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RESEARCH ARTICLE

Calculation of meteorological water balance in Iraq

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Abstract: The hydrology section is divided into two main components, surface and groundwater. 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. Prediction of monthly evapotranspiration can be obtained depending on observed monthly average temperatures at a meteorological station in each year. Calculating of water balance in Iraq depending on meteorological data and Thornthwaite method was the aim of this research. Results of corrected potential evapotranspiration (PEc) obtained from applying Thornthwaite formula were compared with annual and monthly rainfall in thirty two meteorological station in order to estimate actual evapotranspiration (AE). The results showed that the annual summation of rainfall increased from south west towards north east according to the increasing ratio of rainfall due to the impact of Mediterranean climate condition on Iraq. Actual evapotranspiration depends directly on water excess during calculating water balance. Water surplus contour map indicates increased values towards north-east direction of Iraq, where water surplus depends directly on both rainfall and actual evapotranspiration.

Keywords: meteorological water balance, thornthwaite formula, evapotranspiration, Iraq

1 Introduction

Water is a vital component to the development of any area. The demand of water has 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 changes in climate factors that affect directly on the hydrological cycle[2].

The study of the water balance in hydrology is the application of the principle of conservation of mass. This states that, for any arbitrary volume and during any period of time, the difference between total input and output will be balanced by the change of water storage[3]. Knowledge of the water balance assists the prediction of the consequences of artificial changes in the regime of streams, lakes, and ground-water basin[4]. Classical method of water balance calculations considers precipitation on the input side and runoff, evaporation and infiltration on the output one. It aims at the best estimate possible of the water balance components with the simplest formulation and the minimum set of input data[5]. The water balance equation can be expressed as follows[6]:

$$Input - Output = Change\ in\ Storage \quad (1)$$

Rainfall is the only input element in the water balance, where set of outputs as evaporation, transpiration and consumption. Evaporation reflects the loss of water from water surfaces or soil, while transpiration and consumption reflect evaporation from plants. These two processes are called potential Evapotranspiration (PE) which reflects the water losses with abundant quantity of water exist in the basin area and it can be calculated by specific equations, while actual Evapotranspiration (AE) can be determined when quantity of water is limited[7]. The second element of the water balance is soil moisture content, which depends on soil type, texture and depth. This element affects on surface runoff and groundwater recharge, which represents the last elements of the water balance[7]. 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[8]. It can be defined as a combination of two separate processes through which, water is lost from the soil surface via evaporation process and from the crop by transpiration[9]. 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

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used in arid and semi-arid regions[10]. Potential Evapotranspiration can be calculated by applying following formula[7]:

$$PE = 16\left[\frac{10tn}{J}\right]^{a} \tag{2}$$

$$J = \sum_{1}^{12} j \tag{3}$$

$$j = \left[\frac{tn}{5}\right]^{1.514} \tag{4}$$

$$a = 0.016J + 0.5 \tag{5}$$

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[11].

Using meteorological data to calculate water balance in Iraq depending on Thornthwaite method is the aim of this research. The water balance is useful to predict water surplus and water deficit. The calculation of water balance will facilitate hydrological studies of lakes, river basins, and ground-water basins outcomes as well as reducing cost and time.

Iraq is sited between latitude (29.00 °- 37.22 °N) and longitude (38.45 °- 48.30 °E). Climate of Iraq is continental and subtropical semi-arid type whereas the mountainous regions are classified as 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[12].

Previous studies did not indicate using meteorological data to calculate water balance all over Iraq, while many previous studies were used meteorological data to calculate water balance in a specific region in Iraq. Some of these studies are mentioned below as samples:

1. Hyrogeological System of Debagah Basin in North of Iraq[5].
2. Water Balance of North Erbeel Basin[13].
3. Groundwater system of Dibdibba sandstone aquifer in south of Iraq[14].
4. Study of Morphometric Properties and Water Balance Using Thornthwaite Method in Khanaqin Basin, East of Iraq[7].
5. Calculating of Groundwater Recharge Using Meteorological Water Balance and Water level Fluctuation in Khan Al-Baghdadi Area[2].
6. Temperature—Potential Evapotranspiration Relationship in Iraq Using Thornthwaite Method[8].
7. Derivation Mathematical Equations for Future Calculation of Potential Evapotranspiration in Iraq, a Review of Application of Thornthwaite Evapotranspiration[9].
8. Estimation of Water Balance in Iraq using Meteorological Data[15].
9. Rainfall Returns Periods in Iraq[12].
10. Derivation mathematical equations to estimate water surplus and groundwater recharge in Iraq[16].

