Temperature – Potential Evapotranspiration Relationship in Iraq Using Thornthwaite Method

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Abstract

One of the most important outcomes in the water balance equation for any natural area or water body is Evapotranspiration and it is also a crucial component of the hydrologic cycle. The relationship of temperature - evapotranspiration was obtained using the Thornthwaite method in Iraq by dividing the area into (7) sectors according to geographic latitude. Each sector has multi meteorological stations where (32) stations were used with different periods of records. A mathematical relationship was obtained between mean temperature and corrected potential evapotranspiration (PEc) with (97.45) to (99.84) coefficient of determination. Mean temperature has a symmetrical decreasing pattern from south-east towards north-west of Iraq affected by Mediterranean Sea climate conditions, while correcting potential evapotranspiration (PEc) has the opposite direction of increasing values due to a direct relationship with temperature.

Keywords: Potential Evapotranspiration, Thornthwaite Method, Iraq.

1. Introduction

Water is a vital component to the development of any area. The demand of water increased recently because of the growing population, where water for agriculture and other demands becomes limited [1]. Climate and hydrological conditions in any hydrological basin are multi-combined reflection of natural factors of morphology and soil nature, as well as the changing in climate factors that affect directly on hydrological cycle [2]. The water balance equation for any natural area or water body indicates the relative values of inflow, outflow and change in water storage in the area or water body [3]. One of the most important outcomes in water balance equation for any natural area or water body is Evapotranspiration and it is also a crucial component of hydrologic cycle [4]. It can be defined as the combination of two separate processes through which, water is lost from the soil surface via evaporation process and from the crop by transpiration [5]. Evapotranspiration consider a main requirement in planning and designing any irrigation project in arid and semiarid regions [6]. Thornthwaite method is one of the significant methods used to estimate the potential Evapotranspiration (PE) that is based on the monthly average temperature. This method can be appropriately used in arid and semi-arid regions [7]. Thornthwaite method is widely used for estimating potential evapotranspiration was derived by (Thornthwaite,1948) [8], who correlated mean monthly temperature with evapotranspiration as determined from water balance for valleys where sufficient moisture water was available to maintain active transpiration. Potential Evapotranspiration can be calculated by applying following formula [9]:

$$PE = 16\left[\frac{10tn}{J}\right]^a \qquad \text{------- (1)}$$

$$J = \sum_{1}^{12} j \qquad \text{------- (2)}$$

$$j = \left[\frac{tn}{5}\right]^{1.514} \qquad \text{------- (3)}$$

$$a = 0.016J + 0.5 \qquad \text{--------- (4)}$$

PE: potential evapotranspiration, J: Heat Index, j: Coefficient monthly temperature (° C), a: Constant, tn: Average monthly temperature (° C).

Prediction of monthly evapotranspiration can be obtained depending on observed monthly average temperatures at a meteorological station in each year, despite the fact that this formula is shown by many researches to underestimate (PE), it has been accepted widely around the globe [10]. Thus relationship can be estimated between those two parameters in order to facilitate calculation of water balance of lakes, river basins, and ground-water basins as well as reducing cost and time.

The relationship of temperature - evapotranspiration obtained by Thornthwaite method in Iraq is the main objective of this research. Temperature as a key factor controlling on monthly evapotranspiration can be obtained by dividing Iraqi area into (7) sectors according to geographic latitude. Each sector has multi meteorological stations where (32) stations were used all over Iraq.

Iraq is sited between latitude (29.00°- 37.22°N) and longitude (38.45°- 48.30°E), while climate of Iraq is generally as continental and subtropical semi-arid type whereas the mountainous regions are classified a Mediterranean climate. It is characterized by a very hot summer and a short cold winter and also by the breadth of the daily and annual temperature because of the lack of large water bodies that reduce the coldness of winter and summer heat [11].

Many pervious studies were used Thornthwaite method to calculate evapotranspiration in specific region of Iraq in order to estimate water balance, while one research has been found using geographic information system to estimate the Evapotranspiration in Iraq according to Thornthwaite formula. This research used (11) meteorological stations to estimate global warming influence on the annual mean value of temperature and yet on the annual mean value of the evapotranspiration for more than three decades in Iraq [12].

2. Material:

The materials used in this research were:

1- Annual and monthly temperature records for (32) meteorological stations with their geographic coordinates from date of station operation until 2015 [13].

