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Computation of Climatic Water Balance of AL-Sulaymania Meteorological Station for the Period 1980-2016, Kurdistan Region, Northeast of Iraq

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HIGHLIGHTS

- In this study, the water surplus was calculated from the total rainfall, and the water deficit was also calculated.
- The surface runoff in the study area and the groundwater were calculated from the total rainfall.
- The climate of the study area it can be considered Humid to moist.

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ABSTRACT

AL-Sulaymania city is located in the northeast of Iraq at an altitude of 845 m from the sea levelbetween longitudes (44 30 00 – 46 20 00) east and latitudes (34 33 00- 36 30 00) north. It covers an area of approximately 20000 km^2. The study area includes several geological formations (from the oldest to the earliest), Balambo Formation (Early Cretaceous), Qumchuqa, Kometan, Shiranish, Tanjero, Kolosh, Sinjar Formation and Quaternary deposits. The climatic data recorded by AL-Sulaymania meteorological station for the period (1980-2016) shows that the total falling rain was (423.86) mm, the temperature was (13.88 ° C), relative humidity was (22.36%), wind speed was (2.08m / s), sunshine was (8.06 hours / day), and the total evaporation from free surfaces was (1747.4mm). The climate of the study area is wet in winter and dry in summer.Corrected potentialevapotranspiration was calculatedtheoretically byapplying Thornthwaite method, where the value was 589.02mm, the water surplus was also calculated, which accounted for 74.24% divided into surface runoffand its value was 41.02 mmand GroundwaterRecharge which was 92.65mm,whilethewater deficit represents25.76 % of theannualrainfall.

1. Introduction

Sulaimaniyahprovince is located in the northeast of Iraq at an altitude of 845 m from the sea level. It is located between longitudes (44 30 00 – 46 20 00) east and latitudes (34 33 00- 36 30 00) north. It covers an area of approximately 20000 km^2, as shown in Figure 1.The study area is within the range of high torsions according to the physiographic distribution of Iraq, where the region is located within the upper limits and adjacent to the interference zone and in particular the zone of Balambo and Tangiero[1]. The study area includes several geological formations (from the oldestto the earliest), BalamboFormation (Early Cretaceous), Qumchuqa, Kometan, Shiranish, Tanjero, Kolosh,Sinjar Formation, and Quaternary deposits [2].The study aims to calculate the climatic water balance using theclimatic data obtained from the Sulaymaniyah MeteorologicalStation,calculatethepotential evapotranspiration,water surplus, and water deficit,anddeterminethe type of climate prevailing in the study area.

2. Materials and Method

The climatic data recorded at AL-Sulaymania Station for the period (1980-2016) from the Iraqi Meteorological Organization was utilized [3] in order to determine the monthly mean values of climatic parameters, as shown in Table (1) and Figure (2). The Thornthwaite equation was usedto calculate the evaporation potential values in the study area. The water balance of the region was calculated by using -Lerner method[4].In addition, the two of the climate classifications were used to delineate the type of climate in the study area.The first classification was proposed by Kettaneh and Gangopadhyaya [5]. This classification is based on the humidity index (H.I.), which represents the ratio between rainfall and corrected

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evapotranspiration. The second classification was proposed by AL-Kubaisi [6] and is based on dryness coefficients dependingon annual rainfall and temperature.

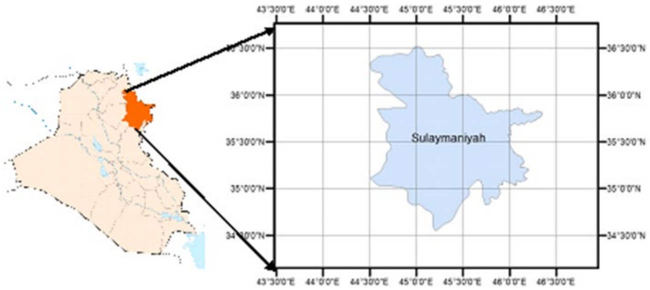

Figure 1: Location of the study area

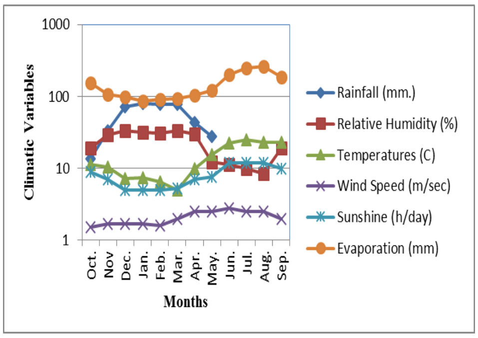

Figure 2: Relationships between the climatic variables in the study area for the period (1980-2016)

