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Estimation of Water Balance in Iraq using Meteorological Data

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Abstract

Water balance techniques are a means of a solution of important theoretical and practical hydrological problems. The water balance equation for any natural area or water body indicates the relative values of inflow, outflow, and change in water storage for the area or water body. Estimating water balance in Iraq, depending on meteorological data and the Thornthwaite method, was the aim of this research. The results of corrected potential Evapotranspiration (PEc) obtained from applying the Thornthwaite formula were compared with annual and monthly rainfall in (32) meteorological stations to estimate actual Evapotranspiration (AE). The results showed that the annual summation of rainfall increased from the south-west towards north-east. According to the increasing ratio of rainfall due to the impact of the Mediterranean climate condition on Iraq. Actual Evapotranspiration depends directly on water excess during calculating water balance. The water surplus contour map indicates increased values towards the north-east direction of Iraq, where water surplus depends directly on both rainfall and actual Evapotranspiration.

Keywords: *Water Balance, Meteorological data, Thornthwaite Method, Iraq*

I. INTRODUCTION

Water is a vital component to the development of any area. The water demand 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 a multi-combined reflection of natural factors of morphology and soil nature and climate factors that directly affect the hydrological cycle [2]. The study of the water balance is the application in the hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that, for any arbitrary volume and period, the difference between total input and output balanced by the change of water storage [3]. Knowledge of the water balance helps predict the consequences of artificial changes in the regime of streams, lakes, and groundwater basins [4]. The 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 --------- (1)

Rainfall is the only input element in the water balance, where a set of outputs as evaporation, transpiration, and consumption. Evaporation reflects the loss of water from water surfaces or soil. At the same time, transpiration and consumption are the processes of water evaporation from plants, these two processes are called potential Evapotranspiration (PE), which reflected the water losses with an abundant quantity of water exist in the basin area, and specific equations can calculate it. In contrast, actual Evapotranspiration (AE) can be determined when the 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 surface runoff and groundwater recharge, representing 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 combining two separate processes through which water is lost from the soil surface via the evaporation process and from the crop by transpiration [9]. Thornthwaite method is one of the effective methods used to estimate the potential Evapotranspiration (PE) based on the monthly average temperature. This method can be appropriately used in arid and semi-arid regions [10]. Potential Evapotranspiration can be calculated by applying the following formula [7]:

$$PE = 16\left[\frac{10tn}{J}\right]^{a} \qquad \text{-------- (2)}$$

$$J = \sum_{1}^{12} j \qquad \text{-------- (3)}$$

$$j = \left[\frac{tn}{5}\right]^{1.514} \qquad \text{-------- (4)}$$

$$a = 0.016J + 0.5 \qquad \text{-------- (5)}$$

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 each year; even though this formula is shown by many researchers to underestimate (PE), it has been accepted widely around the globe [11]. Using meteorological data to estimate water balance in Iraq, depending on the Thornthwaite method, is the aim of this research. The water balance predicts water surplus and water deficit. The calculation of water balance facilitates hydrological studies of lakes, river basins, and groundwater basins outcomes and reduces cost and time.

Iraq is sited between latitude (29.00°-37.22°N) and longitude (38.45°- 48.30°E), while the 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 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:

- Hydrogeological System of Debagah Basin In North of Iraq [5].

- Water Balance of North Erbeel Basin [13]

- Study of Morphometric Properties and Water Balance Using Thornthwaite Method in Khanaqin Basin, East of Iraq [7].

- Derivation Mathematical Equations for Future Calculation of Potential Evapotranspiration in Iraq, a Review of Application of Thornthwaite Evapotranspiration [14].

- Calculating of Groundwater Recharge using Meteorological Water Balance and Water level Fluctuation in Khan Al-Baghdadi Area [2].

- Temperature – Potential Evapotranspiration Relationship in Iraq Using Thornthwaite Method [18].

- Rainfall Returns Periods in Iraq [12].

II. 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 date of station operation till 2015 [16].
2- Thornthwaite formula [17].
3- Water balance equations [5, 6, 7].
4- Excel and Surfer programs demonstrating tables of results and contour maps.

Temperature as a key factor controlling potential Evapotranspiration (PE) can be obtained using data recorded in meteorological stations. (32) Stations were used all over Iraq, where annual and monthly air temperatures were adopted to calculate potential Evapotranspiration (PE) using the Thornthwaite method, Table 1, fig 1. The corrected potential Evapotranspiration (PEc) were compared with annual and monthly rainfall in each station to obtain actual Evapotranspiration (AE). Finally, excel and surfer programs were used to show results and demonstrate the contour map of (PEc), (AE), water surplus (WS), and rainfall in Iraq.

