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Estimation of Water Surplus and Natural Groundwater Recharge in Iraq

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Abstract

The hydrology section is divided into two main components, surface water and groundwater. Estimation of water surplus and natural groundwater recharge in Iraq meteorological data was the aim of this research. In thirty two meteorological stations, the corrected potential evapotranspiration (PEc) was compared with monthly and annual rainfall in order to estimate actual evapotranspiration (AE) using water balance equation. Water surplus was divided into runoff and natural groundwater recharge where runoff coefficient method was used to estimate runoff. The obtained mathematical relationship between rainfall with both water surplus and actual evapotranspiration can be used to estimate these two parameters directly from rainfall. The results indicate that water surplus increased towards north-east direction of Iraq, while the minimum values of runoff and groundwater recharge located in western desert of Iraq. The climate conditions of desert was the major influence on reducing rainfall and rising temperature resulting decreasing water surplus, runoff and groundwater recharge.

Keywords: Water Surplus Estimation, Runoff and Groundwater Recharge, Iraq.

Introduction

Hydrologic cycle which occurs continuously in nature is the water transfer cycle[1]. There are three important phases of the hydrologic cycle which are (*a*) Evaporation (ET) and evapotranspiration (PE) (*b*) precipitation (P) and (*c*) runoff [2].

The mean annual precipitation, surface runoff and evapotranspiration considered as the main surface water hydrology components. Meanwhile recharge of groundwater is computed by water-balance depending on the average soil moisture storage changing in the unsaturated zone [3]. The loss of water from the ground to the atmosphere through transpiration from plants and direct evaporation is an important part of the water balance problem [4]. Direct measurement of these parameters is difficult, nevertheless this difficulty led to development of several numbers of formulas designed especially to estimate water loss from meteorological data directly [5].

Recently, the importance of scientific and practical problems of water balance has been highlighted by freshwater shortages predictions in several areas in the world, because of the development industry, urbanization, as well as agricultural production increasing [6].

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Hydrologists often use water balances (W.S.) to determine the size of water fluxes across catchments boundaries. Due to increased variability of water supply in many purposes recently, it is necessary to analyze both extremes: water deficit and water surplus. Following formula describe (W.S.) [5]:

Storage change = Input – Output --------- (1)

Studies of water balance give an indirect assessment of the unknown water balance elements compared to known elements and it aims to evaluate and predict the possible components of water balance depending on simplest formulation as well as adopting lowest input data [7].

Thornthwaite method was developed in multi drainage basins from rainfall and runoff data resulted as Thornthwaite's empirical formula [8]. This empirical relationship was build between air temperature and (PE). It can be used for any location when daily maximum and minimum temperatures are recorded [9]. The following formula applied to calculate Potential Evapotranspiration [10]:

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

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

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

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

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

Monthly (PE) forecasts can be estimated based on monthly temperatures recorded at meteorological station, although many researches shows this formula to underestimate (PE), even though it seem that this formula has been widely accepted globally [11].

The aim of this research is water balance calculating to predict water surplus and natural groundwater recharge using meteorological data distributed in all over Iraq depending on Thornthwaite equations.

Iraq located between (29° 00′ 00" - 37° 22′ 00" N) latitude and (38° 45′ 00" - 48° 30′ 00" E) longitude. The characteristic of Iraqi climate is very hot summer and short cold winter reflects semi-arid and continental subtropical type [12].

Many earliest researches used meteorological data to estimate water surplus and deficit within some Iraqi locations. While two researches were found used these data to estimate water balance as mentioned below:

1- Temperature – Potential Evapotranspiration Relationship in Iraq Using Thornthwaite Method [13].
2- Derivation Mathematical Equations for Future Calculation of Potential Evapotranspiration in Iraq, a Review of Application of Thornthwaite Evapotranspiration [14, 15].

Material and Methodology

Following materials were used in this paper:

1- Thirty two Iraqi meteorological stations and their geographic coordinates as well as monthly and annual Temperature records until 2016 [16].
2- Thornthwaite and water balance equations [17, 5,6,7].
3- Runoff coefficient method [18].
4- Microsoft Excel, Grapher and Surfer software used to demonstrate tables, graphs and contouring maps.

