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Climatic Parameters Use for Evaluating Water Budget and Drought Analysis in Erbil Sub-basin, Kurdistan Region, Northern-Iraq

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ABSTRACT

Major theoretical and practical hydrological issues may be solved using methods to maintain water balance. Evaluating the climate characteristics and environmental circumstances to be employed in the methods of water managing approach used in the Erbil sub-basin, northern Iraq, is the primary goal of this study. The studied area is a part of the region influenced by the Mediterranean climatological system. The climatic parameters of the research region were evaluated using the climatic data collected in the Erbil meteorological station for the period 1980-2022. The research result shows that the mean annual rainfall is 411.26 mm/year and the average monthly relative humidity is 41.12 %, the mean temperature is 20.62 °C, mean sunshine duration 8.35 hr./day and annual pan evaporation is 1200.96 mm / year. Potential evapotranspiration considered by Thornthwaite method is 1588.94 mm. The water surplus and deficit are 216.14 mm and 1393.81 mm, respectively. The surface runoff calculating from soil conservation system (SCS) technique which is about 86 mm / year and groundwater recharge is about 130.14 mm / year. The groundwater Budgets is about 187661880 m^3 / year. The climatic situation in the area is variety from winter its wet to the summer its dry climates. Also, it could be measured that the climate in the area is determined was (Humid to very humid). The draught index according to SPI analysis show that the drought was observed during Moderately drought in (1983, 1999, 2000, 2010, 2015, and 2021) to severely drought in (2022.

1.Introduction

The primary components of the natural hydrological cycle include rainfall, snowfall, sleet, etc., as well as storing evaporating and intercepting depressed. Water is a crucial component for the development of a given area. As a result of the expanding population, there is an abundance of demand for water. At the same time, water is limited for agricultural as well as other usages (Subedi and Chavez, 2015). The water balance is an achievable concept that may be applied effectively provided the basin's climatic factors and meteorology circumstances have been established (Jirjees et al., 2020). Evapotranspiration represents the significant consequences in the water managing process in any environmental region or aquatic condition. It provides an essential part of the water cycle and should be taken into consideration when constructing and managing any project involving irrigation (Al-Dabbas and Abdulla, 2019). Understanding these processes of hydrology is important because basins exist in the environment where the water balance maintains a sufficient amount of water. So appropriate usage of land and management of water are necessary for the continued development of hydrological basins. An integrative knowledge of the basin system's hydrological balancing is necessary for attaining this (Javadinejad et al., 2019).

The aims of this research are to indicate the evidences of climatic change by studying the climatic parameters and drought analysis in the region.

2. The Study Area

Erbil basin is separated into three secondary sub-basins: Kapran sub-basin in the northern part and the central basin which contains Erbil city and Bash Tepa sub-basins in the southern part. It is surrounded on the Upper and Lower Zab River from the NW and SE part, individually. The central Erbil sub-basin cover an area approximately (1442 Km^2), and is located between latitudes (36° - 36° 20') north and longitudes (43° 40 00 - 44° 10' 00) east (Fig 1). The geological outcrop at the central Erbil plain comprises Quaternary deposits in addition to formations from the Upper Miocene to the Recent, including the Injana, Muqdadiya, and Bai Hassan formations. Tectonically, the researched region is situated in the Foot Hill (Low Folded Zone). The groundwater direction movement from Eastern part to Western part in the study area (Jassim and Goff, 2006).

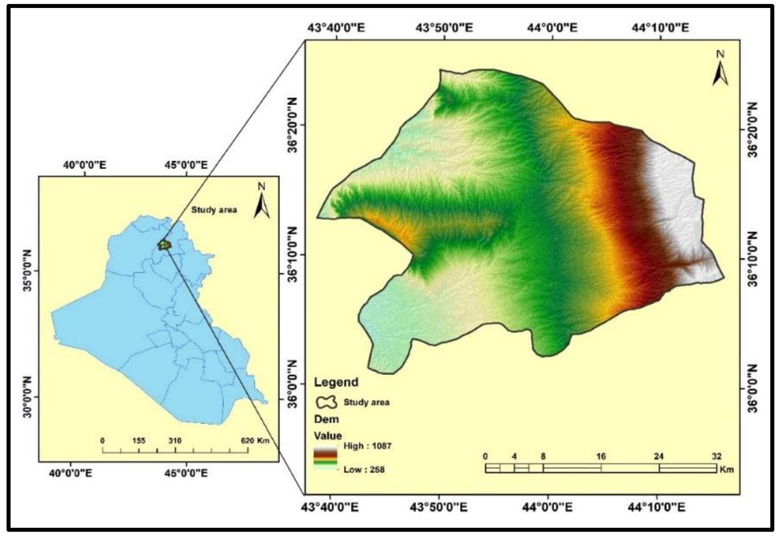


Figure 1: Map shows the location of Erbil sub-basin.

