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Study Evapotranspiration in Iraq Using the Penniman-Monteith Equation for the Period (2008-2020)

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Abstract

Evapotranspiration is considered an essential element for the stability of the ecosystem due to its importance in many aspects, including the water cycle, which is an important source of fresh water for humans, animals and plants. It also has great importance in influencing climate, temperatures and regulating weather. It also enters into the design of irrigation networks for crops and knowing their water needs to prevent drought and desertification. The Penman-Monteith method is effective and accurate for calculating daily reference evapotranspiration and has been adopted by the Food and Agriculture Organization (FAO) as a standard method. This study aims to calculate the variation in evapotranspiration rates in Iraq using the Penman-Monteith method over the past thirteen years (2008-2020) in five equal periods (2008, 2011, 2014, 2017, and 2022). This study showed that the total rates of evapotranspiration are decreasing and these values reached their peak in 2008 and then decreased significantly in subsequent years. The reason for this decrease is the decrease in wind speed and the increase in relative humidity. It was found that evapotranspiration rates in the central and southern governorates are higher than in the northern governorates. However, there are deviations in the rates for some stations, such as in 2020, which witnessed a general decrease in evapotranspiration rates, with the exception of some stations that recorded an increase. For example, Khanaqin station recorded the highest increase in evapotranspiration rates, which amounted to 23.6%. The reason for this increase is the increase in temperatures by 5.2% and the decrease in relative humidity by -6.5%.

Article Info.

Keywords:
Evapotranspiration, Penman-Monteith, Global Warming, GIS, Metrological Data.

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1. Introduction

Evapotranspiration is one of the basic components of the hydrological cycle [1]. Evapotranspiration is a fundamental process that links the various components of the hydrological cycle. Evaporation provides vapor that condenses and falls as rain or snow until water returns to the soil and water bodies. Thus, evapotranspiration contributes to the continuity of the hydrological cycle [2]. Evapotranspiration combines two processes: evaporation that occurs in the soil and transpiration that appears in plants. The two processes are synchronized and depend on air temperature, solar radiation, wind speed, and relative humidity [3, 4]. There are many studies in this field in Iraq, the most important of which is a study conducted by Laith and Hala in 2020. The study aimed to create an integrated system that allows for accurate calculation and analysis of evapotranspiration rates in Iraq over an extended period of time. They concluded that the main causes of drought that leads to land degradation and desertification are high rates of evapotranspiration and low rainfall. They calculated the daily evapotranspiration figures and verified the total annual amount for the years 1987, 1997, 2007 and 2017. They found that evapotranspiration rates in Iraq peaked in the 1980s and then declined rapidly in most parts of the country using spatial analysis approaches [5]. Also, a study by Al-Talib et al., 2021, on the Food and Agriculture Organization (FAO) Penman-Monteith approach estimated the monthly reference evapotranspiration for Iraq based on data collected over 31 years from 23 meteorological stations. It was found that July represents the highest evapotranspiration rates, while January represents the lowest. According to the results, air temperature has the greatest effect on evapotranspiration in Iraq based on the FAO Penman-Monteith technique [6]. Also, Bakr et al., 2021 compared the performance of some mathematical models in selected areas in Iraq. The results showed that the Penman-Monteith model is the best model for calculating evapotranspiration in Iraq, as it achieved values close to the observed evapotranspiration values with high correlation and a small absolute error coefficient [7].

Evapotranspiration is one of the factors that deplete natural water resources and affect water sustainability. Water consumption and availability are related to many factors, including weather, climate, irrigation, agriculture, pollution and water loss, and these reasons have affected water availability, especially in dry areas [8]. Many scientific attempts to estimate evapotranspiration can be classified into five: radiation, mass transfer, water balance, combined methods, and temperature-based methods [9, 10].

One of the basic methods in this field, proposed by the FAO as a standard method, is the use of the Penman-Monteith formula [11]. This method is considered one of the most reliable and comprehensive methods for calculating daily evapotranspiration rates, as it requires daily data and depends on the maximum and minimum temperature and wind speed. These data are taken from weather stations [12]. This method was developed by climate scientists Penman and Monteith in the 1950s and 1960s [13, 14]. This study aims to calculate the variation in evapotranspiration rates in Iraq over the past thirteen years (2008-2020) in five equal periods (2008, 2011, 2014, 2017, and 2022).

2. Methodology

Iraq is located in southwest Asia and occupies an area of 438,320 km^2, extending between longitudes 38° 45' to 48° 45' east and latitudes 29° 5' to 37° 22' north [15]. Its climate is characterized by cold, rainy winters and hot, dry summers About 90% of precipitation falls in the winter. Climate models have shown that temperatures will continue to rise and decrease precipitation in the coming years. These factors led to drought in most of the country [16]. Iraq is affected by the desert climate in the southern and southwestern regions, while the northern regions are colder and receive more rain Iraq has three rivers: the Tigris, the Euphrates, and the Shatt al-Arab. Agricultural lands extend along the rivers in central and southern Iraq, occupying an area of about 70% of agricultural lands that rely on irrigation water [17]. The remaining part of agricultural land is located in the north, occupies an area of 30%, and depends on rainwater. The country often suffers from natural disasters such as severe drought and water shortages, especially in desert areas due to severe climate fluctuations. Therefore, accurate assessment of evapotranspiration rates is essential to monitor the water needs of agricultural lands and prevent their drought and desertification [18, 19].