The method adopted in this research to estimate evapotranspiration depends on empirical methods belongs to Thornthwaite formula. The basic assumption considered that temperature is an excellent parameter of the evaporative influence of the atmosphere. This method became very common due to limited data requirements [19]. Monthly and annual air temperatures of thirty two stations distributed in Iraq, figure (1) were used to estimate potential - evapotranspiration (PE), table (1). The results compared with monthly and annual rainfall to predict Actual - evapotranspiration (AE) using water balance equation. Water surplus was divided into runoff and natural groundwater recharge where runoff coefficient method was used to estimate runoff. Finally surfer software presented contouring maps of rainfall, water surplus (WS), runoff and natural groundwater recharge.

Table 1 - Coordinates of Iraqi meteorological stations [13].

No.	Name of Station	Stations Attitude		No.	Name of Station	Stations Attitude	
		Long.	Lat.			Long.	Lat.
1	Ainaltamer	44° 43' 00"	32° 33' 00"	17	Makhmoor	43° 36' 00"	35° 45' 00"
2	Amarah	47° 10' 00"	31° 51' 00"	18	Mosul	43° 09' 00"	36° 19' 00"
3	Anah	41° 57' 00"	34° 28' 00"	19	Najaf	44° 19' 00"	31° 59' 00"
4	Azizyah	45° 04' 00"	32° 55' 00"	20	Nukhaib	42° 15' 00"	32° 02' 00"
5	Baaj	41° 44' 00"	36° 02' 00"	21	Nasiriyah	46° 14' 00"	31° 05' 00"
6	Badra	45° 57' 00"	33° 06' 00"	22	Qaim	41° 01' 00"	34° 23' 00"
7	Baghdad	44° 14' 00"	33° 14' 00"	23	Rabiah	42° 06' 00"	36° 48' 00"
8	Baiji	43° 29' 00"	34° 56' 00"	24	Ramadi	43° 09' 00"	3°3 27' 00"
9	Basrah	47° 47' 00"	30° 34' 00"	25	Rutba	40° 17' 00"	33° 02' 00"
10	Diwaniyah	44° 59' 00"	31° 59' 00"	26	Samaraa	4353' 00"	34° 11' 00"
11	Hai	46° 03' 00"	32° 10' 00"	27	Samawah	45° 16' 00"	31° 18' 00"
12	Hilla	44° 27' 00"	32° 27' 00"	28	Sinjar	41° 50' 00"	36° 19' 00"
13	Karbalaa	44° 01' 00"	32° 37' 00"	29	Tel-Afer	42° 29' 00"	36° 22' 00"
14	Khalis	44° 32' 00"	33° 50' 00"	30	Tikrit	43° 42' 00"	34° 34' 00"
15	Khanaqin	45° 26' 00"	34° 18' 00"	31	Tuz	44° 39' 00"	34° 53' 00"
16	Kirkuk	44° 24' 00"	35° 28' 00"	32	Erbeel	36° 09' 00"	44° 00' 00"

