RESEARCH ARTICLE

Calculation of meteorological water balance in Iraq

Hussein Ilaibi Zamil Al-Sudani

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]:

\[
\text{Input} - \text{Output} = \text{Change in Storage} \quad (1)
\]

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
used in arid and semi-arid regions\cite{10}. Potential Evapotranspiration can be calculated by applying following formula\cite{7}:

\[
P E = 16 \left[ \frac{10 t n}{J} \right]^a
\]  \hspace{1cm} (2)

\[
J = \sum_{j=1}^{12} j
\]  \hspace{1cm} (3)

\[
j = \left[ \frac{t n}{5} \right]^{1.514}
\]  \hspace{1cm} (4)

\[
a = 0.016 J + 0.5
\]  \hspace{1cm} (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\cite{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\cite{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\cite{5}.
2. Water Balance of North Erbeel Basin\cite{13}.
3. Groundwater system of Dibdibba sandstone aquifer in south of Iraq\cite{14}.
4. Study of Morphometric Properties and Water Balance Using Thornthwaite Method in Khanaqin Basin, East of Iraq\cite{7}.
5. Calculating of Groundwater Recharge Using Meteorological Water Balance and Water level Fluctuation in Khan Al-Baghdadi Area\cite{2}.
6. Temperature—Potential Evapotranspiration Relationship in Iraq Using Thornthwaite Method\cite{8}.
7. Derivation Mathematical Equations for Future Calculation of Potential Evapotranspiration in Iraq, a Review of Application of Thornthwaite Evapotranspiration\cite{9}.
8. Estimation of Water Balance in Iraq using Meteorological Data\cite{15}.
9. Rainfall Returns Periods in Iraq\cite{12}.
10. Derivation mathematical equations to estimate water surplus and groundwater recharge in Iraq\cite{16}.

![Figure 1. Distribution map of meteorological stations in Iraq](image)

**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\cite{17}.
2. Thornthwaite formula\cite{18}.
3. Water balance equations\cite{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  | 433600               | 354500            | Makhmoor 17 |
| 471000               | 315100            | Amarah      | 430900               | 361000            | Mosul 18    |
| 415700               | 342800            | Anah        | 441900               | 315900            | Najaf 19    |
| 450400               | 325500            | Ariziyah    | 421500               | 320200            | Nukhbat 20  |
| 414400               | 360200            | Baaj        | 461400               | 310500            | Nasiriyah 21|
| 455700               | 330600            | Badra       | 410100               | 342300            | Qaim 22     |
| 441400               | 331400            | Baghdad     | 420600               | 364800            | Rabiah 23   |
| 432900               | 345600            | Baaj        | 430900               | 332700            | Ramadi 24   |
| 474700               | 303400            | Basrah      | 401700               | 330200            | Rutba 25    |
| 445900               | 315900            | Diwaniyah   | 435000               | 341100            | Samarra 26  |
| 460300               | 321000            | Hai         | 451600               | 311800            | Samawah 27  |
| 442700               | 327200            | Hilla       | 415000               | 361900            | Sinjar 28   |
| 440100               | 323700            | Karbalaa    | 422900               | 362200            | Tel-Afer 29 |
| 443200               | 335000            | Khalis      | 434200               | 334300            | Tikrit 30   |
| 452600               | 341800            | Khanasquin  | 443900               | 345300            | Tuz 31      |
| 442400               | 352800            | Kirkuk      | 369000               | 440000            | Erbeel 32   |

### Table 2. Mean annual temperatures and corrected evapotranspiration (P(Ec)) calculated in each meteorological station in Iraq

| St. No. | Annual Mean Temp. (°C) | Sum of corrected (P(Ec)) (mm) | Duration (years) | St. No. | Annual Mean Temp. (°C) | Sum of corrected (P(Ec)) (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                     | 1    |
| 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                 | 1515.115                     | 17               | 30      | 23.047                 | 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](image)

![Figure 3. Contour map of annual corrected Potential Evapotranspiration (P(Ec)) in Iraq](image)
Table 3. Mean rainfall, (P Ec), (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                    | 35.08                         | 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                    | 34.50                         | 34.50            |
| 15      | 308.46                   | 1751.83                      | 140.86                    | 54.36                         | 54.36            |
| 16      | 376.00                   | 1662.42                      | 152.20                    | 59.52                         |                  |
| 17      | 306.91                   | 1792.03                      | 143.46                    | 53.20                         |                  |
| 18      | 373.00                   | 1327.29                      | 148.05                    | 60.30                         |                  |
| 19      | 94.05                    | 2185.64                      | 73.02                     | 22.36                         |                  |
| 20      | 72.15                    | 1579.06                      | 63.18                     | 12.42                         |                  |
| 21      | 119.48                   | 2257.15                      | 90.60                     | 24.17                         |                  |
| 22      | 140.62                   | 1383.53                      | 98.25                     | 30.13                         |                  |
| 23      | 367.12                   | 1122.65                      | 160.10                    | 36.39                         |                  |
| 24      | 110.51                   | 1515.10                      | 86.40                     | 21.82                         |                  |
| 25      | 116.65                   | 1182.17                      | 93.06                     | 20.22                         |                  |
| 26      | 151.54                   | 1845.08                      | 101.50                    | 33.03                         |                  |
| 27      | 104.68                   | 2242.73                      | 78.98                     | 24.55                         |                  |
| 28      | 389.31                   | 1599.5                       | 153.83                    | 60.50                         |                  |
| 29      | 322.84                   | 1464.71                      | 139.77                    | 56.70                         |                  |
| 30      | 181.87                   | 1910.05                      | 104.89                    | 42.32                         |                  |
| 31      | 254.02                   | 1768.05                      | 136.52                    | 46.25                         |                  |
| 32      | 449.00                   | 1488.11                      | 305.30                    | 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\cite{18} showed in equations (2,3,4 and 5), the monthly corrected potential evapotranspiration (P Ec) 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, (P Ec), (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 (P Ec) 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 contourd 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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