Table 1 shows the stations that were used to measure the annual potential evapotranspiration rates in Iraq. Evapotranspiration is calculated based on data taken from meteorological stations.

Fig. 1 shows the geographical distribution of the stations in Iraq. To ensure comprehensive coverage, the stations were chosen in all parts of the country from north to south.

Table 1: Position of the meteorological stations.

Stations	Latitude (Degrees)	Longitude (Degrees)
Mousel	36.19	43.09
Kirkuk	35.28	44.24
Khanaqeen	34.21	45.23
Haditha	34.08	42.21
Baghdad	33.18	44.24
Rutba	33.02	40.17
Karbala	32.34	44.03
Alhai	32.08	46.02
Najaf	31.57	44.19
Amara	31.5	47.1
Nasriya	31.01	46.14
Basrah	30.31	47.47

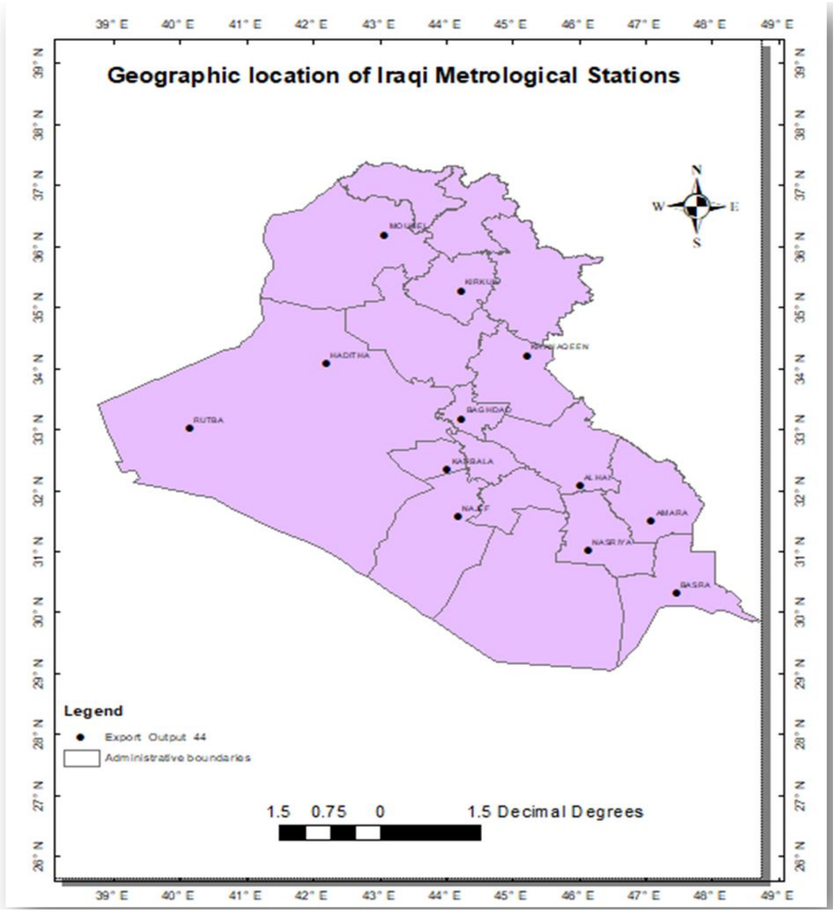

Figure 1: The geographical location of the meteorological stations in Iraq.

The daily reference evapotranspiration ratio was calculated using the standard Penman-Monteith formula shown in the equation below [20, 21]:

$$\mathrm{ETref} = (0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \mathrm{Y} \times \mathrm{Cn}/\mathrm{T} + 273(\mathrm{es} - \mathrm{ea})\mathrm{U2})/(\Delta + \mathrm{Y}(1 + \mathrm{cd} \times \mathrm{U2}) \quad (\mathbf{1})$$

where ETref is the reference evapotranspiration (mm/day), Rn is the net radiation at the crop surface (MJ m^{-2} day^{-1}), Δ is the slope of the saturation vapor pressure curve (kPa/°C),G is the heat flux density to the soil (MJ m^{-2} day^{-1}) = 0, ϒ is the psychrometric constant (kPa/°C), T is the average daily temperature (°C), U2 is the average daily wind speed at 2 m above the soil surface (m/s), es is the average saturation vapor pressure (kPa), ea is the average actual vapor pressure (kPa), Cn is the numerator constant that varies with the reference crop =900, Cd is the denominator constant that varies with the reference crop =0.34, u2 is the wind speed at 2 m above the ground, m/s^{-1}, defined as:

$$\mathrm{u2} = \mathrm{uz} \times \left(\frac{4.87}{\ln(67.8\mathrm{zw} - 5.42}\right) \quad (2)$$

where uz is measured wind speed z m above the ground surface, m s^{-1}, zw is the height of the measurement above the ground surface, m. If the wind speed is given in miles per hour (mi h^{-1}), the conversion to m s^{-1} is required.