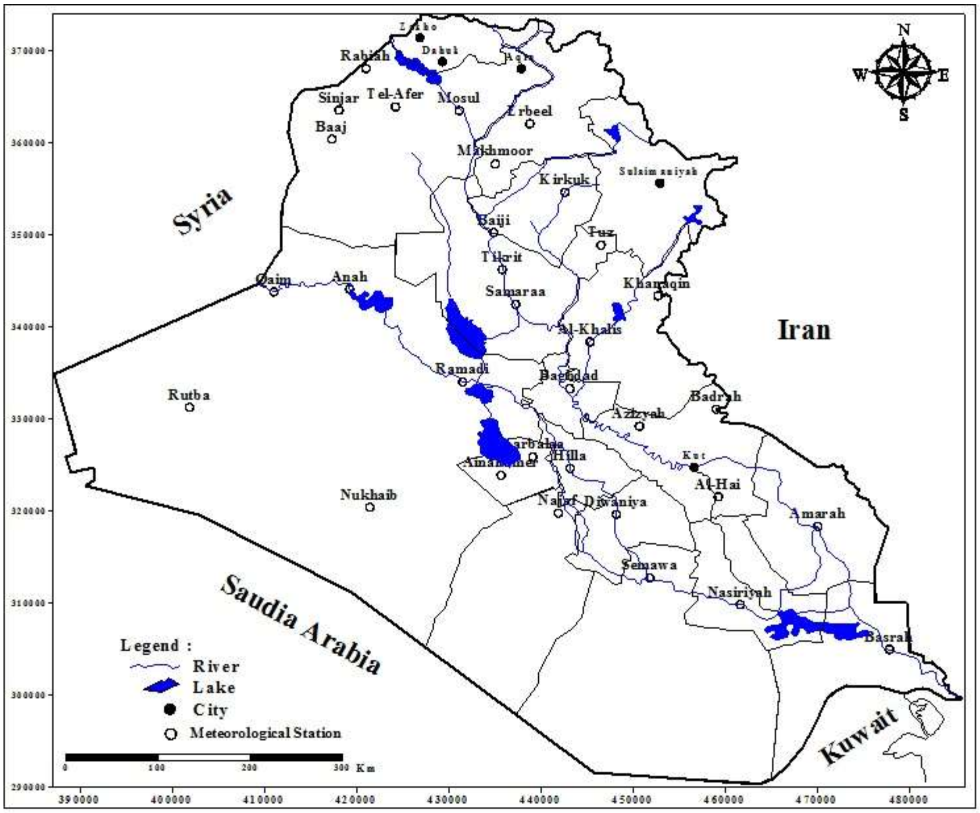

Figure 1- Iraqi meteorological stations distribution

Results and discussion

Depending on Thornthwaite equations [17], corrected monthly potential evapotranspiration (PEc) was estimated. The mean annual rainfall, (PEc), (AE) and water surplus (WS) showed in table (2). The rainfall as mean annual summation in thirty two stations was illustrated in figure (2). Figure (3) shows the distribution of actual evapotranspiration (AE) in Iraq.

Table 2 - Average Summation of (P), (PEc), (AE) and (WS) in Iraqi meteorological station

Station No.	(P) (mm)	(PEc) (mm)	(AE) (mm)	(WS) (mm)	Water surplus %	Duration (years)
1	92.469	1579.066	72.88234	19.58666	21.18	20
2	178.687	2318.14	103.6623	75.02467	42	35
3	142.529	1388.118	97.11806	45.41094	31.86	38
4	117.814	2014.677	82.7288	35.0852	29.78	15
5	229.04	1361.543	112.2714	116.7686	50.98	17
6	204.843	2330.101	108.4218	96.42122	47.07	15
7	136.702	1674.369	92.2237	44.4783	32.5	66
8	199.6981	1697.278	116.6699	83.02824	41.57	30
9	144.805	2132.123	102.3255	42.47953	29.33	67
10	112.441	2033.104	84.34017	28.10083	25	38
11	139.17	2139.199	96.59776	42.57224	30.6	68
12	108.981	1773.72	80.0853	28.8957	26.51	25
13	103.4592	2087.377	76.60349	26.85571	25.95	38
14	162.6836	1511.515	106.5557	56.12789	34.5	17
15	308.659	1751.833	140.8596	167.7994	54.36	60
16	376	1662.425	152.2042	223.8048	59.52	68
17	306.914	1792.035	143.459	163.455	53.2	19
18	372.995	1327.295	148.0522	224.9428	60.3	70
19	94.05	2185.641	73.0197	21.0303	22.36	40
20	72.1554	1579.066	63.18704	8.96836	12.42	20
21	119.4807	2257.156	90.5997	28.881	24.17	73
22	140.624	1383.538	98.24673	42.37727	30.13	20
23	367.12	1122.652	160.1051	207.0149	56.39	31
24	110.512	1515.101	86.3939	24.1181	21.82	25
25	116.65	1182.171	93.06902	23.58918	20.22	35
26	151.5433	1845.079	101.488	50.05526	33.03	26
27	104.682	2242.733	78.98249	25.69951	24.55	38
28	389.308	1399.499	153.8117	235.4963	60.5	42
29	322.8445	1464.71	139.7751	183.0694	56.7	25
30	181.878	1910.049	104.8913	76.9867	42.32	24
31	254.026	1768.054	136.522	117.504	46.25	17
32	449	1488.116	305.302	143.697	32	40