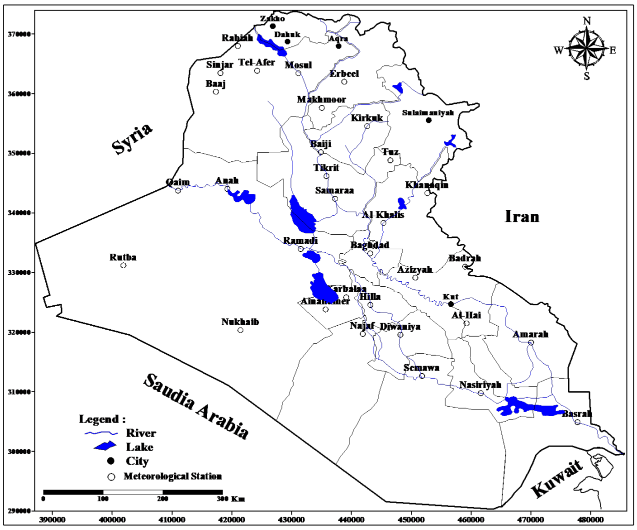

Figure 1. Distribution map of meteorological stations in Iraq

2 Material and methods

The materials used in this research were:

1. Annual and monthly temperature and rainfall records for (32) meteorological stations with their geographic coordinates from the date of station operation till 2015[17].
2. Thornthwaite formula[18].
3. Water balance equations[5–7].
4. Surfer program is used to construct the contour maps.

Temperature as a key factor controlling on potential evapotranspiration (PE) can be obtained by using data recorded in the meteorological stations. Thirty two stations were used all over Iraq, where annual and monthly air temperatures were adopted to calculate potential evapotranspiration (PE) using Thornthwaite method (Table 1, Figure 1). Results of corrected potential evapotranspiration (PEc) were compared with annual and monthly rainfall in each station to obtain actual evapotranspiration (AE). Finally surfer program was used to construct contour map of (PEc), (AE), water surplus (WS) and rainfall 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