$$\mathrm{ea} = 0.611 \times \exp\left(\frac{17.27\mathrm{Tmin}}{\mathrm{Tmin} + 237.3}\right) \quad (3)$$

$$\mathrm{es} = 0.611(\exp\left(\frac{17.27\mathrm{Tmax}}{\mathrm{Tmax} + 237.3}\right) + \exp\left(\frac{17.27\mathrm{Tmin}}{\mathrm{Tmin} + 237.3}\right) \quad (4)$$

$$\mathrm{Rn} = \mathrm{Rns} - \mathrm{Rnl} \quad (5)$$

$$\mathrm{Rns} = 0.77\mathrm{R} \quad (6)$$

$$\mathrm{Rs} = \mathrm{kRs} \times \mathrm{Ra}(\mathrm{Tmax} - \mathrm{Tmin})^{0.5} \quad (7)$$

kRs=0.16

$$\Delta = \frac{2503\exp(17.27\ \mathrm{T})}{(\mathrm{T_{Max}} + 273.3)^2} \quad (8)$$

where T is the mean temperature (°C)

$$\mathrm{T} = \frac{\mathrm{Tmax} + \mathrm{Tmin}}{2} \quad (9)$$

$$\mathrm{PETvar} = \left(\mathrm{PET\ new} - \mathrm{PET}\frac{\mathrm{old}}{\mathrm{PET}}\mathrm{old}\right) \times 100\% \quad (10)$$

Eq. (1) was applied to calculate the values of evapotranspiration in Iraq for the last 13 years (2008-2020) and to know the essential factors affecting their values [22-24]. The results obtained after applying the Penman-Monteith equation are shown in Table 2.

Fig. 2 shows evapotranspiration rates on a map of Iraq using Arc GIS, and applying the spatial analysis method (interpolation). Interpolation is a spatial analysis method used to estimate values in unmeasured locations based on data available in nearby locations. Fig. 2 shows the map of Iraq in the form of colors and percentages.

Blue color represents the lowest percentage; red color represents the highest percentage, and the remaining percentages range in between [25-27].

Table 2: Annual potential evapotranspiration (mm/day) for 2008, 2011, 2014, 2017, and 2020.

Stations	2008 (mm/day) PET	2011 (mm/day) PET	2014 (mm/day) PET	2017 (mm/day) PET	2020 (mm/day) PET
Mousel	1564.9	1513.6	1814	1986.7	1933.3
Kirkuk	3015	2480.1	2286.3	2149.1	2228.2
Khanaqeen	1317.9	1513.8	1560.4	1889.2	1629.3
Haditha	2846.9	2900.3	3018.4	2957.3	3170.5
Baghdad	4599.3	3696.6	3867.5	5004.4	4768.5
Rutba	2727.8	1951.3	2328.5	2638.6	2640.4
Karbala	3885	3973.8	3765.4	3245.3	2772.2
Alhai	4539.1	3979.4	4063.3	3372.8	4319.6
Najef	3025.8	2806.7	3003.3	2054.4	1607
Amara	4870.8	4936.5	4294.9	4732.7	4024.6
Nasriya	4565.4	4816.9	4534.5	4472.8	4200.6
Basrah	6067.3	6030.1	5121.7	4643.6	3924.6

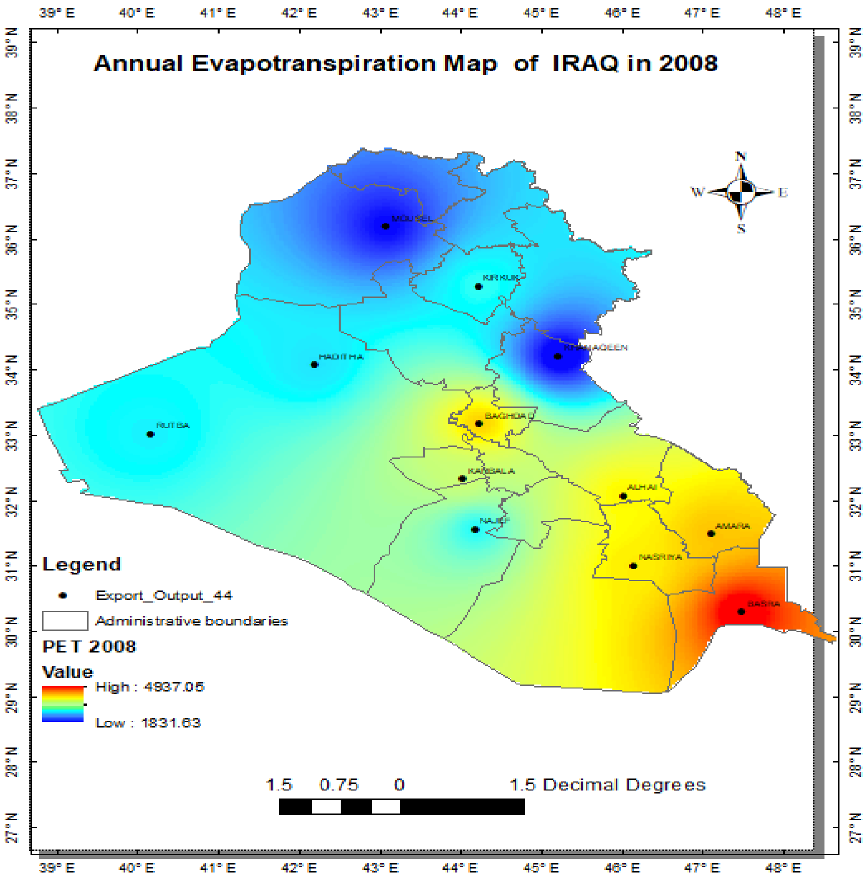

Figure 2: The Annual Evapotranspiration Map of Iraq in 2008 using Penman-Monteith method.