Table 1. The geographical position of meteorological stations in Iraq

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

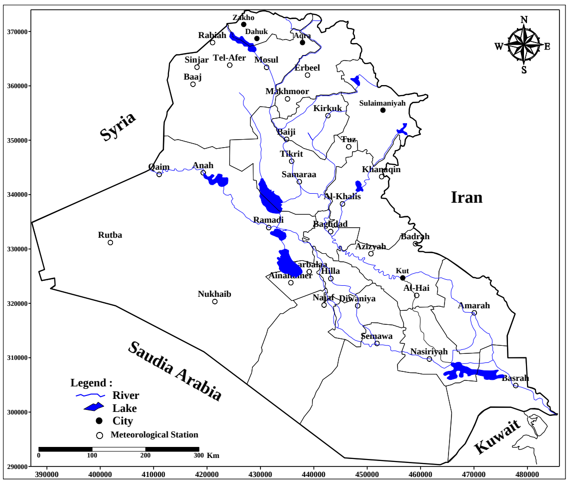


Figure 1: Distribution map of Meteorological stations in Iraq.

III. RESULTS AND DISCUSSION

Using Thornthwaite formula [17] showed in equation (2,3,4,5) previously, the monthly corrected potential Evapotranspiration (PEc) was calculated as shown in Table 2 after using the correction factor of sunlight duration and number of daylight 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 (32) stations was demonstrated in fig. (4), while fig. (5) shows the distribution of corrected potential Evapotranspiration (PEc) in Iraq. The mean annual summation of rainfall has a symmetrical increasing pattern from the south-west towards north-east according to the increasing ratio of rainfall due to the impact of the Mediterranean climate condition on Iraq. On the other hand, the distribution of corrected potential Evapotranspiration (PEc), as shown in fig. (5), has a similar pattern in increased values from south-east towards the 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 the Mediterranean Sea and its climate condition, which reduces the mean annual and monthly temperatures as well as the potential Evapotranspiration consequently.

Fig. (6) 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 equals potential Evapotranspiration, which produces water surplus. While whenever potential Evapotranspiration was greater than rainfall, the actual Evapotranspiration equal rainfall, producing water deficit [2,5,7,14].

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)
1	22.279	1579.066	20
2	24.804	2318.14	35
3	20.958	1388.118	38
4	23.968	2014.677	15
5	20.487	1361.543	17
6	24.546	2330.101	15
7	22.694	1674.369	66
8	22.44	1697.278	30
9	24.876	2132.123	67
10	24.262	2033.104	38
11	24.435	2139.199	68
12	23.259	1773.72	25
13	24.114	2087.377	38
14	22.016	1511.515	17
15	22.834	1751.833	60
16	22.195	1662.425	68
17	22.677	1792.035	19
18	20.1093	1327.295	70
19	24.406	2185.641	40
20	22.279	1579.066	20
21	25.092	2257.156	73
22	20.966	1383.538	20
23	18.52	1122.652	31
24	22.073	1515.101	25
25	19.738	1182.171	35
26	23.136	1845.079	26
27	24.748	2242.733	38
28	20.556	1399.499	42
29	21.043	1464.71	25
30	23.0471	1910.049	24
31	22.794	1768.054	17
32	21.321	1488.116	40

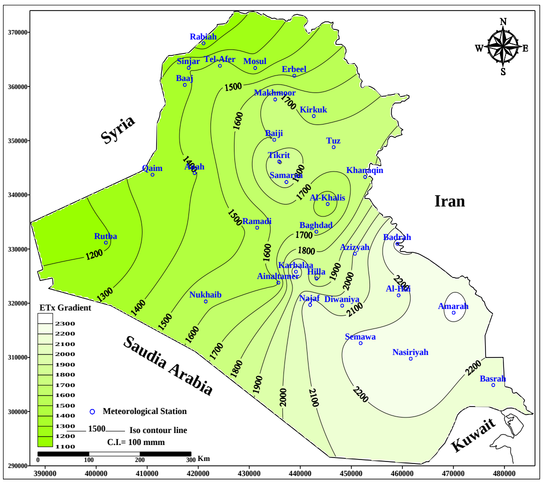
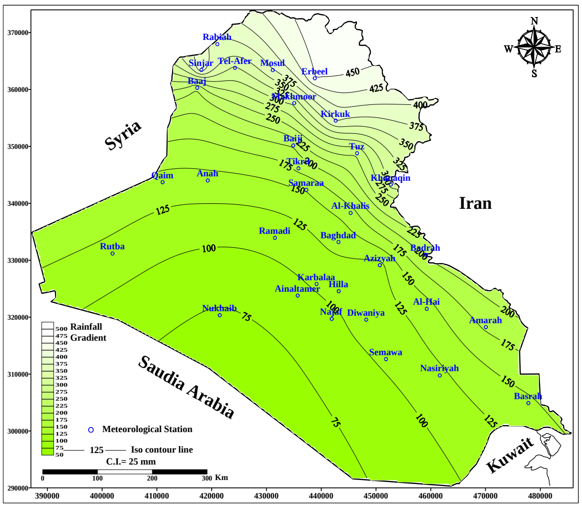


Figure 4. Contour map of annual summation of Rainfall in Iraq.