Table 2. 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

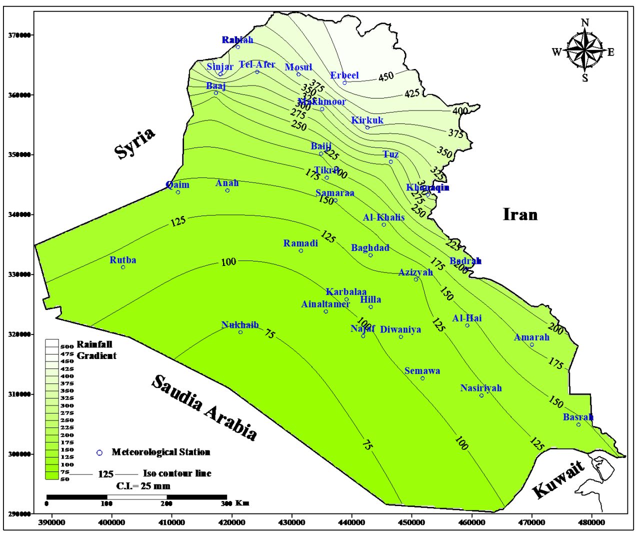

Figure 2. Contour map of annual summation of rainfall in Iraq

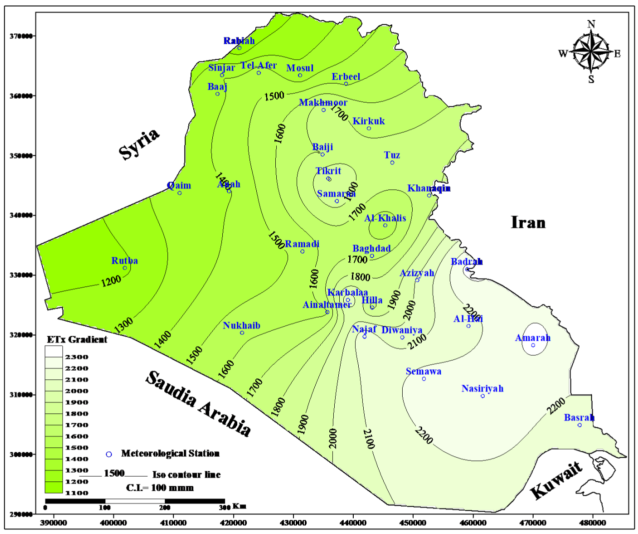

Figure 3. Contour map of annual corrected Potential Evapotranspiration (PEc) in Iraq

Table 3. Mean rainfall, (PEc), (AE) and (WS) in meteorological station in Iraq

St. No.	Ave. Sum of Rainfall (mm)	Ave. Sum of Potential ET (mm)	Ave. Sum of Actual ET (mm)	Ave. Sum of water surplus (mm)	water surplus (%)
1	92.47	1579.07	72.88	19.59	21.18
2	178.68	2318.14	103.66	75.02	42.00
3	142.52	1388.12	97.12	45.41	31.86
4	117.81	2014.68	82.73	35.08	29.78
5	229.04	1361.54	112.27	116.76	50.98
6	204.84	2330.10	108.42	96.42	47.07
7	136.70	1674.37	92.22	44.48	32.5
8	199.70	1697.27	116.67	83.03	41.57
9	144.80	2132.12	102.32	42.48	29.33
10	112.44	2033.10	84.34	28.10	25.00
11	139.17	2139.20	96.60	42.57	30.60
12	108.98	1773.72	80.08	28.90	26.51
13	103.46	2087.37	76.60	26.85	25.95
14	162.68	1511.51	106.55	56.13	34.50
15	308.66	1751.83	140.86	167.80	54.36
16	376.00	1662.42	152.20	223.80	59.52
17	306.91	1792.03	143.46	163.45	53.20
18	373.00	1327.29	148.05	224.94	60.30
19	94.05	2185.64	73.02	21.03	22.36
20	72.15	1579.06	63.18	8.97	12.42
21	119.48	2257.15	90.60	28.88	24.17
22	140.62	1383.53	98.25	42.37	30.13
23	367.12	1122.65	160.10	207.01	56.39
24	110.51	1515.10	86.40	24.11	21.82
25	116.65	1182.17	93.06	23.59	20.22
26	151.54	1845.08	101.50	50.05	33.03
27	104.68	2242.73	78.98	25.70	24.55
28	389.31	1399.5	153.81	235.49	60.50
29	322.84	1464.71	139.77	183.06	56.70
30	181.87	1910.05	104.89	76.99	42.32
31	254.02	1768.05	136.52	117.50	46.25
32	449.00	1488.11	305.30	143.69	32.00