Table 1: Monthly average records of climatic parameters in AL-Sulaymaniastation for the period [3]

Months	Rainfall (mm)	Relative Humidity (%)	Temperatures (C°)	Wind Speed (m/sec)	Sunshine (h/day)	Evaporation (mm)
Oct.	13.54	18.9	11.24	1.5	8.8	152.8
Nov.	33.2	29.3	10.4	1.7	7.0	107.3
Dec.	71.7	33.4	7.2	1.7	5.0	97.2
Jan.	79.8	31.7	7.48	1.7	5.0	86.5
Feb.	77.7	31.06	6.5	1.6	5.0	89.7
Mar.	77.3	33.2	4.93	2.0	5.2	94.2
Apr.	43.12	30.09	9.9	2.5	7.0	104.0
May.	27.5	12.09	15.6	2.5	7.7	122.3
June	0.0	11.24	22.6	2.8	12.0	199.3
July	0.0	10.0	24.6	2.5	12.0	247.7
Aug.	0.0	8.45	23.3	2.5	12.0	261.1
Sep.	0.0	18.9	22.9	2.0	10.0	185.3
Total	423.86					1747.4
Average		22.36	13.88	2.08	8.06	

3. Results and Discussion

The climatic elements studies have identified six main variable elements. These elements are rainfall in (mm), relative humidity in (%), temperature in (°C), wind speed in (m/s), sunshine duration in (h/day) and evaporation in (mm). Below is the description of the variable climate elements during the studied period (1980-2016):

3.1 Rainfall (P)

Rainfall plays a major rule in thehydrological cycle;it's the main source of flow or drought of rivers and the growth or lack of agriculture in some areas [7].Rainfall varies monthly, where the wet period extends from October (13.54 mm) and continues to May (27.5 mm), and the maximum rainfall was recorded in January (79.8 mm). The drought extends from June (0 mm) to September (0 mm), as shown in Table 1.

3.2 Relative Humidity (RH %)

Relative humidity is a manifestation of atmospheric humidity, which is the ratio of the actual vapor pressure in a certain volume of air to the saturation of vapor pressure at the same temperature [8].In the study area, the maximum monthly average is (33.4 %) in December and the minimum is (8.45 %) in August, while the annual average of relative humidity is (22.36 %), as shown in Table 1.

3.3 Temperature (T)

Temperature is the main element of the climate.It isdependent upon latitude, the nature of the surface, the altitude, and the prevailing winds.The average temperature for the period from 1980-2016 in AL-Sulaymania station is high in the months of summer (June, July, August and September). The highest degree of the monthly average temperature has been recorded in July, which is (24.6 ºC). The monthly average temperature drops during the months of winter (December, January, February, and March), where the lowest degree of the monthly average was (4.93 ºC) which was recorded in March,See Table 1.

3.4 Wind Speed (WS)

The wind increaseswith the high temperatures and thus increasing evaporation ofsoil water [9]. Valleys are few while speed increases in the flat areas. The wind speed within the study area representingthe average of wind speed is faster in the summer months (June, July, and August), and June has the highest average wind speed (2.8 m/sec). The average wind speeddrops during the winter months and the month of October has the minimum average wind speed of (1.5 m / sec), as shown in Table 1.

3.5 Sunshine Duration

The sunshineduration means the number of hours of sunshine in one day [10], and it affectsthe temperature,relative humidity, and evaporation. Sunshine rates vary at the stationof the study area during the months of the year,as it reached the maximum sunshine duration that occurs in (June, July and August) with a monthly average of (12.0 hour/day), while the minimum monthly average is (5.0 hour/day) that occurs during (December, January and February),and the annual average is (5.0 hour/day), as shown inTable 1.