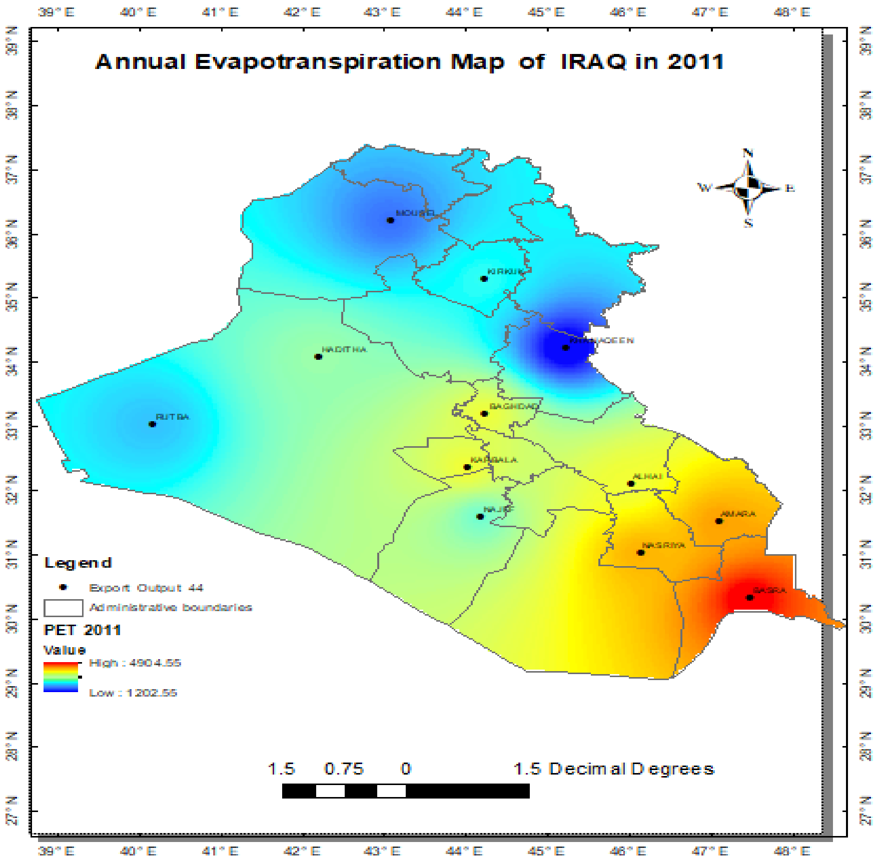

Figure 3: The Annual Evapotranspiration Map of Iraq in 2011 using Penman-Monteith method.

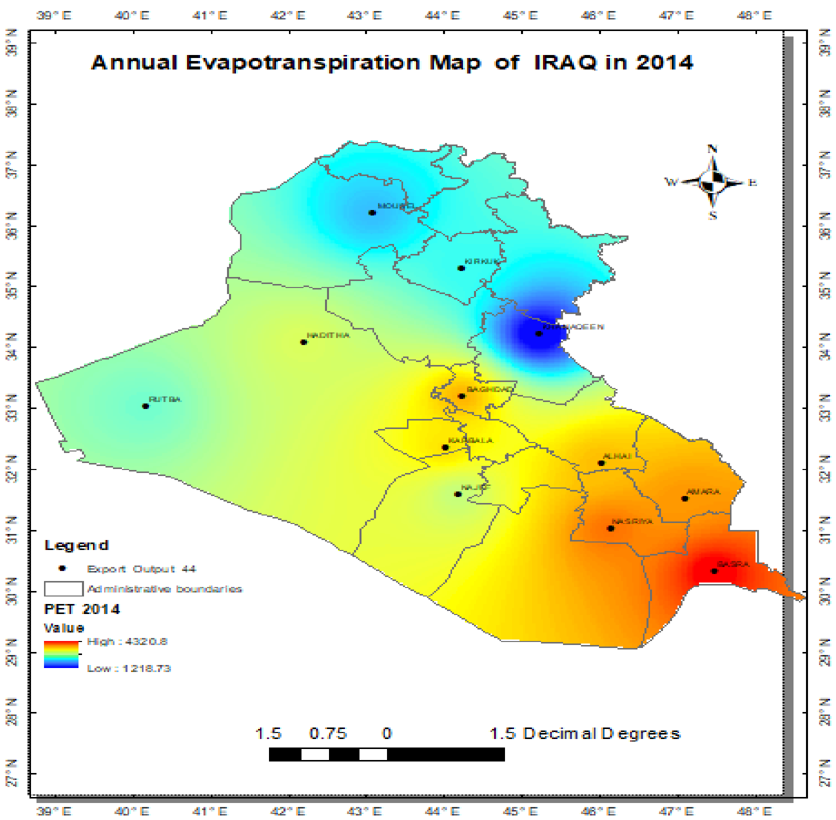

Figure 4: The Annual Evapotranspiration Map of Iraq in 2014 using Penman-Monteith method.