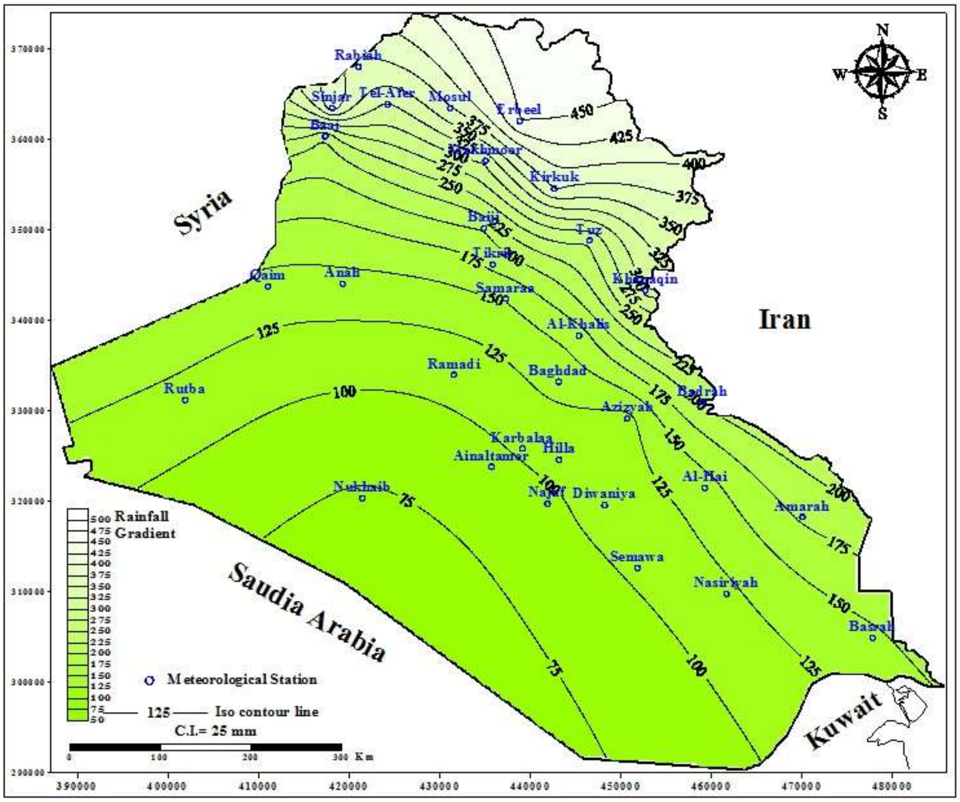

Figure 2 - Annual summation of Rainfall contour map in Iraq

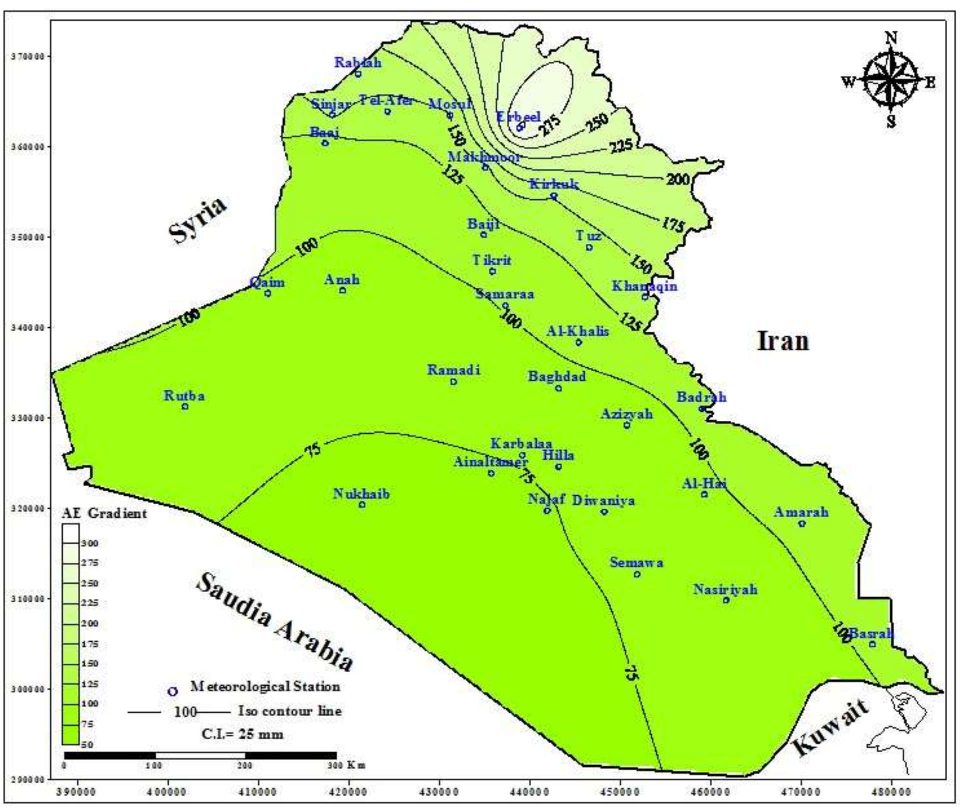

Figure 3 - Actual Evapotranspiration (AE) contour map in Iraq.

The mean annual summation of rainfall appears to have a symmetrical increasing pattern from southwest to northeast according to the increased rainfall due to direct influence of the climate of Mediterranean Sea on Iraq. Furthermore, the distribution of actual evapotranspiration (AE) as showed in figure (3) has the same paradigm of rainfall distribution due to direct effects of exceeded water resulting from water balance calculation on actual evapotranspiration. When (PE) is less than rainfall, (AE) will be equal to (PE) causing excess water (surplus) , while the greater the (PE) than rainfall, the (AE) will be equal to rainfall producing water deficit [12, 13].

Figure (4) illustrates the obtained contour map of the water surplus. It shows the same paradigm of rainfall and actual evapotranspiration distribution with respect to increasing values to the northeast direction of Iraq. Water surplus depends directly on both rainfall and actual evapotranspiration.

