapotranspiration was calculated based on data from 23 weather stations located in different regions in Iraq (Figure 1). These data include maximum and minimum air temperature, wind speed, and actual duration of sunshine in a day and they are the average of 31 years (1980 – 2010). The main characteristics of the studied weather stations are listed in Table 1 (Al-Khazraji, 2014).

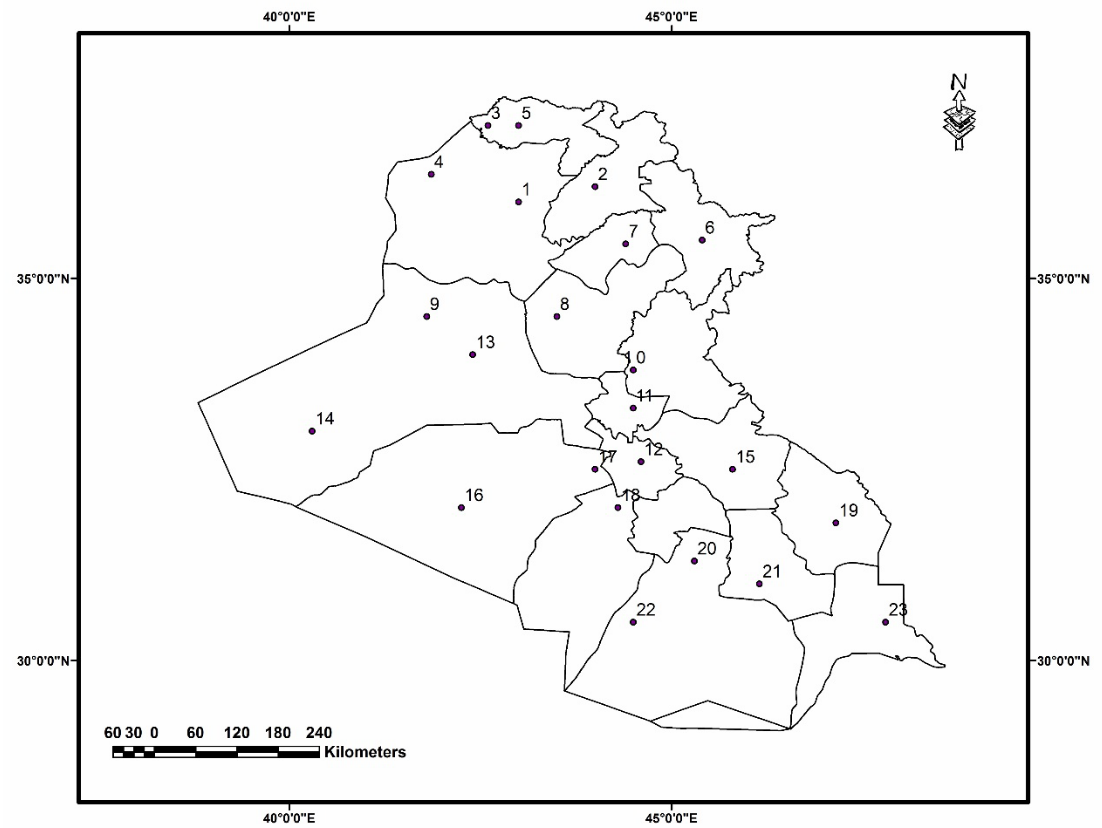

Figure 1 Locations of 23 analyzed weather stations on the map of Iraq

Iraq lies between latitudes 29° and 38°N, and longitudes 39°and 49°E (a small area lies west of 39°). The total area of Iraq is equal to 437,072 km^2. Most of Iraq has a hot arid climate with subtropical influence. Summer temperatures average above 40 °C for most of the country and frequently exceed 48°C. Winter temperatures infrequently exceed 21 °C with maxima roughly 15°C to 19°C and night-time lows 2°C to 5°C. Typically, precipitation is low; most places receive less than 250 mm annually, with maximum rainfall occurring during the winter months. Rainfall during the summer is extremely rare, except in the far north of the country. The northern mountainous regions have cold winters with occasional heavy snows, sometimes causing extensive flooding.