2- Thornthwaite formula [8].

3- Grapher and Surfer programs demonstrating graphs and contour maps.

3. Methodology:

In this research annual and monthly air temperatures of (32) meteorological stations were used to calculate potential evapotranspiration (PE) using Thornthwaite method. These stations were divided according to Iraqi geographic latitude from (30-31) in the south to (36-37) in the north of Iraq, Table (1) Fig (1). Calculated potential evapotranspiration (PE) was compared with temperature in all station located in the same sector. Statistical approach was used to identify the types of equations for each group of stations using Grapher program. Finally Surfer program was used to demonstrate contour map of heat and corrected potential evapotranspiration (PEc) in Iraq.

Table 1: Geographical position of meteorological stations in Iraq

Location of stations		Name of Station	Station No.	Location of stations		Name of Station	Station No.
Long.	Lat.			Long.	Lat.		
444300	323300	Ainaltamer	1	433600	354500	Makhmoor	17
471000	315100	Amarah	2	430900	361900	Mosul	18
415700	342800	Anah	3	441900	315900	Najaf	19
450400	325500	Azizyah	4	421500	320200	Nukhaib	20
414400	360200	Baaj	5	461400	310500	Nasiriyah	21
455700	330600	Badra	6	410100	342300	Qaim	22
441400	331400	Baghdad	7	420600	364800	Rabiah	23
432900	345600	Baiji	8	430900	332700	Ramadi	24
474700	303400	Basrah	9	401700	330200	Rutba	25
445900	315900	Diwaniyah	10	435300	341100	Samaraa	26
460300	321000	Hai	11	451600	311800	Samawah	27
442700	322700	Hilla	12	415000	361900	Sinjar	28
440100	323700	Karbalaa	13	422900	362200	Tel-Afer	29
443200	335000	Khalis	14	434200	343400	Tikrit	30
452600	341800	Khanaqin	15	443900	345300	Tuz	31
442400	352800	Kirkuk	16	360900	440000	Erbeel	32

4. Results and discussion:

Table 2 shows the (7) groups of meteorological stations located in each sector according to Iraqi latitude. Using Thornthwaite formula [8] showed in equation (1,2,3,4) previously, the annual corrected potential evapotranspiration (PEc) was calculated after using correction factor of sunlight duration and number of day light according to latitude, Table 3. Table 4 shows the mean annual temperature and summation of annual (PEc).
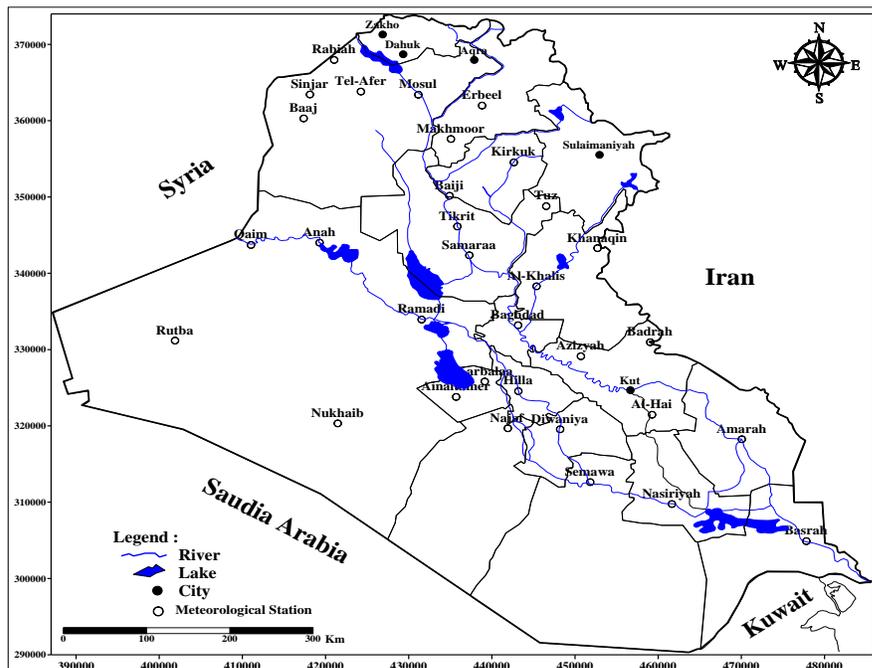

Fig. 1: Distribution map of Meteorological stations in Iraq.