3.6 Evaporation (E)

Evaporation is defined as the process of transforming water from liquid to gaseous[8].The monthly average evaporation in AL-Sulaymania station for the period between 1980-2016 increasedduring the summer months (June, July, August, and September), where the highest rate is recorded in August (261.1 mm), while the evaporation rate decreased during the winter months (December, January, and February), where the lowest rate is recorded in January (86.5 mm), see Table 1.Figure 2 shows the various relations between all the mentioned climatic elements for the study area. The rainfall curve has an inverse relation with thetemperature, evaporation, and sunshine duration, and it has a direct relation with relative humidity.The highest temperature, evaporation and sunshine duration values occur in the months from June to September, and the lowest value occursin the other months whenthe rainfall happens.

4. Evapotranspiration

The potential evapotranspiration is a combinedterm of evaporation and transpiration, definedas the total loss of water through evaporation and transpiration from the soil plant system [11]. The evapotranspiration in the study area was calculated for each month by usingequations, which had been derived by (Thornthwait, 1948) [12, 13]. The evapotranspiration in the study area is calculated for each month as follows:

$$PEx = 16\,[10tn / J]^{a} \quad (1)$$

$$J = \sum_{j=1}^{12} j \text{ For the 12 month} \quad (2)$$

$$j = [tn / 5]^{1.514} \quad (3)$$

$$a = (675 \times 10^{-9})\,J^3 - (771 \times 10^{-7})\,J^2 + (179 \times 10^{-4})\,J + 0.492 \quad (4)$$

$$a = 0.016\,J + 0.5 \quad (5)$$

The value of (a) equals (1.49).
Where:PEx = Potential evapotranspiration for each month (mm / month).
t = Monthly mean air temperature (C°).
n = Number of monthly measurement.
J = Annual heat index (C°).
j = Monthly temperature parameter (C°).
a = Constant.

After the Potential Evapotranspiration (PE) values are extracted, correct evapotranspiration (PEc) values can be calculated from the following equation [12]:

$$PEc = K^{*}\,PEx \quad (6)$$

Where: (PEc) is the Correct evapotranspiration (mm) and(K) is the correction coefficient related to hours between sunrise and sunset in the month.

$$K = DT/360 \qquad (7)$$

Where: (D): Number of days in the month.
(T): Average number of hours between sunrise and sunset in the month.

The results are clear in Table 2.The highest value of the potential evapotranspiration (PEx) is (124.4 mm) in July, and the lowest value is (11.34 mm) in March, while the total amount is (698.08 mm). The highest value of the corrected evapotranspiration (PEc) is (128.5 mm) in July and the lowest value is (5.06 mm) in March, while the total amount is (589.02 mm).The correlation graph of each potential evapotranspiration PE, and correct evapotranspiration PEcare explained in Figure (3).

Table 2: Monthly average records of climatic parameters in AL-Sulaymaniastation for the period [3]

Months	Temperatures (C°)	j	PEx	K	PEc	Evaporation (mm)
Oct.	11.24	3.4	38.72	0.757	29.31	152.8
Nov.	10.4	3.03	34.49	0.583	20.1	107.3
Dec.	7.2	1.73	19.94	0.43	8.57	97.2
Jan.	7.48	1.84	21.1	0.43	9.07	86.5
Feb.	6.5	1.48	17.12	0.388	6.64	89.7
Mar.	4.93	0.97	11.34	0.447	5.06	94.2
Apr.	9.9	2.81	32.04	0.583	18.68	104.0
May.	15.6	5.6	63.1	0.663	41.83	122.3
June	22.6	9.81	109.63	1.0	109.63	199.3
July	24.6	11.16	124.4	1.033	128.5	247.7
Aug.	23.3	10.27	114.72	1.033	118.5	261.1
Sep.	22.9	10.01	111.8	0.833	93.13	185.3
Total	166.65	J= 62.11	698.08		589.02	1747.4

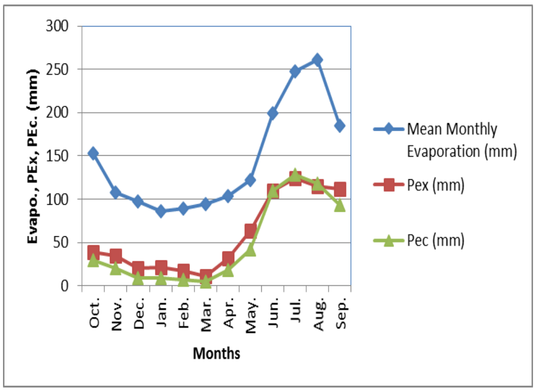

Figure 3: Evaporation, PEx and PEc correlation graph in AL-Sulaymania meteorological station for the period.