Table 1 Main characteristics of the 23 studied weather stations

No.	Station	Latitude (°N)	Longitude (°E)	Elevation (m.a.s.l)
1	Hammam Al-Allil	36.00	43.00	223
2	Erbil	36.20	44.00	420
3	Zakho	37.00	42.60	433
4	Sinjar	36.30	40.83	456
5	Amedi	37.00	43.00	1202
6	Sulaymaniyah	35.50	45.40	883
7	Kirkuk	35.45	44.40	331
8	Baiji	34.50	43.50	115
9	Anah	34.50	41.80	139
10	Khalis	33.80	44.50	42
11	Baghdad	33.30	44.50	32
12	Hillah	32.60	44.60	27
13	Haditha	34.00	42.40	634
14	Rutba	33.00	40.30	630
15	Kut	32.50	45.80	23
16	Al-Nukhib	32.00	42.25	305
17	Karbala	32.50	44.00	29
18	Najaf	32.00	44.30	33
19	Amarah	31.80	47.15	9
20	Samawah	31.30	45.30	6
21	Nasiriyah	31.00	46.15	5
22	Al-Salman	30.50	44.50	220
23	Basrah	30.50	47.80	2

2.2 FAO Penman-Monteith procedure

Reference crop evapotranspiration or reference evapotranspiration (ETo) can be defined as the evapotranspiration rate from reference surface, which is a presumptive grass of 12 cm height, an albedo of 0.23 and a fixed surface resistance of 70 s m^{-1}. The FAO Penman–Monteith is the most commonly used method for estimating evapotranspiration. It can be considered as a generalized approach to predict the reference evapotranspiration in agricultural and environmental studies. This method is suitable for predicting ETo for various climatic circumstances and even in the case of missing meteorological variables. The FAO Penman–Monteith equation to predict ETo is (Allen et al., 1998; Jensen and Allen, 2016):

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where ETo is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), Δ is the slope of the vapour pressure curve (kPa °C^{-1}), γ is the psychrometric constant (kPa °C^{-1}). The guidelines for computing the different variables included in the FAO Penman–Monteith equation were explained in details by Allen et al. (1998).

2.3 Interpolation techniques

In order to generalize the calculated values of ETo for the considered 23 climatic stations on the whole area of Iraq, an interpolation technique, which is a kriging method was used. Surfer version 8.02 was used to implement the interpolation. The interpolation was performed via two ways. The first way was done by interpolating the climatological factors that considered in FAO Penman–Monteith equation and then calculating the ETo from the resulted data. These climatological factors are air temperature (T), wind speed at 2 m height (u_2), elevation (z), and actual duration of sunshine (n). These parameters were interpolated for each month and for each station. Then, the resulted parameters from the interpolation were utilized to calculate ETo. The second way was performed by interpolating the ETo values of the recommended 23 available metrological stations which is easier than the first way. The spatial interpolation was widely utilized by many researchers in order to provide metrological data in locations where the weather stations are not available and to study the trend of these climatological parameters (Okechukwu and

Mbajiorgu, 2020; Yang et al., 2011; Xu et al., 2006; Hodam et al., 2017; da Silva Júnior et al., 2019; Sharma and Irmak, 2012).

2.4 Model performance

Some statistical indices were considered in order to evaluate the two interpolation ways. These statistical criteria include mean absolute error (MAE), mean bias error (MBE), RMSE, and model efficiency (EF). Willmott et al. (2012) introduced the following equations to calculate the statistical indices:

$$MAE = \frac{1}{N}\left|\sum_{i=1}^{N}(P_i - O_i)\right| \quad (2)$$

$$MBE = \frac{1}{N}\left(\sum_{i=1}^{N}(P_i - O_i)\right) \quad (3)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2\right]^{0.5} \quad (4)$$

$$EF = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O})^2} \quad (5)$$

Where N is the total number of data, P and O referred to the predicted (ETo2) and observed (ETo1) data, respectively, and $\bar{O}$ is the mean value of observed data. The model is of good performance when the values of MBE, MAE, and RMSE are small as much as possible while EF values should be close to one.

Additionally, a graphical assessment was considered by plotting the observed and estimated values of ETo and their relation with 1:1 line.