Table 2: Groups of meteorological stations located in each sector

Sector No.	Sum of Station	Geographic latitude	Stations
1	2	30-31	Basrah and Nasriyah
2	4	31-32	Amarah, Diwaniyah, Najaf and Samawah
3	6	32-33	Aintamer Aziziyah, Hai, Hella, Karbala and Nukhaib
4	5	33-34	Badra, Baghdad, Khalis, Ramadi, Rutba
5	6	34-35	Anah, Khanaqin, Qaim, Samaraa, Tikrit and Tuz
6	3	35-36	Baiji, Kirkuk and Makhmoor
7	6	36-37	Erbeel, Baaj, Mosul, Rabiah, Sinjar and Tel-Afar

Table 3: Constant K in Thornthwaite method* [8]

Latitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
60° N	0.54	0.67	0.97	1.19	1.33	1.56	1.55	1.33	1.07	0.84	0.58	0.48
50° N	0.71	0.84	0.98	1.14	1.28	1.36	1.33	1.21	1.06	0.9	0.76	0.68
40 °N	0.8	0.89	0.99	1.1	1.2	1.25	1.23	1.15	1.04	0.93	0.83	0.78
30° N	0.87	0.93	1	1.7	1.14	1.17	1.16	1.11	1.03	0.96	0.89	0.85
20° N	0.92	0.96	1	1.05	1.09	1.11	1.1	1.07	1.02	0.98	0.93	0.91
10° N	0.97	0.98	1	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96
00° N	1	1	1	1	1	1	1	1	1	1	1	1
10°S	1.05	1.04	1.02	0.99	0.97	0.96	0.97	0.98	1	1.03	1.05	1.06
20° S	1.1	1.07	1.02	0.98	0.93	0.91	0.92	0.96	1	1.05	1.09	1.11
30° S	1.16	1.11	1.03	0.94	0.89	0.85	0.87	0.93	1	1.07	1.14	1.17
40°S	1.23	1.15	1.04	0.93	0.83	0.78	0.8	0.98	0.99	1.1	1.2	1.25
50° S	1.33	1.19	1.05	0.98	0.75	0.68	0.7	0.82	0.97	1.13	1.27	1.36

K: is a constant to correct PE for latitude other than 0°.

Table 4: Mean annual temperatures and corrected evapotranspiration (PEc) calculated in each meteorological station in Iraq

St. No.	Annual Mean Tem. (C)	Sum of corrected (PEc) (mm)	Duration (years)	St. No.	Annual Mean Tem. (C)	Sum of corrected (PEc) (mm)	Duration (years)
1	22.279	1579.066	20	17	22.677	1792.035	19
2	24.804	2318.14	35	18	20.1093	1327.295	70
3	20.958	1388.118	38	19	24.406	2185.641	40
4	23.968	2014.677	15	20	22.279	1579.066	20
5	20.487	1361.543	17	21	25.092	2257.156	73
6	24.546	2330.101	15	22	20.966	1383.538	20
7	22.694	1674.369	66	23	18.52	1122.652	31
8	22.44	1697.278	30	24	22.073	1515.101	25
9	24.876	2132.123	67	25	19.738	1182.171	35
10	24.262	2033.104	38	26	23.136	1845.079	26
11	24.435	2139.199	68	27	24.748	2242.733	38
12	23.259	1773.72	25	28	20.556	1399.499	42
13	24.114	2087.377	38	29	21.043	1464.71	25
14	22.016	1511.515	17	30	23.0471	1910.049	24
15	22.834	1751.833	60	31	22.794	1768.054	17
16	22.195	1662.425	68	32	21.321	1488.116	40

Depending on Table 4, Figs. 2 and 3 show the mathematical relationship between monthly mean temperature and monthly corrected potential evapotranspiration (PEc) calculated in each group within (7) sectors. Table 5 shows the obtained equation of mathematical relationship between temperature and (PEc) in each sector.