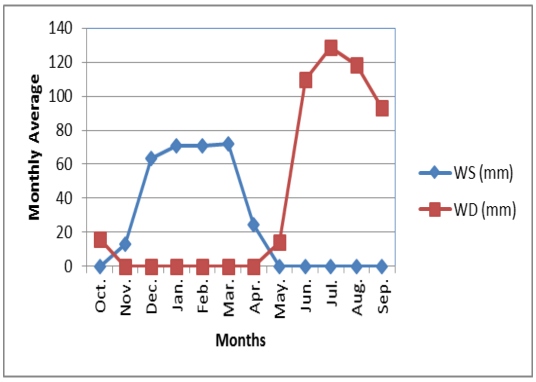

Figure 4: Therelationship between water surplus (WS) and the water deficit (WD) for the study area.

5. Water Surplus (WS) and Water Deficit (WD)

Water surplus is definedas the excess of rainfall values over the corrected evapotranspiration values during specific months of the year, while water deficit is the excess of corrected evapotranspiration values over rainfall values during the remaining months of that year. The actual potential evapotranspiration (APE) could be derived as follows [12]:

$$WS = P - PEc \qquad (8)$$

$$PEc = APE, \text{ when } P > PEc \qquad (9)$$

$$WD = PEc - P \qquad (10)$$

$$P = APE, \text{ when } P < PEc \qquad (11)$$

Where:WS: Water surplus (mm).
WD: Water deficit (mm).
APE: Actual Evapotranspiration (mm).
PEc: Correct potential evapotranspiration.
P: Rainfall

In the first case (water surplus period), values of rainfall aregreater than correct evapotranspiration,therefore the actual evapotranspiration equals the correct evapotranspiration. The water surplusrepresents the surface runoff plus the groundwater recharge after the soil is fully saturated. The soilmoisture is consumed either by evaporation from the soil or by plant. Therefore, it is considered as apart of the water losses as that of potential evapotranspiration [12, 14]. In the second case (water deficitperiod), correct evapotranspiration is greater than rainfall; where the actual evapotranspiration equals the rainfall. The monthly averages of APE, WS and WD are shown in Table 3.

The water surplus amount is (314.7 mm) from annual average rainfall (423.86 mm) and it is restricted between November and April because rainfall amounts exceed PEc,where the soil moisture is considered =0), and the water surplus ratio from the yearly rainfall can be represented as follows[4]:

WS % = WS/P ×100
WS% = 314.7 /423.86×100
= 74.24%
WD% = 100 – WS%
WD% = 100 – 74.24 %
= 25.76 %

Figure (4) shows the relationship between the monthly means of rainfall and the corrected evapotranspiration, which shows the water surplus and water deficit periods.

Table 3: Mean monthly values of evapotranspiration for the period at AL-Sulaymania meteorological station, where the values are calculated using the Thornthwaite method

Months	P(MM)	PE_C (MM)	APE (MM)	W_S (MM)	W_D (MM)
Oct.	13.54	29.31	13.54	0.0	15.77
Nov.	33.2	20.1	20.1	13.1	0.0
Dec.	71.7	8.57	8.57	63.13	0.0
Jan.	79.8	9.07	9.07	70.73	0.0
Feb.	77.7	6.64	6.64	71.06	0.0
Mar.	77.3	5.06	5.06	72.24	0.0
Apr.	43.12	18.68	18.68	24.44	0.0
May.	27.5	41.83	27.5	0.0	14.33
June	0.0	109.63	0.0	0.0	109.63
July	0.0	128.5	0.0	0.0	128.5
Aug.	0.0	118.5	0.0	0.0	118.5
Sep.	0.0	93.13	0.0	0.0	93.13
Total	423.86	589.02		314.7	479.86

6. Groundwater Recharge

Groundwater recharge dependson the amount of annual rainfall falling and the space of the studied area. Rainfall average rate for the period (1980-2016) was (423.86) mm andthe water surplus was calculated and it equals(314.7) mm. The surface runoff accounted and used the following formula [15] to calculate the annual amount of water that rechargesthe groundwater.

$$Rs = (P\text{-}178)\ P/2540 \quad (12)$$

$$= (423.86\text{-}178)\ 423.86/2540$$

$$= 41.02\ \text{mm}$$

$$R_e = 0.87\ (P\text{-}50) \quad (13)$$

Where:R_s: Surface runoff (mm)
R_e: Recharge (mm)
P: Total monthly rainfall (mm)

The application of the preceding formula was used to calculate the monthly recharge of climate information obtained from Erbil meteorological station and the results are shown in Table 4.