3 Results and discussion

3.1 ETo zones of Iraq

After conducting the FAO 56-Penman–Monteith procedure on the climatological date of the considered 23 weather stations, the values of monthly ETo were calculated and listed in Table 2. It is clear from Table 2 that Iraq can be divided into three main zones according to the mean values of ETo. The first zone is the northern zone of lowest values of ETo within the range of 3.479 mm day^{-1} ≤ ETo ≤ 3.953 mm day^{-1}. The second zone is the intermediate zone of medium values of ETo within the range of 4.197 mm day^{-1} ≤ ETo ≤ 4.959 mm day^{-1}. The third zone is the southern zone of highest values of ETo within the range of 5.072 mm day^{-1} ≤ ETo ≤ 5.687 mm day^{-1}. It can be noted from Table 2 that the values of ETo of the same month of each zone are approximate. Therefore, the average value of the monthly ETo for each zone can be as shown in Table 3. Figure 2 illustrates the location of these zones on the map of Iraq. Figure 2 was plotted using Surfer version 8.02 by implementing the interpolation depending on a kriging technique. There was an excellent agreement between measured and interpolated values of ETo which represented by the resulted high value of the determination coefficient (R^2) of 0.99. Table 3 can be represented as a graph for the three main zones (Figure 3). Table 3 and Fig. 3 demonstrate that the range of ETo values for each zone is as follows: 0.940 mm day^{-1} ≤ ETo ≤ 7.144 mm day^{-1} for the northern zone, 1.374 mm day^{-1} ≤ ETo ≤ 8.393 mm day^{-1} for the intermediate zone, and 1.922 mm day^{-1} ≤ ETo ≤ 9.414 mm day^{-1} for the southern zone. Table 3 and Figure 3 are very important as they represent a quick guide to estimate ETo at any point within each zone and that is crucial for design purposes.

Table 2 Average monthly reference ETo (mm day-1) for the considered weather stations

Station no.	Station name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1	Hammam Al-Allil	0.823	1.708	2.831	3.955	4.827	5.787	7.597	6.928	5.454	2.708	1.52	1.099	3.77
2	Erbil	1.134	1.801	2.579	3.717	5.289	6.826	7.287	6.656	5.377	3.48	2.043	1.251	3.953
3	Zakho	0.892	1.395	2.123	3.403	4.853	6.373	7.055	6.521	4.994	3.05	1.673	0.976	3.609
4	Sinjar	0.895	1.474	2.318	3.538	5.171	6.7	7.432	6.861	5.288	3.233	1.771	1.083	3.814
5	Amedi	0.944	1.425	2.276	3.262	4.69	5.947	6.673	6.178	4.657	2.957	1.654	1.078	3.479
6	Sulaymaniyah	0.898	1.423	2.118	3.259	4.634	6.265	6.893	6.576	4.876	3.09	1.734	0.981	3.562
7	Kirkuk	0.994	1.643	2.515	3.729	5.255	6.642	7.074	6.715	5.148	3.342	1.935	1.195	3.849
8	Baiji	1.135	1.829	2.846	4.197	5.657	7.345	7.901	7.339	5.468	3.39	1.975	1.28	4.197
9	Anah	1.375	2.2	3.222	4.607	6.235	7.901	8.902	8.191	6.048	3.697	2.185	1.47	4.669
10	Khalis	1.506	2.273	3.381	4.614	5.977	7.612	8.029	7.404	5.661	3.76	2.333	1.614	4.514
11	Baghdad	1.461	2.166	3.292	4.483	6.136	7.906	8.492	7.888	6.117	4.163	2.516	1.647	4.689
12	Hillah	1.357	2.135	3.284	4.411	5.726	7.245	7.664	6.895	5.349	3.526	2.196	1.476	4.272

13	Haditha	1.069	1.724	2.794	4.411	6.604	8.97	10.246	9.383	6.719	4.089	2.197	1.306	4.959
14	Rutba	1.563	2.298	3.228	4.557	5.774	7.074	7.624	6.996	5.483	3.868	2.383	1.64	4.374
17	Karbala	1.531	2.295	3.419	4.787	6.25	8.03	8.619	7.925	6.128	4.073	2.458	1.658	4.764
18	Najaf	1.371	2.169	3.23	4.541	5.875	7.65	8.055	7.478	5.739	3.81	2.267	1.505	4.474
15	Kut	1.745	2.532	3.572	5.188	7.11	9.584	10.399	9.839	7.901	5.089	3.163	2.124	5.687
16	Al-Nukhib	1.888	2.623	3.728	5.226	6.789	8.433	8.761	8.152	6.355	4.459	2.663	1.784	5.072
19	Amarah	1.748	2.56	3.657	5.214	6.968	9.349	9.85	9.334	7.551	4.97	3.072	1.987	5.522
20	Samawah	1.825	2.706	3.826	5.262	6.765	8.344	8.713	8.208	6.739	4.678	2.922	2.03	5.168
21	Nasiriyah	1.976	2.778	3.976	5.37	7.092	9.019	9.435	8.98	7.398	5.147	3.22	2.215	5.551
22	Al-Salman	2.276	3.009	4.025	5.485	6.596	8.794	9.181	8.435	6.939	4.641	3.295	2.47	5.429
23	Basrah	1.994	2.791	3.891	5.324	6.993	9.25	9.557	9.112	7.422	5.044	3.259	2.233	5.573