Table 5: Equations obtained between temperature and (PEc) in each sector

Sector No.	Station No.	Equation and alternate equation	R-squared %
1	9 and 21	log (PEc) = 3.74303 * log (T) + -7.30851 PEc = T ^(3.74303) * 0.000669814	99.84
2	2,10,19 and 27	log(PEc) = 3.62641 * log(T) + -6.91808 PEc = T ^(3.62641) * 0.000989726	99.81
3	1,4,11,12,13 and 20	log (PEc) = 3.28486 * log (T) + -5.77718 PEc = T ^(3.28486) * 0.00309742	99.15
4	6,7,14,24 and 25	log (PEc) = 2.97073 * log (T) + -4.73113 PEc = T ^(2.97073) * 0.00881649	97.45
5	3,15,22,26,30 and 31	log (PEc) = 3.02967 * log (T) + -4.92707 PEc = T ^(3.02967) * 0.00724772	98.96
6	8,16 and17	log (PEc) = 3.0942 * log (T) + -5.14115 PEc = T ^(3.0942) * 0.00585097	99.74
7	5,18,23,28,29 and 32	log (PEc) = 2.61248 * log (T) + -3.54622 PEc = T ^(2.61248) * 0.0288333	98.93

It seems that sector (4) has the lower coefficient of determination (R-squared) among other sectors. This sector located within latitude (33-34) and has (5) meteorological stations distributed on wide range in middle of Iraq from west to east. Four of these stations are closed together (Badra, Khalis, Baghdad and Ramadi) while Rutba station is located almost near the Iraqi – Jordanian border. The recorded mean temperatures in four stations which located in the middle and eastern side of Iraq was ranged (22.016 - 24.546 ☐ C) and potential evapotranspiration was ranged (1511.515 - 2330.101 mm), while mean temperatures in Rutba station was (19.738) and potential evapotranspiration was (1182.171 mm) due to desert climate. This difference affects on potential evapotranspiration calculated in this station compared to other stations in the same sector.
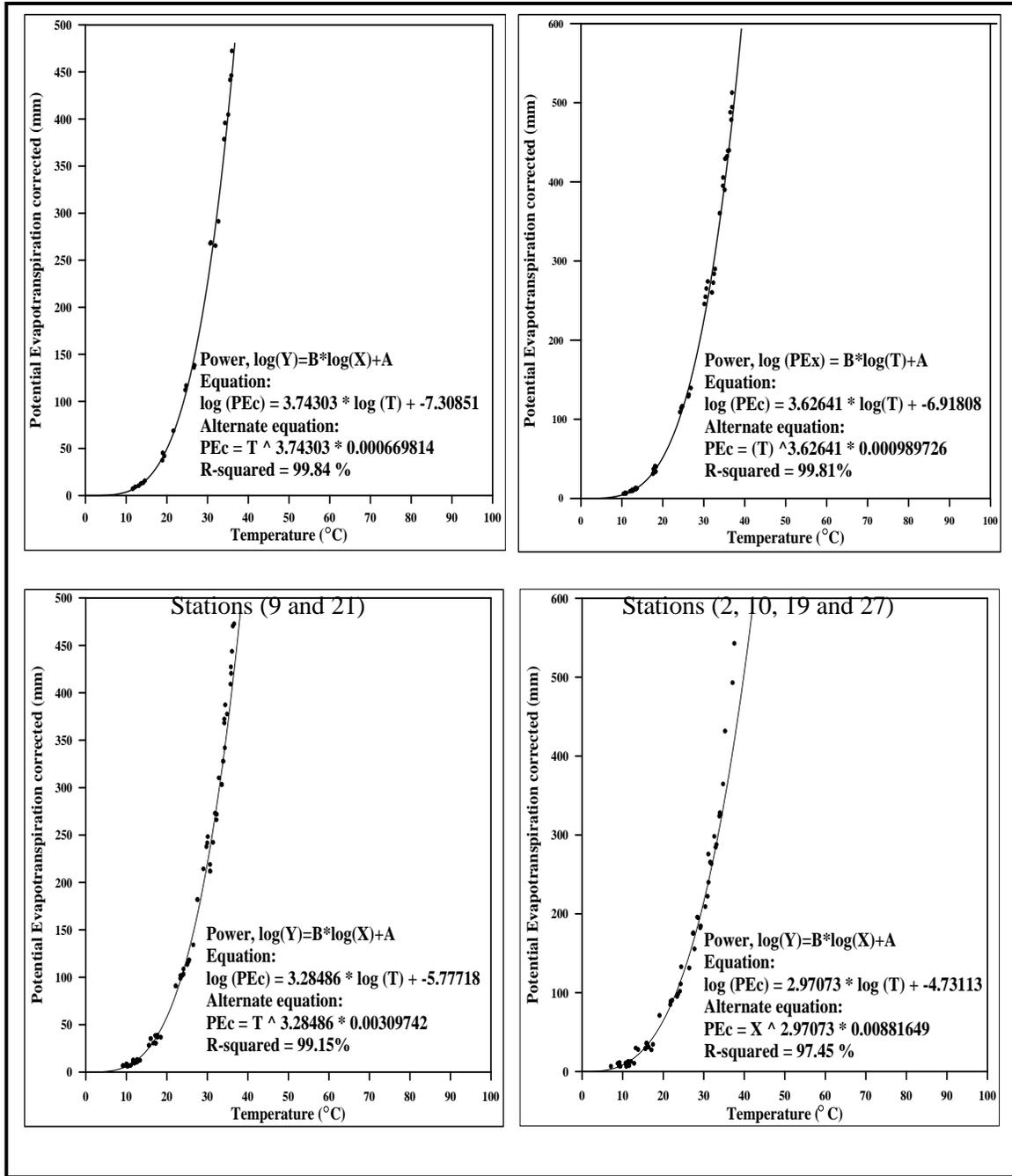
Stations (1, 4,11,12,13 and 20)   Stations (6, 7, 14, 24 and 25)