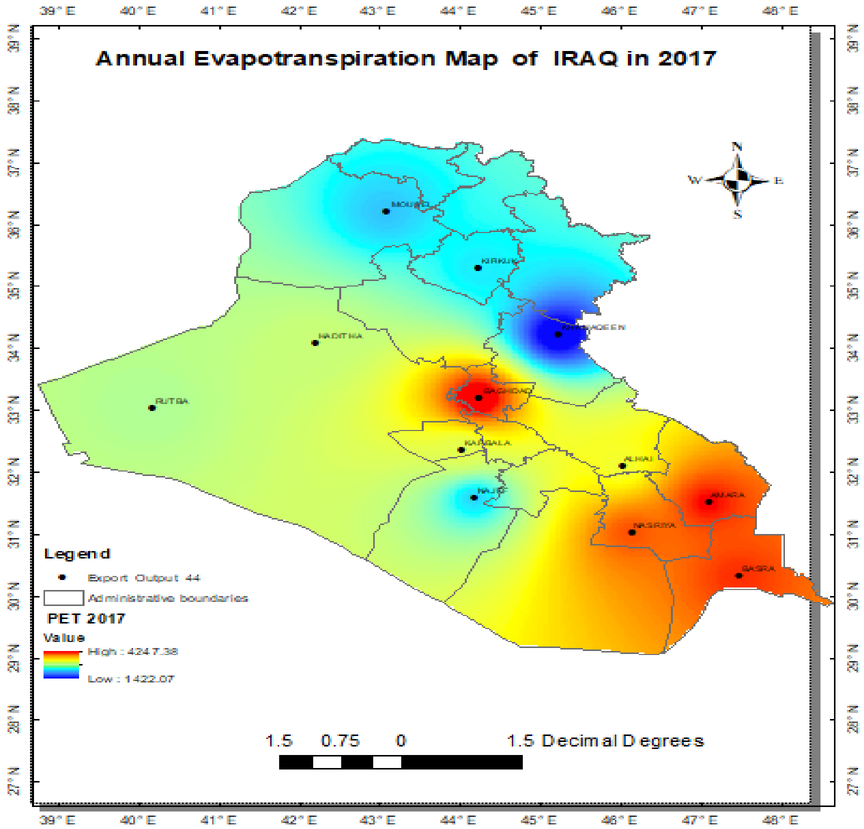

Figure 5: The Annual Evapotranspiration Map of Iraq in 2017 using Penman-Monteith method.

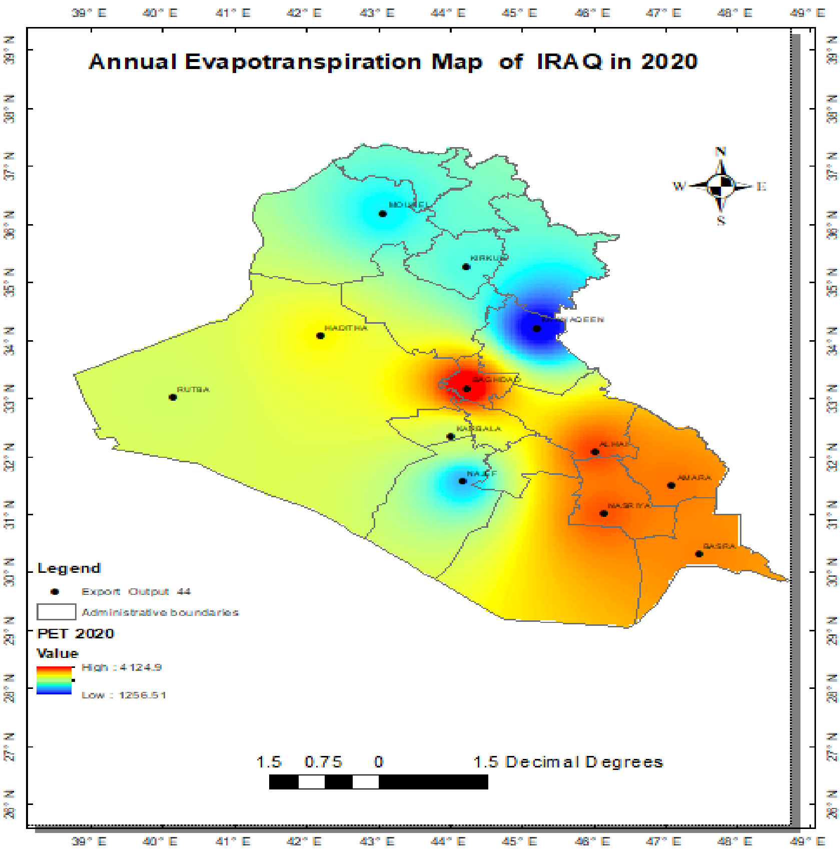

Figure 6: The Annual Evapotranspiration Map of Iraq in 2020 using Penman-Monteith method.