3.2 Maximum and minimum ETo

It is obvious from Table 2 that minimum values of ETo occurred in January while maximum values occurred in July. Figures 4 and 5 depict contour maps for minimum and maximum ETo of Iraq. Three main regions can be noted for the minimum and maximum ETo from Figures 4 and 5, respectively. These maps are of importance as they provide a quick guide to predict ETo in any point within each region especially maximum ETo which is always recommended for design purposes in irrigation and drainage projects. For instance, instead of collecting climatological data and doing PM-procedure for calculating ETo, it is simply can be estimated based on the resulted regions. That can be considered saving time and effort.

Table 3 Average values of ETo (mm day^{-1}) of the three main zones

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northern	0.940	1.553	2.394	3.552	4.960	6.363	7.144	6.634	5.113	3.123	1.761	1.095
Intermediate	1.374	2.121	3.189	4.512	6.026	7.748	8.393	7.722	5.857	3.820	2.279	1.510
Southern	1.922	2.714	3.811	5.296	6.902	8.967	9.414	8.866	7.186	4.861	3.085	2.121

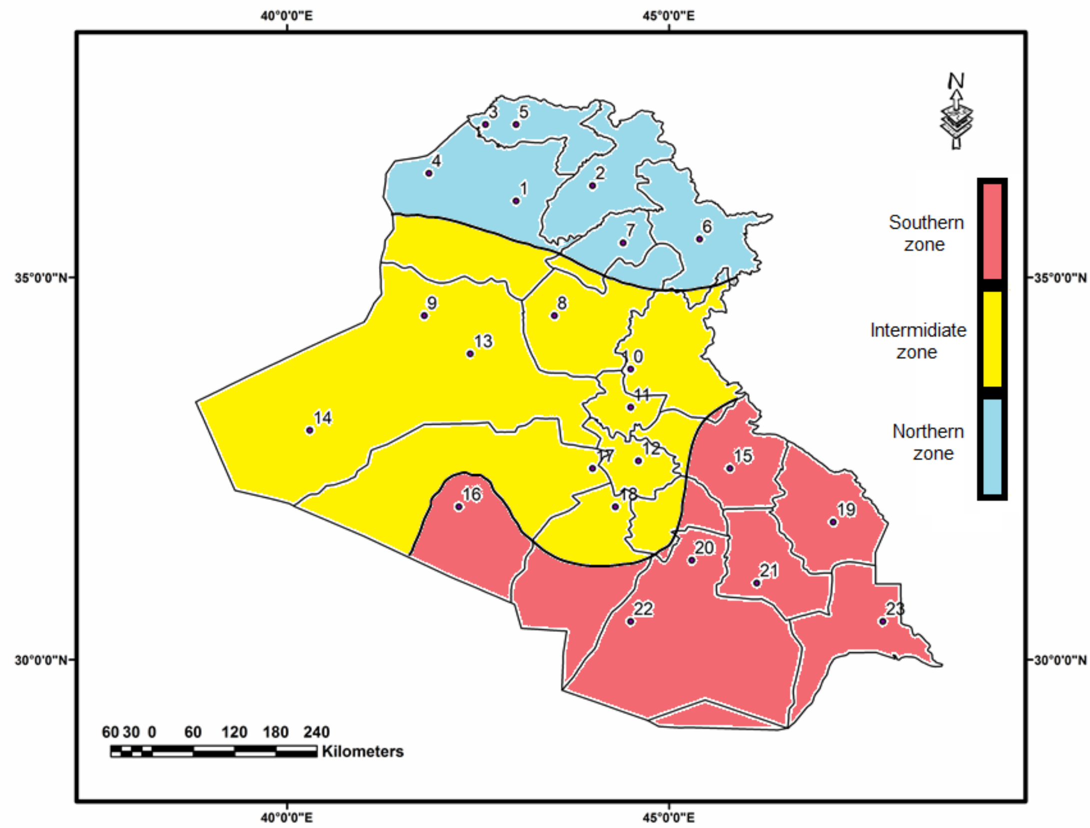

Figure 2 Locations of the three main zones of ETo in Iraq

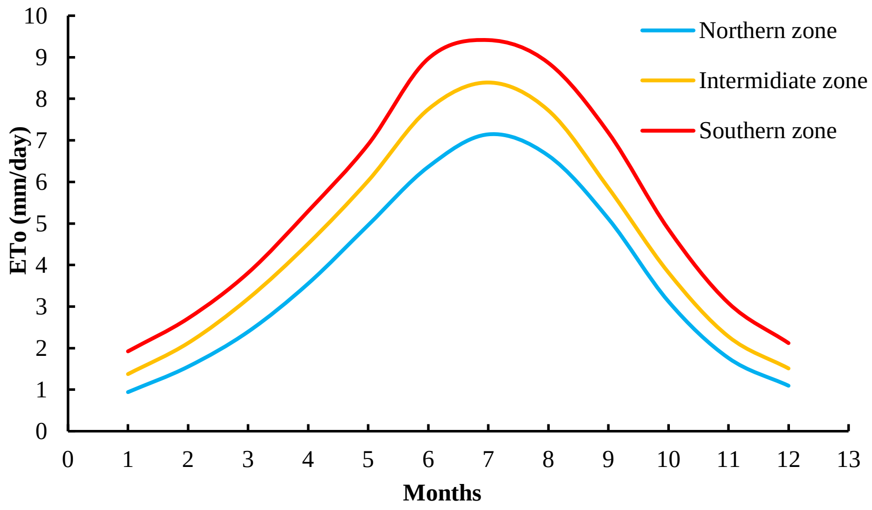

Figure 3 Range of the ETo (mm day^{-1}) values of the three main zones in Iraq

3.3 Generalization of ETo on the map of Iraq

As mentioned previously, 23 meteorological stations distributed in different locations of Iraq were considered in this study (Figure 1). However, it is possible to see some regions on the map without meteorological station. In this case, some approximation can be accepted by using the climatological data of the nearest meteorological station. Instead, spatial interpolation can be used to provide climatological data from the meteorological stations. Surfer version 8.02 was used to implement the interpolation depending on a kriging technique. The interpolation was done based on dividing the map of Iraq longitudinally from 38.8°E to 48.6°E with interval of 0.2° and latitudinally from 29.2°N to 37.4°N with interval of 0.2°. The results revealed that there was an excellent agreement between the two ways based on graphical and statistical assessment. Figure 6 shows the relation between ETo that calculated by the two ways. It is clear from Fig. 6 that all the points are well fitted to the 1:1 line and have a uniform distribution around the best fitting line. The statistical assessment was performed by calculating the performance indices mentioned in section 2.4. The values of statistical criteria for the two ways of interpolation are shown in Table 4.