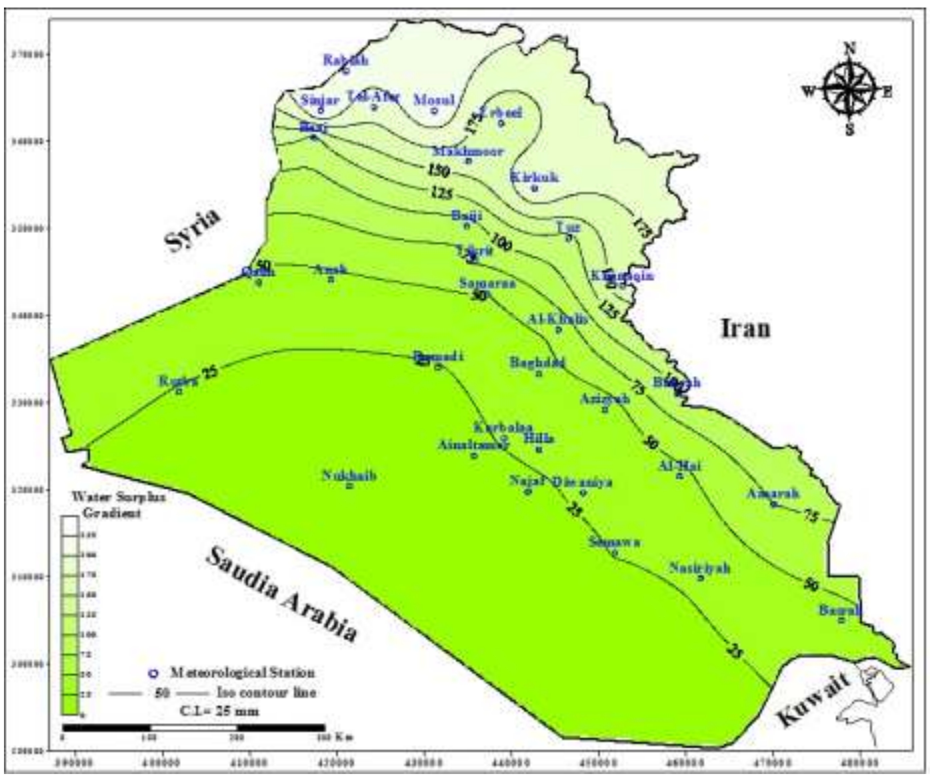

Figure 4 - Annual water surplus (WS) contour map in Iraq.

A mathematical relationship between mean annual of rainfall with both annual summation of water surplus and annual summation of actual evapotranspiration were obtained as shown in figure (5). The coefficient of determination were (99.2%) and (95.37%) for the first and second relationship respectively. These two relationships can be used to obtain water surplus or actual evapotranspiration directly from mean annual rainfall as they are the major outputs of water balance equation.

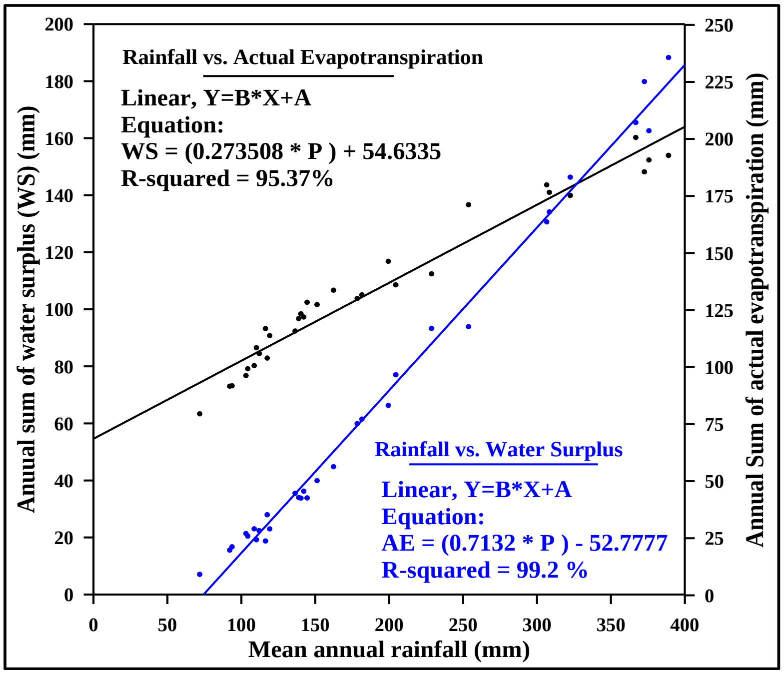

Figure 5 - The relationship of rainfall versus (WS) and (AE)

Runoff coefficient method [18] was used to calculate runoff by applying following formula:

$$Q = KP \qquad \text{---------} (6)$$

Where, Q: Runoff P: Precipitation and K: A constant having a value less than (1) or at most equal to (1).

The value of K depends upon the imperviousness of the drainage area. Its value increases with the increase in, imperviousness of the catchments area, and may approach unity (1.0) as the area becomes fully impervious. The value of K depending on roof type and was estimated as (0.1) depending on (Muhaimeed et al, 2014) [20]. Table (3) shows water balance components as actual evapotranspiration (AE), water surplus (WS), runoff and groundwater recharge. Figure (5) shows annual runoff contoured map while figure (6) shows annual groundwater recharge contoured map in Iraq.

As shown in both figures (5 and 6) the minimum values of runoff and groundwater recharge located in south-west direction of Iraq (western desert). These values were calculated depending on water balance and water surplus which indicate that climate conditions of desert area. These conditions was the major influence on rising temperature resulting increased values of potential evapotranspiration which effect directly on actual evapotranspiration. The opposite influence of these conditions effects on reducing rainfall which is the only input components of water balance [21].