Fig. 2: Mathematical relationship between temperatures and (PEc).

Stations (3, 15,22,26,30 and 31)

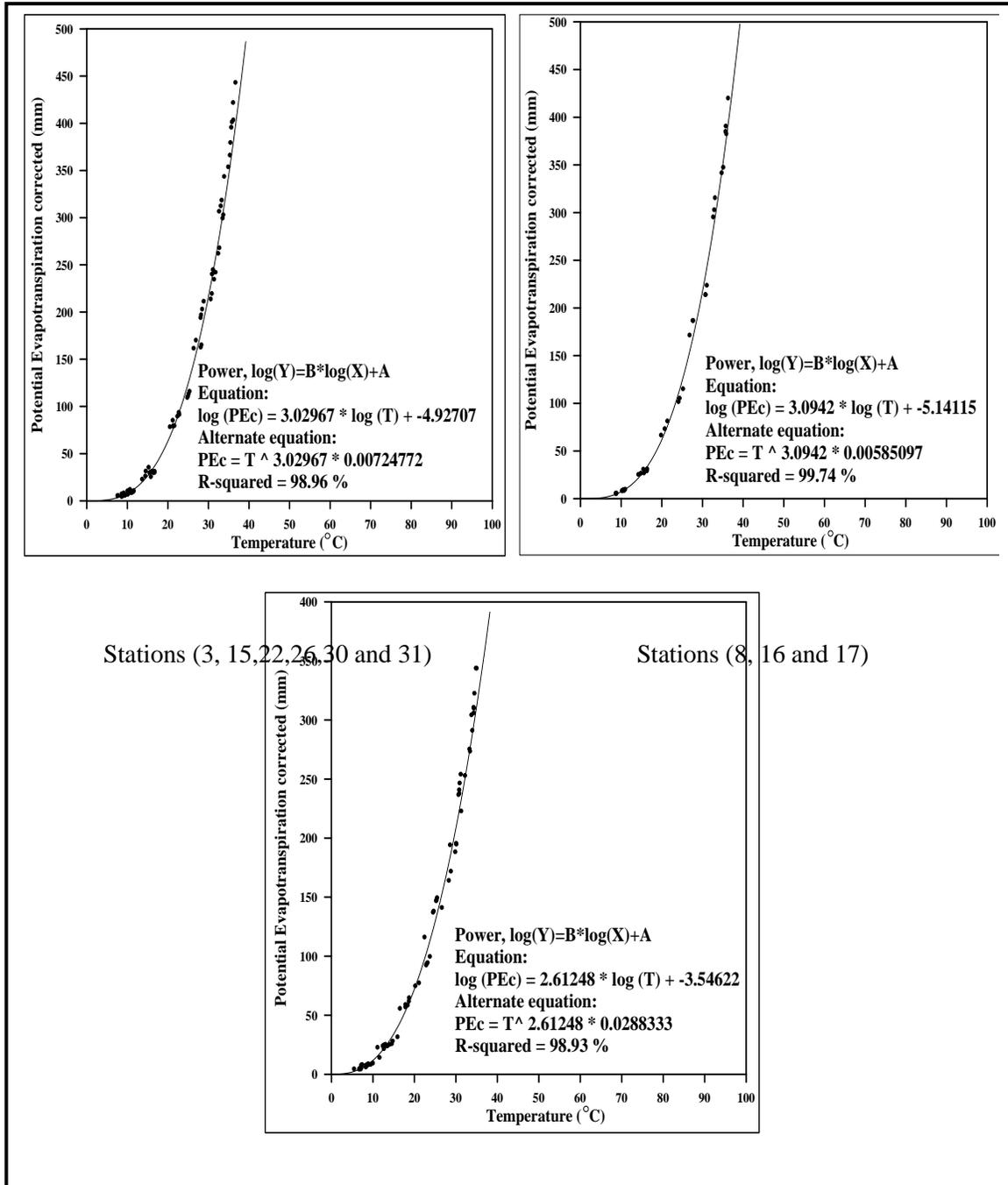**Stations (8, 16 and 17)**

Stations (5, 18,23,28,29 and 32)

Fig. 3: Mathematical relationship between temperatures and (PEc).

Depending on Table 4, the mean temperature in (32) stations was demonstrated in Fig. 4, while Fig. 5 show the distribution of correcting potential evapotranspiration (PEc) in Iraq. It seems that mean temperature has a symmetrical decreasing