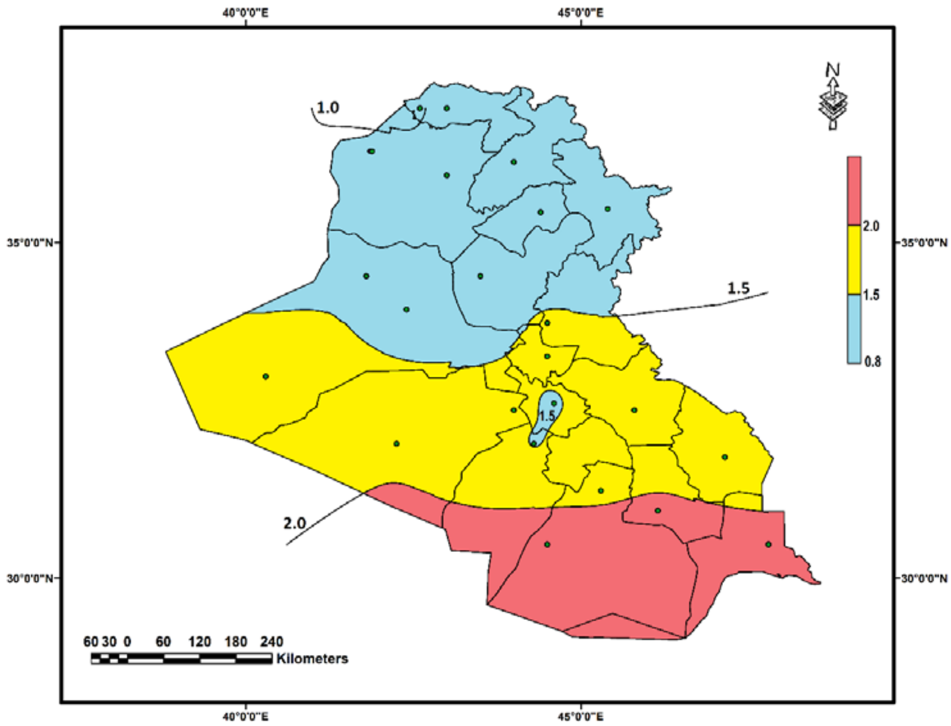

Figure 4 Distribution of minimum ETo values on the map of Iraq

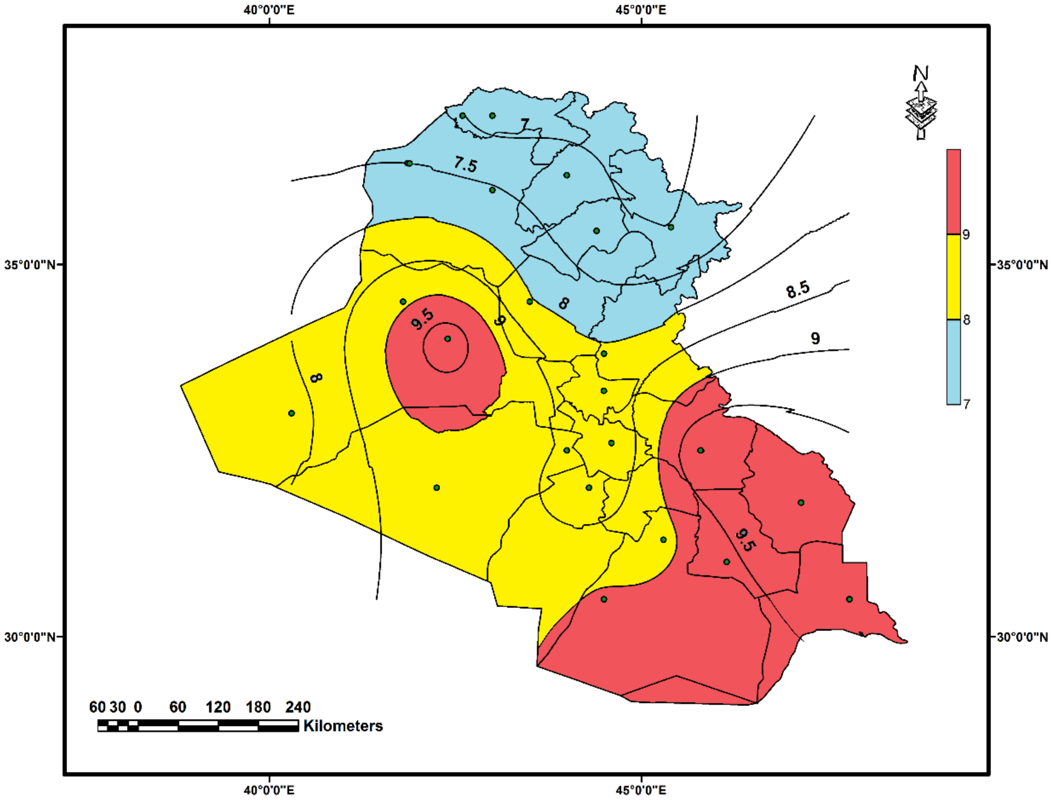

Figure 5 Distribution of maximum ETo values on the map of Iraq

Table 4 illustrates that the two interpolation methods have good agreement as they have small values of MAE, MBE and RMSE, and value of EF is close to unity.

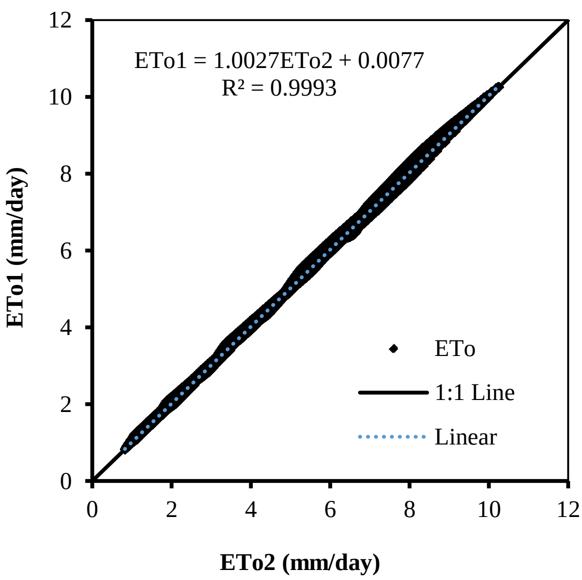

Figure 6 Relation between ETo (mm day^{-1}) values estimated by two ways of interpolation