3. Results and Discussion

Table 3 shows the percentage of potential evapotranspiration variation for the study period 2008-2022, where the 2008 rates were relied upon as a reference for the subsequent years.

Table 3: The Annual PETvar for (2008-2011), (2008-2014), (2008-2017), (2008-2020).

Stations	(2008-2011) var%	(2008-2014) var%	(2008-2017) var%	(2008-2020) var%
Mousel	-3.2781647	15.91795	26.953799	23.54144035
Kirkuk	-17.741294	-24.169154	-28.719735	-26.09618574
Khanaqeen	14.8645573	18.4004856	43.3492678	23.62849989
Haditha	1.87572447	6.02409639	3.87790228	11.3667498
Baghdad	-19.6269	-15.911117	8.80786207	3.67882069
Rutba	-28.466163	-14.63817	-3.2700345	-3.204047218
Karbala	2.28571429	-3.0785071	-16.465894	-28.64350064
Alhai	-12.330638	-10.482254	-25.694521	-4.835760393
Najef	-7.2410602	-0.743605	-32.103906	-46.89007866
Amara	1.3488544	-11.82352	-2.8352632	-17.37291615
Nasriya	5.50882727	-0.6768301	-2.0282998	-7.990537521
Basrah	-0.6131228	-15.585186	-23.465133	-35.31554398

The general evapotranspiration rates decreased for the study period (2008-2020). The peak of the evapotranspiration transition was in 2008 and significantly decreased in subsequent years. The reasons for this decrease are either a decrease in the maximum temperature, a decrease in wind speed rates, or an increase in the percentage of relative humidity; as the humidity increases, the rate of evapotranspiration decreases, and the minimum temperature increases as shown in (Fig. 7,8,9,10,11).

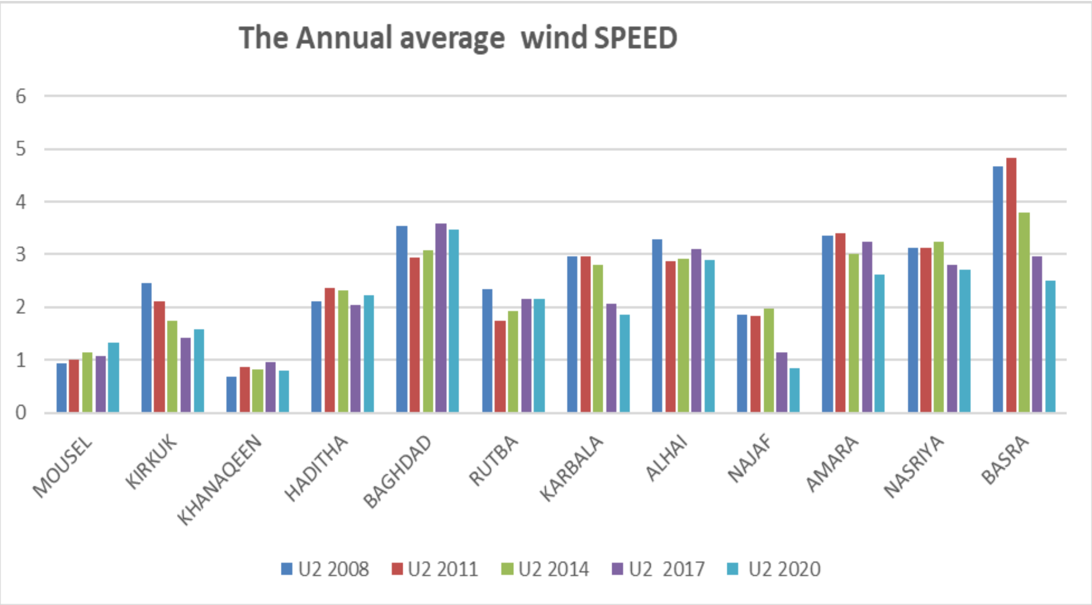

Figure 7: The Annual average U2 for Iraq (2008, 2011, 2014, 2017, 2020).