pattern from south-east towards north-west due to high relative humidity rates in the north-west part of Iraq because of its geographic location towards Mediterranean Sea and its climate condition which reduce the mean annual and monthly temperatures. On the other hand the

distribution of correcting potential evapotranspiration (PEc) as shown in Fig. 5 has the opposite direction of increased value of Evapotranspiration due to a direct relationship with temperature.
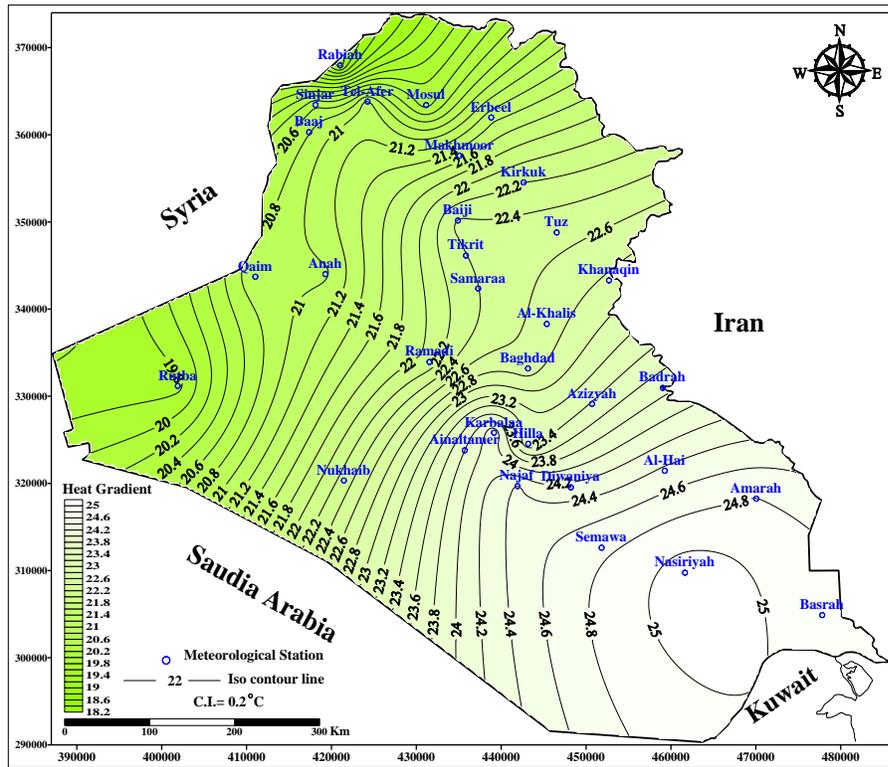