Table 3 - Water balance component as (AE) and (WS), runoff and groundwater recharge

Station No.	Rainfall (mm)	Actual Evaptransopration (mm)	Water surplus (mm)	Runoff (mm)	Groundwater recharge (mm)
1	92.469	72.88234	19.58666	9.2469	10.33976
2	178.687	103.6623	75.02467	17.8687	57.15597
3	142.529	97.11806	45.41094	14.2529	31.15804
4	117.814	82.7288	35.0852	11.7814	23.3038
5	229.04	112.2714	116.7686	22.904	93.8646
6	204.843	108.4218	96.42122	20.4843	75.93692
7	136.702	92.2237	44.4783	13.6702	30.8081
8	199.6981	116.6699	83.02824	19.96981	63.05843
9	144.805	102.3255	42.47953	14.4805	27.99903
10	112.441	84.34017	28.10083	11.2441	16.85673
11	139.17	96.59776	42.57224	13.917	28.65524
12	108.981	80.0853	28.8957	10.8981	17.9976
13	103.4592	76.60349	26.85571	10.34592	16.50979
14	162.6836	106.5557	56.12789	16.26836	39.85953
15	308.659	140.8596	167.7994	30.8659	136.9335
16	376	152.2042	223.8048	37.6	165.7935
17	306.914	143.459	163.455	30.6914	132.7636
18	372.995	148.0522	224.9428	37.2995	187.6433
19	94.05	73.0197	21.0303	9.405	11.6253
20	72.1554	63.18704	8.96836	7.21554	1.75282
21	119.4807	90.5997	28.881	11.94807	16.93293
22	140.624	98.24673	42.37727	14.0624	28.31487
23	367.12	160.1051	207.0149	36.712	170.3029
24	110.512	86.3939	24.1181	11.0512	13.0669
25	116.65	93.06902	23.58918	11.665	11.92418
26	151.5433	101.488	50.05526	15.15433	34.90093
27	104.682	78.98249	25.69951	10.4682	15.23131
28	389.308	153.8117	235.4963	38.9308	196.5655
29	322.8445	139.7751	183.0694	32.28445	150.7849
30	181.878	104.8913	76.9867	18.1878	58.7989
31	254.026	136.522	117.504	25.4026	92.1014
32	449	305.302	143.697	44.9	98.79771

Conclusions

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

2. 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.

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

4- The obtained mathematical relationship between rainfall with both water surplus and actual evapotranspiration can be used to estimate these two parameters directly from rainfall.

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

Conflict of Interests.

There are non-conflicts of interest .

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الخلاصة

يقسم علم الهيدرولوجيا الى مكونين اساسيين هما المياه السطحية والمياه الجوفية. يهدف البحث الى تقدير الجريان السطحي والتغذية الطبيعية للمياه الجوفية في العراق اعتماداً على معادلة التوازن المائي وبيانات الارصاد الجوية التي يمكن من خلالها حساب التبخر – نتح كامن والحقيقي بطريقة ثورنثويت . قورنت قيم التبخر – نتح كامن مع مجموع المعدل السنوي للامطار في (32) محطة انواء جوية لغرض الحصول على قيم التبخر – نتح الحقيقي باستخدام معادلة التوازن المائي . انقسم الفائض المائي المتحقق إلى جريان سطحي وتغذية طبيعية للمياه الجوفية بعد استخدام طريقة معامل الجريان السطحي لحساب الجريان السطحي المتحقق من الزيادة المائية. اشارت النتائج إلى أن الفائض المائي ازداد باتجاه الشمال الشرقي للعراق ، في حين أن الحد الأدنى لقيم الجريان السطحي والمياه الجوفية تواجدت في منطقة الصحراء الغربية. لقد كان للظروف المناخية الصحراوية التأثير الرئيسي على انخفاض معدلات الساقط المطري وارتفاع درجة الحرارة مما أدى إلى انخفاض الفائض المائي والجريان السطحي والتغذية الطبيعية للمياه الجوفية.

الكلمات الدالة : تقدير الزيادة المائية ، الجريان السطحي والتغذية الطبيعية للمياه الجوفية ، العراق .