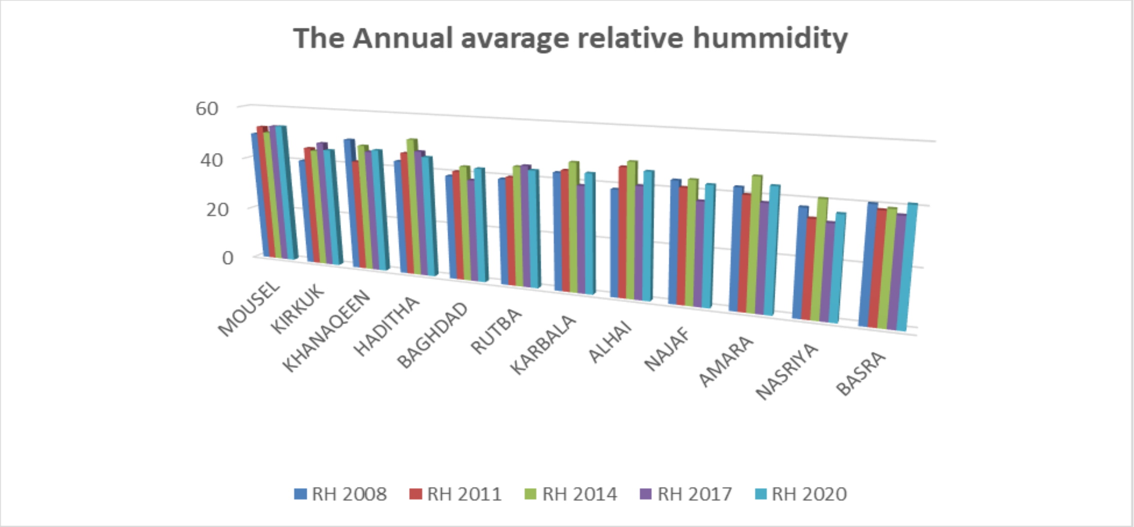

Figure 8: The Annual average Rn for Iraq (2008, 2011, 2014, 2017,2020).

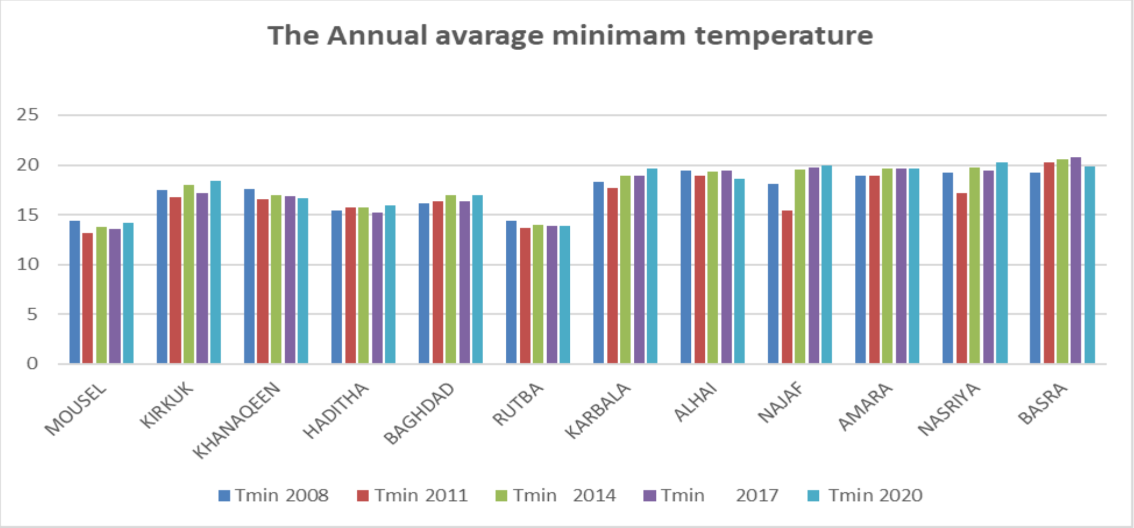

Figure 9: The Annual Average Tmin for Iraq (2008, 2011, 2014, 2017, 2020).

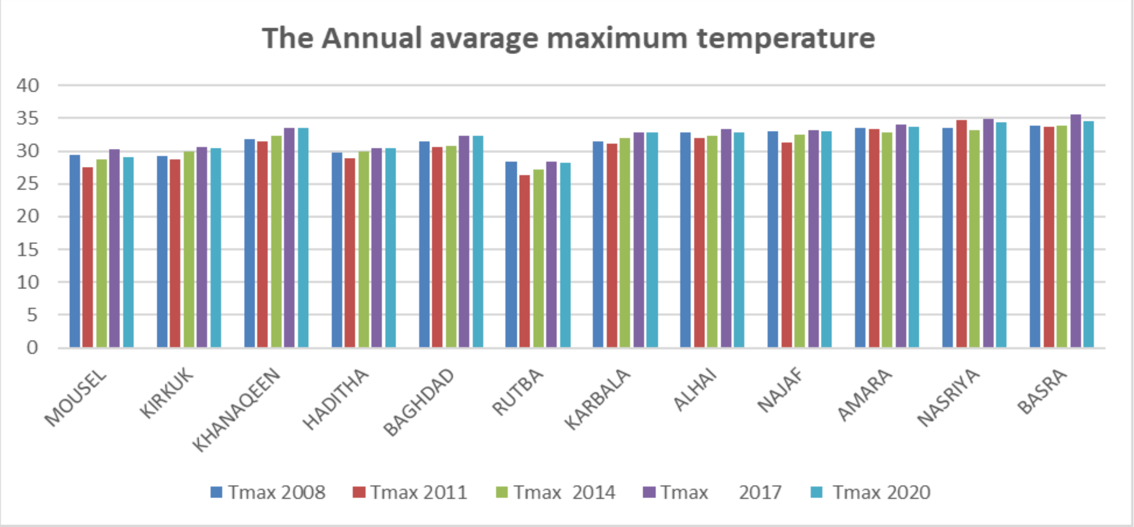

Figure 10: The Annual Average Tmax for Iraq (2008, 2011, 2014, 2017, 2020).