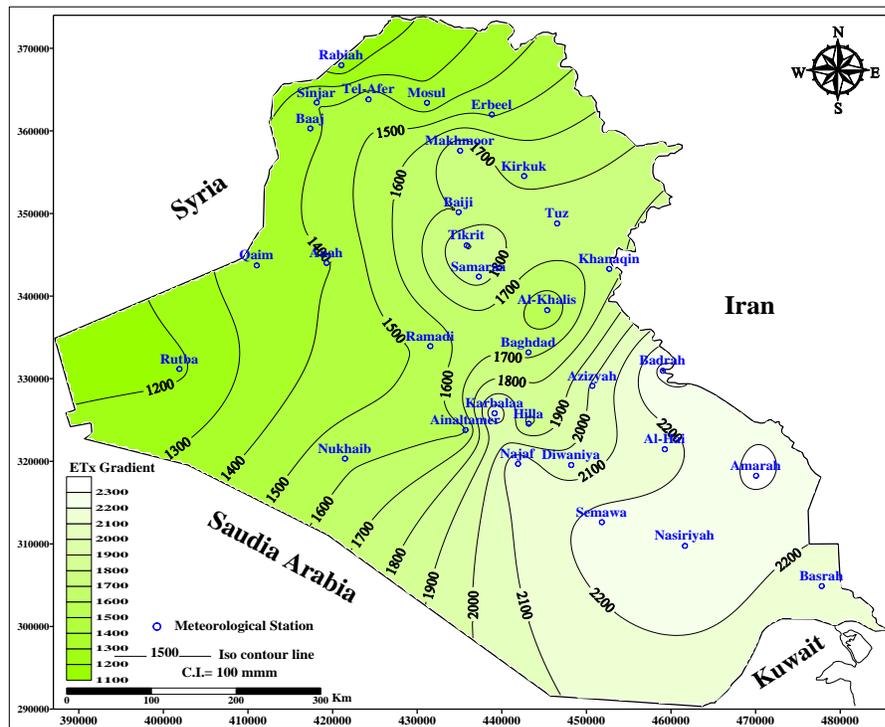**Fig. 4: Contour map of mean annual Temperature in Iraq.**

Fig. 5: Contour map of annual corrected Potential Evapotranspiration (PEc) in Iraq.

5. Conclusions:

1- Thornthwaite method is one of the significant methods used to estimate the potential Evapotranspiration (PE) that is based on annual and monthly average temperature.

2- A mathematical relationship can be obtained between mean temperature with corrected potential evapotranspiration (PEc) using thornthwaite formula with (97.45) to (99.84) coefficient of determination in (7) sectors.

3- Mean temperature has a symmetrical decreasing pattern from south-east towards north-west of Iraq infected by Mediterranean Sea climate conditions, while corrected potential evapotranspiration (PEc) has the opposite direction of increasing values due to direct relationship with temperature.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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العلاقة بين درجة الحرارة والتبخر – نتح كامن في العراق باستخدام طريقة ثورنثويت

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خلاصة

احدى أهم النتائج في معادلة الموازنة المائية لاي منطقة طبيعية او جسم مائي هي التبخر – نتح كامن وهو أيضا عنصر مهم وحاسم في الدورة الهيدرولوجية. في هذا البحث تم ايجاد العلاقة الارتباطية بين درجة الحرارة والتبخر – نتح كامن باستخدام طريقة ثورنثويت في العراق من خلال تقسيم المنطقة إلى (٧) قطاعات بحسب خطوط العرض الجغرافية الممتدة من الجنوب الى الشمال. تضمن كل قطاع مجموعة من محطات الرصد الجوية حيث تم استخدام (٣٢) محطة تضمنت بيانات درجات الحرارة لفترات تسجيل مختلفة. توصل البحث الى ايجاد علاقة رياضية بين متوسط درجة الحرارة مع معامل التبخر – نتح كامن المصحح وبمعامل ارتباط تراوح بين (٩٧٫٤٥) إلى (٩٩٫٨٤). بينت النتائج بان متوسط درجات الحرارة تميز بوجود نمط تزايد متماثل اتجه من الجنوب الشرقي إلى الشمال الغربي من العراق متأثرًا بالظروف المناخية للبحر الأبيض المتوسط، في الوقت الذي تناقصت قيم التبخر – نتح كامن المصحح بشكل عكسي لنمط تزايد درجات الحرارة تنظراً لارتباطه المباشر بها.

الكلمات الداله: التبخر – نتح كامن، طريقة ثورنثويت، العراق.