* ETo1: Estimated by the first way (interpolation of climatological factors), ETo2: Estimated by the second way (interpolation of ETo directly of 23 metrological stations)

As the value of MBE is positive, it means that the values of ETo from the second interpolation way are slightly higher than those of the first way.

Therefore, it is better to recommend the second way for design purposes. The results showed in Fig. 6 and the statistical values listed in Table 4 revealed that spatial interpolation was an active method in generalization of climatological parameters in Iraq. These results agreed with the results of other studies conducted in other countries such as China (Xu et al., 2006; Yang et al., 2011; McVicar et al., 2007), Nigeria (Okechukwu and Mbajiorgu, 2020), India (Hodam et al., 2017), USA (Sharma and Irmak, 2012; Ha et al., 2011; Kiefer et al., 2019), Spain (Tomas-Burguera et al., 2018), Australia (Jeffrey et al., 2001), Brazil (da Silva Júnior et al., 2019), and Greece (Mardikis et al., 2005).

Table 4 Values of statistical indices for the two ways of interpolation

MAE (mm day^{-1})	MBE (mm day^{-1})	RMSE (mm day^{-1})	EF
0.0427	0.0199	0.0693	0.9992

3.4 The effect of climatological factors on ETo

In studies of evapotranspiration, it is vital to investigate the climatological element that has the largest impact on the values of ETo. It was found from previous studies that the effect of climatological factors varied with respect to geographic location. Yang et al. (2011)

concluded that the most affected factor on ETo estimation of the Yellow River Basin, China, was relative humidity, followed by air temperature, solar radiation and wind speed. Additionally, Wang et al. (2014) deduced that the most sensitive element in predicting ETo in the Hetao Irrigation District in northern China was mean daily air temperature, followed by wind speed and relative humidity. It can be noted from the FAO 56-Penman–Monteith equation that the principal factors considered in estimating ETo are climatological parameters viz air temperature (*T*), wind speed at 2 m height (u_2), latitude (φ), elevation (*z*), actual duration of sunshine (*n*) and relative humidity (*RH*). Regarding the available climatological data in this study, the effect of each parameter was assessed using sensitivity analysis by changing one variable and fixing the others. The maximum, minimum, and average values of the climatological parameters are shown in Table 5. Making use of the interpolation conducted previously, an empirical formula was derived to relate ETo and climatological parameters as follows:

$$ETo = 0.013184Z^{0.0036}\psi^{0.118482}\varphi^{0.058192}u_2^{0.330347}T_{mn}^{0.294532}T_{mx}^{1.864085}T^{-1.17281}n^{0.653452} \quad (6)$$

Where *Z* is elevation, ψ is longitude, φ is latitude, T_{mn}, T_{mx}, and *T* are minimum, maximum and average air temperature, respectively and *n* is actual duration of sunshine. Some statistical criteria were computed to show the goodness of Equation 6 such as MAE = 0.193 mm day^{-1}, RMSE = 8.736 mm day^{-1}, and determination coefficient (R^2) = 0.991. It is clear that good agreement was achieved from Equation 6. Figure 7 shows the relation between ETo values that calculated from FAO 56-Penman–Monteith equation and those estimated from Equation 6. It is obvious from Figure 7 that there is a good agreement between ETo values from both FAO 56-Penman–Monteith equation and Equation 6. Using Equation 6 and increasing the value of each climatological parameter by 20% and fixing the values of the remaining parameters by considering the average values, the change of ETo values as percentage is illustrated in Table 6. It is obvious from Table 6 that the climatological parameter which has the largest impact on ETo is the air temperature especially maximum air temperature followed by sunshine duration, wind speed, longitude, latitude and elevation.