R_e = 92.65/423.86 × 100 = 21.85%

In general, from the application of water balance calculations depending on monthly averages of rainfall and potential evapotranspiration for the period (1980 - 2016), it can benoticed thatthe total annual rainfall reached (423.86 mm) and wasachieved from a water surplus of (314.7) mm divided into surface runoff value of (41.02) mm and rate of annual rainfall of (9.67%),groundwater recharge was (92.65) mm, and the percentage of annual rainfall was (21.85%). Overall, the proportion of water surplus rate of the annual rainfall was (74.24%) with an offset of(25.76%) total water loss by actual evapotranspiration.

Table 4: The values of water surplus and water deficit for the study area in mm.

Type. 1	Evaluation	Type. 2	Evaluation
AI-1>1.0	Humid to moist	AI-2>4.5	Humid
		2.5<AI-2<4.0	Humid to moist
		1.85<AI-2<2.5	Moist
		1.5<AI-2<1.5	Moist to sub arid
AI-1<1.0	Sub arid to arid	1.0≤AI-2<1.5	Sub arid
		AI-2<1.0	Arid

Evaluation of monthly climate averages in the study area after [5].

7. Classification of Climate

Different classifications for climate were proposed by many scientists and researchers to find the variation of the climate elements on which they depend, and there is a difficulty in combiningthem in one classification [16]. In this work, two of these classifications were applied to find the type of climate in the study area as follows:

The authors in [5] suggested a classification basedon humidity index (H.I) which represents the ratio between the rainfalls to correct potential evapotranspiration, and the evaluation of monthly climate averages in the study area is shown in Table 5.

Table 5: Monthly recharge in the study area for the period

Months	Monthly P (mm)	R_e (mm)
Oct.	13.54	0.0
Nov.	33.2	0.0
Dec.	71.7	18.88
Jan.	79.8	25.92
Feb.	77.7	24.1
Mar.	77.3	23.75
Apr.	43.12	0.0
May.	27.5	0.0
June	0.0	0.0
July	0.0	0.0
Aug.	0.0	0.0
Sep.	0.0	0.0
Total	423.86	92.65

The second classification of [6] was used to determine the classification of the climate of the study area.This classification dependson the annual dryness treatment depending on the amount of rainfall and temperature, and according to this relationship, the value of (AI-1) represents the classification ofthe dominated climate, and the value of (AI-2) represents a modification of the latter classification, see Table 6, and the values become as follows:

When comparing this value with the climate type in Table (6) it appears that the dominated climate in the study area is humid to moist.AI- 2 = 2.96, when comparing this value with the values in Table(6) the type of the dominated climate in the study area according to this formula is humid to moist.

Table 6: Climate classification depending on values of annual dryness treatment (A-I.1 and A-I.2) after [6].

Months	P (mm)	PEc (mm)	H.I	Kettaneh and Gangopadhyaya,1974
Oct.	13.54	29.31	0.46	Moderate to dry
Nov.	33.2	20.1	1.65	Humid
Dec.	71.7	8.57	8.36	Humid
Jan.	79.8	9.07	8.8	Humid
Feb.	77.7	6.64	11.7	Humid
Mar.	77.3	5.06	15.27	Humid
Apr.	43.12	18.68	2.3	Humid
May.	27.5	41.83	0.65	Moist
June	0.0	109.63	0.0	Very dry
July	0.0	128.5	0.0	Very dry
Aug.	0.0	118.5	0.0	Very dry
Sep.	0.0	93.13	0.0	Very dry

8.

9.

10.

Conclusions

1. This study presented that the water surplus was restricted in the months of November, December, January, February, March, April and May and it is (74.24%) of the total rainfall of (423.86 mm), while the percentage of water deficit represents (25.76%).
2. The water surplus is divided into surface runoff (41.02 mm) with a rate of (9.67%) and groundwater recharge of (92.65 mm) with a rate of (21.85%) of the total rainfall.
3. The climate of the study area is diverse between the wet climates in winter to the dry climate in summer and in most cases, it can be considered that the climate of the study area ishumid to moist.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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