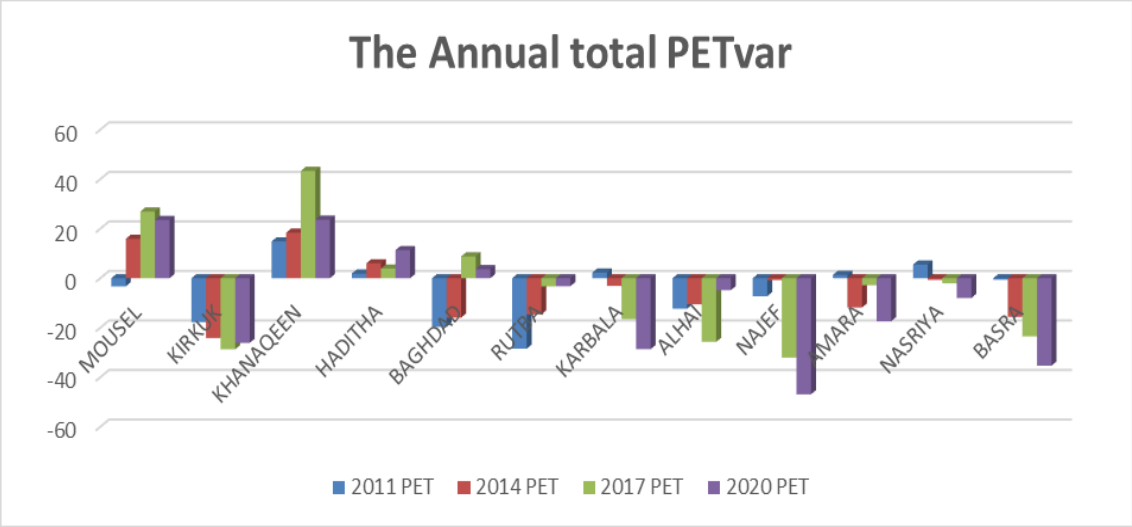

Figure 11: The Annual PETvar for Iraq (2008, 2011, 2014, 2017, 2020)

Also, Figures 7-11 show that the rate of evapotranspiration in the southern governorates is higher than in the northern governorates because the climate of Iraq in the central and southern parts is affected by the climate of the Arabian Desert, which is dry subtropical. The climate of the Arabian Gulf is subtropical and humid, and Evaporation is at its highest levels in the summer months, especially in August and July.

There were some deviations in these rates, as in 2020, which witnessed a general decline in evapotranspiration rates, except in some stations that recorded an increase. For example, Khanaqin station recorded the highest increase in evapotranspiration rates, and this increase was due to the high temperature and decrease in relative humidity.

2. Conclusions

In this study, many points can be concluded aaccurate calculation of evapotranspiration rates is of great importance in agriculture planning and climate modelling. Low evapotranspiration rates in Iraq have two main causes: a decrease in wind speed, which is the main factor, and an increase in relative humidity. The relationship between evapotranspiration and humidity is inverse. Whenever the rate of evapotranspiration increases, there is a decrease in relative humidity.

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Conflict of interest

Authors declare that they have no conflict of interest.

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دراسة التبخر والنتح في العراق باستخدام معادلة بينيمان-مونتيث للفترة (2008-2020)

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الخلاصة

يعتبر تبخرالنتح عنصرا أساسيا لاستقرار النظام البيئي، وذلك لأهميته في العديد من الجوانب، بما في ذلك دورة المياه، التي تعد مصدرا هاما للمياه العذبة للإنسان والحيوان والنبات، كما أن لها أهمية كبيرة في التأثير على درجات الحرارة وتنظيم الطقس. وكذلك تصميم شبكات الري للزراعة ومعرفة احتياجاتها من المياه لمنع الجفاف والتصحر. تعتبر طريقة بينمان مونتيث طريقة فعالة ودقيقة لحساب التبخر المرجعي اليومي. وقد اعتمدتها منظمة الأغذية والزراعة (الفاو) كأسلوب قياسي، وتهدف هذه الدراسة إلى حساب التباين في معدلات التبخر نتح في العراق خلال السنوات الثلاث عشرة الماضية (2008-2020) في خمس فترات زمنية متساوية (2008، 2011، 2014، 2017، 2022). أظهرت هذه الدراسة أن المعدلات الإجمالية لتبخرالنتح انخفضت وبلغت هذه القيم ذروتها في عام 2008 ثم انخفضت بشكل ملحوظ في السنوات اللاحقة. ويعود سبب الانخفاض إلى انخفاض سرعة الرياح وزيادة الرطوبة النسبية. وقد تبين أن معدلات تبخرالنتح في محافظات الوسط والجنوب أعلى منها في المحافظات الشمالية، إلا أن هناك انحرافات في معدلات بعض المحطات، كما في عام 2020 شهدنا انخفاضاً عاماً في معدلات تبخرالنتح باستثناء بعض المحطات التي سجلت ارتفاعاً. على سبيل المثال سجلت محطة خانقين أعلى زيادة في معدلات تبخرالنتح وبلغت نسبة الارتفاع 23.6% وسبب هذه الزيادة هو ارتفاع درجة الحرارة بنسبة 5.2% وانخفاض الرطوبة النسبية بنسبة -6.5%.

الكلمات المفتاحية: تبخر النتح، بينمان مونتيث، الاحتباس الحراري، نظم المعلومات الجغرافية، البينات المناخية.