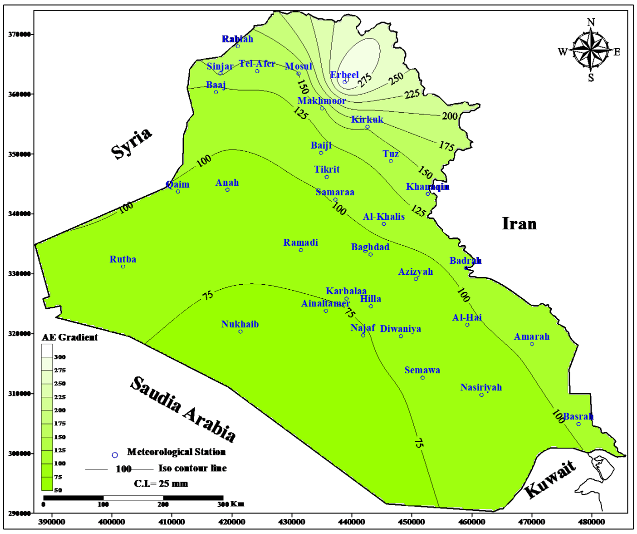

Figure 4. Contour map of annual actual Evapotranspiration (AE) in Iraq

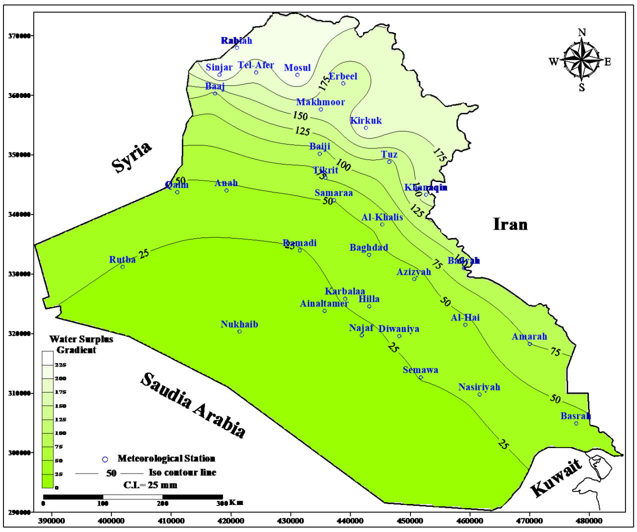

Figure 5. Contour map of annual water surplus (WS) in Iraq

3 Results and discussion

Using Thornthwaite formula[18] showed in equations (2,3,4 and 5), the monthly corrected potential evapotranspiration (PEc) was calculated as shown in Table 2 after using the correction factor of sunlight duration and number of day light according to latitude. Table 3 shows the mean annual rainfall, (PEc), (AE) and water surplus (WS) in each meteorological station in Iraq. Depending on Table 3, the mean annual summation of rainfall in thirty two stations was demonstrated in Figure 2, while Figure 3 shows the distribution of corrected potential evapotranspiration (PEc) in Iraq. It seems that the mean annual summation of rainfall has a symmetrical increasing pattern from south-west towards north-east according to the increasing ratio of rainfall due to impact of Mediterranean climate condition on Iraq. On the other hand the distribution of corrected potential evapotranspiration (PEc) as shown in Figure 3 has a similar pattern in increased values from south-east towards north-west of Iraq. As mentioned before there is a positive relationship between temperature and evapotranspiration, thus 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 as well as the potential evapotranspiration consequently.

Figure 4 shows the actual evapotranspiration (AE) contour map, where a similar pattern of rainfall distribution has been indicated. Since actual evapotranspiration depends directly on water excess during calculating water balance and whenever potential evapotranspiration was less than rainfall, the actual evapotranspiration will be equal to potential evapotranspiration which will produce water surplus. While whenever potential evapotranspiration was greater than rainfall, the actual evapotranspiration will be equal to rainfall producing water deficit[2,5,7].

Figure 5 shows the obtained water surplus contour map in Iraq depending on the water balance equation. The map shows the same pattern of rainfall distribution and actual evapotranspiration regarding increased values towards north-east direction of Iraq. The water surplus depends directly on both rainfall and actual evapotranspiration.

4 Conclusions

1. Annual summation of rainfall has increased values from south-west towards north-east according to increasing ratio of rainfall due to impact of Mediterranean climate condition on Iraq.

2. As potential evapotranspiration less than rainfall, the actual evapotranspiration will be equal to potential evapotranspiration which will produce water surplus.

3. As rainfall less than potential evapotranspiration, the actual evapotranspiration will be equal rainfall producing water deficit.

4. During calculating water balance, actual evapotranspiration seem to depend on water excess.

5. Water surplus contoured map indicates the direction increased values to northeastern part of Iraq, where the surplus of water seem to depend on actual evapotranspiration and rainfall.

6. The minimum values of runoff and groundwater recharge located in western desert of Iraq.

7. The climate conditions of desert was the major influence on reducing rainfall and rising temperature resulting decreasing water surplus, runoff and groundwater recharge.

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