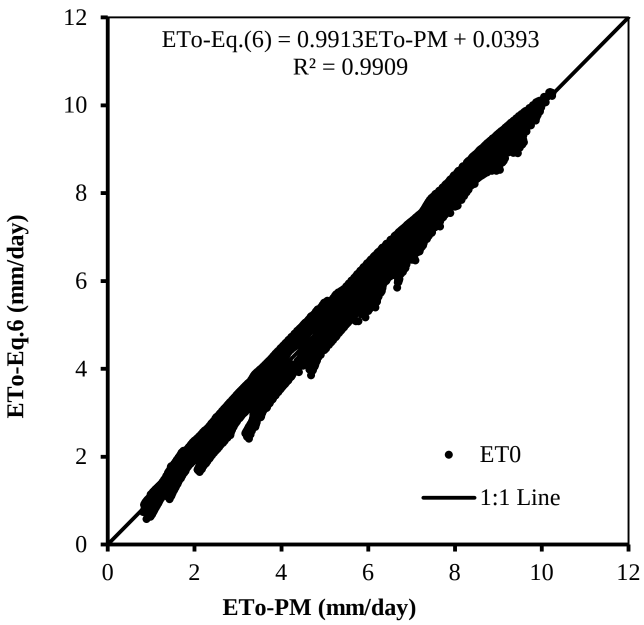

Figure 7 Relation between ETo (mm day^{-1}) values that calculated via FAO 56-PM (ETo-PM) equation and those estimated via Equation 6 (ETo-Equation 6)

Table 5 Maximum, minimum and mean values of climatological parameter considered in the study

	Elevation, Z (m.a.s.l)	Longitude, ψ (°E)	Latitude, φ (°N)	Wind speed, u_2 (m s^{-1})	Min. temp. T_{mn} (°C)	Max. temp. T_{mx} (°C)	Mean temp. T (°C)	Sunshine duration, n (h)
Max.	1202	47.8	37	4.78	30.9	46.2	38.55	14
Min.	2	40.3	30.5	0.69	0.1	9.7	4.9	2.5

Average	602	44.05	33.75	2.735	15.5	27.95	21.725	8.25

Table 6 Response of ETo to the change of each climatological parameter

	Elevation, Z (m.a.s.l)	Longitude, ψ (°E)	Latitude, φ (°N)	Wind speed, u_2 (m s^{-1})	Min. temp. T_{mn} (°C)	Max. temp. T_{mx} (°C)	Mean temp. T (°C)	Sunshine duration, n (h)
Min.	2	40.3	30.5	0.69	0.1	9.7	4.9	2.5
20% increase	2.4	48.36	36.6	0.828	0.12	11.64	5.88	3
Change ETo (%)	0.066	2.184	1.067	6.208	5.517	40.475	19.251	12.653

4 Conclusion

In many applications such as irrigation planning, crop water management, basins water balance, climate characterization and climate change studies, an accurate calculation of ETo is essential. Numerous climatological parameters are required to estimate ETo precisely. These climatological parameters are often not available or inadequate or have doubtful quality. In this study, the monthly ETo was predicted using FAO 56-Penman–Monteith procedure based on data from 23 weather stations in Iraq for 30 years. The results showed that the map of Iraq could be divided into three main regions: northern (low ETo), intermediate (medium ETo), and southern region (high ETo) according to mean monthly ETo values. The average of maximum values of ETo for northern, intermediate, and southern region are 7.144, 8.393, and 9.414 mm day^{-1}, respectively. A spatial interpolation was used to generalize the values of ETo on the entire map of Iraq. Surfer version 8.02 was utilized to conduct the interpolation depending on a kriging method. The interpolation was done based on dividing the map of Iraq longitudinally and latitudinally with interval of 0.2°. Two methods were used to perform the interpolation. The first method was done by interpolating the factors that included in FAO 56-Penman–Monteith procedure and then calculating the ETo from the resulted data. The climatological factors represented by air temperature (T), altitude (z), actual duration of sunshine (n), and wind speed at 2 m height (u_2) were interpolated for each station along 12 months. The second way was carried out by interpolating the ETo values of the recommended 23 available stations directly. It was noted that the values of ETo resulted from the second method were slightly higher than those of the first method. Thus, the second method is more dependable for design purposes. It was concluded that the maximum ETo occurred on July while minimum occurred on January. Therefore, two contour maps were drawn for maximum and minimum ETo. Three zones of ETo for each map were resulted. An empirical equation was derived to relate ETo to the climatological factors. This equation was used to investigate the climatological parameter of largest impact on ETo. It was deduced that the climatological parameter which had the largest impact on ETo was the air temperature especially maximum air temperature followed by sunshine duration, wind speed, longitude, latitude and elevation.

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