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

St. No.	Ave. Sum of Rainfall (mm)	Ave. Sum of Potential Evaptransopration (mm)	Ave. Sum of Actual Evaptransopration (mm)	Ave. Sum of water surplus (mm)	water surplus %
1	92.469	1579.066	72.88234	19.58666	21.18
2	178.687	2318.14	103.6623	75.02467	42
3	142.529	1388.118	97.11806	45.41094	31.86
4	117.814	2014.677	82.7288	35.0852	29.78
5	229.04	1361.543	112.2714	116.7686	50.98
6	204.843	2330.101	108.4218	96.42122	47.07
7	136.702	1674.369	92.2237	44.4783	32.5
8	199.6981	1697.278	116.6699	83.02824	41.57
9	144.805	2132.123	102.3255	42.47953	29.33
10	112.441	2033.104	84.34017	28.10083	25
11	139.17	2139.199	96.59776	42.57224	30.6
12	108.981	1773.72	80.0853	28.8957	26.51
13	103.4592	2087.377	76.60349	26.85571	25.95
14	162.6836	1511.515	106.5557	56.12789	34.5
15	308.659	1751.833	140.8596	167.7994	54.36
16	376	1662.425	152.2042	223.8048	59.52
17	306.914	1792.035	143.459	163.455	53.2
18	372.995	1327.295	148.0522	224.9428	60.3
19	94.05	2185.641	73.0197	21.0303	22.36
20	72.1554	1579.066	63.18704	8.96836	12.42
21	119.4807	2257.156	90.5997	28.881	24.17
22	140.624	1383.538	98.24673	42.37727	30.13
23	367.12	1122.652	160.1051	207.0149	56.39
24	110.512	1515.101	86.3939	24.1181	21.82
25	116.65	1182.171	93.06902	23.58918	20.22
26	151.5433	1845.079	101.488	50.05526	33.03
27	104.682	2242.733	78.98249	25.69951	24.55
28	389.308	1399.499	153.8117	235.4963	60.5
29	322.8445	1464.71	139.7751	183.0694	56.7
30	181.878	1910.049	104.8913	76.9867	42.32
31	254.026	1768.054	136.522	117.504	46.25
32	449	1488.116	305.302	143.697	32



.**Figure 5.** Contour map of annual corrected Potential Evapotranspiration (PEc) in Iraq.

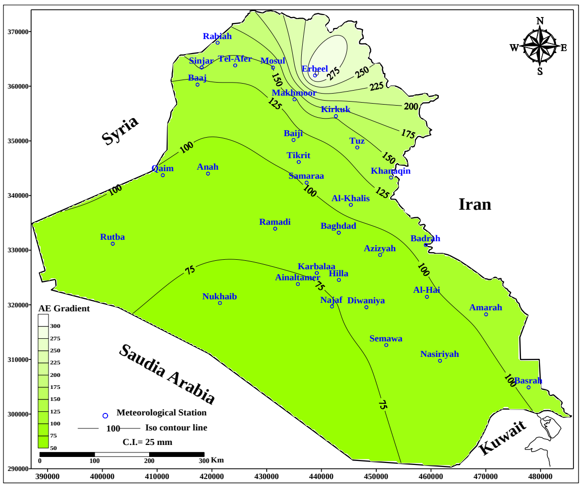


Figure 6: Contour map of actual annual Evapotranspiration (AE) in Iraq.

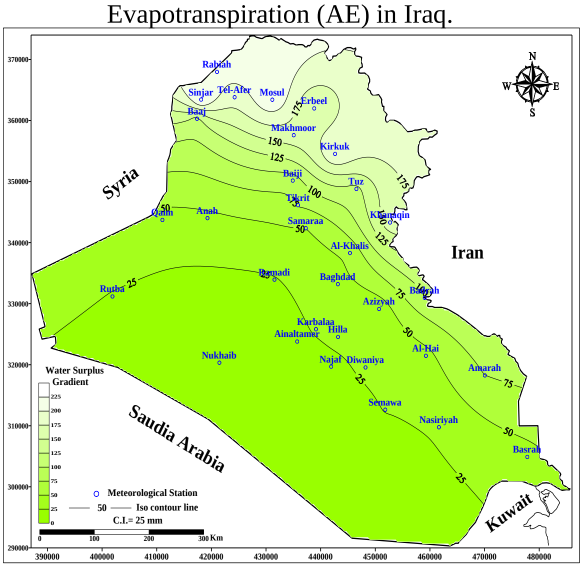


Figure 7: Contour map of annual water surplus (WS) in Iraq.

Fig. (7) 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 the north-east direction of Iraq. The water surplus depends directly on both rainfall and actual Evapotranspiration.

IV. CONCLUSIONS

1- Annual summation of rainfall has increased values from the south-west towards north-east according to the increasing ratio of rainfall due to the impact of Mediterranean climate conditions on Iraq.
2- Actual Evapotranspiration depends directly on water excess during calculating water balance.
3- As potential Evapotranspiration less than rainfall, the actual Evapotranspiration equal to potential Evapotranspiration, which produces water surplus.
4- As rainfall less than potential Evapotranspiration, the actual Evapotranspiration equal rainfall, producing a water deficit.
5- Water surplus contour map indicates increased values towards the north-east direction of Iraq, where water surplus depends directly on both rainfall and actual Evapotranspiration.

V. CONFLICTS OF INTEREST

The author declares that they have no conflicts of interest.

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