3. Materials and Methods

The meteorological data collected at Erbil-meteorological station about (42- years) during (1980-2022). The Erbil-meteorological station located at (44.03890 E) and (36.19500 N) and an elevation of (420 m), were used to calculate the mean monthly values of climatic parameters (Table 1 and Fig 2). Also, calculation of evapotranspiration in the study region using the Thornthwaite technique as well as water surplus, water deficit, surface runoff, and groundwater recharging in the area. Furthermore, the two climatic categories were employed to identify the kind of climate in the research region. The first from (Kettaneh and Gangopadhyaya, 1974) suggested the index of humidity (H.I.) which is measures the relation of rainfall with evapotranspiration in this category. Another from (AL-Kubaisi, 2004) established the dryness coefficients based on annually rainfall and temperature. In addition, determining the drought indices from SPI indices assessment in the research area.

4. Result and Discussion

4.1 Water Availability Elements

Precipitation and humidity are the two significant factors determining the amount of water available. Rainfall analysis is important in many areas, including agricultural strategy, water-management planning, flow estimation, study of the climate, the study of the environment, river flow computation, and life-sustaining activates (Dara et al., 2021). For calculating rainfall variance, the mean monthly rainfall of the 42 years is used. There is an increased tendency in rainfall throughout January to May, and a decreasing from May to August. In January and July, the average monthly rainfall is 77.08 mm and 0.3 mm, respectively. The mean annual amount of rainfall was 411.26 mm (Table 1 and Fig 2&3). The coefficient of variation can be utilized to identify data consistency (Jirjees et al., 2022). The seasonal result of coefficient of variation reveals that the autumn season months had the greatest values such as 90 %, while winter and spring seasons have 36 % and 46 %, respectively (Table 2 and Fig 4). Accordingly, the rainfall during the winter and spring seasons was relatively regular and steady, with little variation in its values and it's the most efficient for creating discharge and agricultural activity in the area.

The rate of evaporation from the surface of the water, soil, and the leaves of plants is controlled by relative humidity; the greater the value of the relative humidity, the lower the rate of evaporation and transpiration (Dara et al., 2021). In January and July, the maximum and minimum mean monthly relative humidity are 63.54 % and 20.19 %, respectively, while the mean annual rate is 41.12 % (Table 1 and Fig 3).

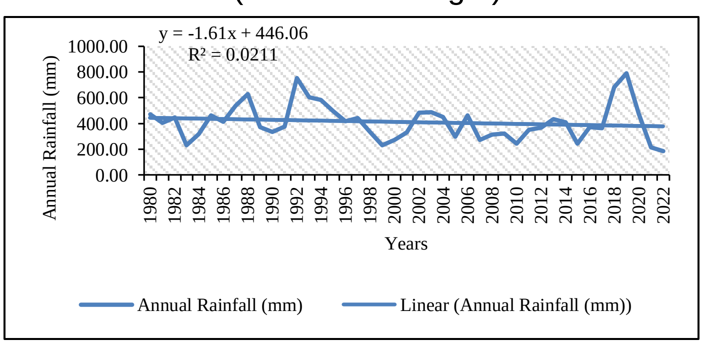


Figure 2: Relation shows the annual rainfall values during (1980-2022) in the study area.

4.2 Water Losses Elements

Water loss components consisting of temperature, wind speed, sunshine, and evaporation. Temperature has a significant impact on both evaporation and evapotranspiration. Plant development and temperature are interrelated, with plants responding to temperature limitations that allow them to carry out their functions (Thornthwaite, 1948). The minimum and maximum mean monthly temperatures are 7.65 ℃ and 34.23 ℃ in July and January, respectively, while the average annual temperature is 20.62℃. The maximum average monthly sunshine of 12.03 hrs/day in July and a minimum average monthly sunshine of 4.06 hrs/day in January, with an average annual sunshine of 8.35 hrs/day. The minimum and maximum mean monthly evaporation are 27.29 mm and 191.87 mm in January and July with an annual evaporation of 1200.96 mm /year (Table 1 and Fig 3).

Table 1: Mean monthly records of climatic elements in Erbil Meteorological Station during (1980-2022) in the area.

Months	Rainfall (mm)	Relative humidity (%)	Temperature (℃)	Sunshine duration (hrs./day)	Evaporation (mm)
Oct	27.04	34.75	22.90	7.91	89.60
Nov	40.89	50.12	14.76	6.53	45.50
Dec	70.15	60.29	9.36	5.51	28.39
Jan	77.06	63.54	7.65	4.96	27.29
Feb	70.27	60.22	9.05	5.76	36.76
Mar	58.20	54.67	12.92	6.77	60.71
Apr	39.22	47.47	18.44	7.68	92.06
May	15.70	33.64	24.93	9.51	142.36
Jun	0.63	22.81	30.71	11.91	178.92
Jul	0.31	20.19	34.23	12.03	191.87
Aug	2.68	21.27	33.53	11.33	175.35
Sep	9.10	24.46	28.92	10.27	132.13
Min.	0.31	20.19	7.65	4.96	27.29
Max.	77.06	63.54	34.23	12.03	191.87
Mean	34.27	41.12	20.62	8.35	100.08
Total	411.26				1200.96

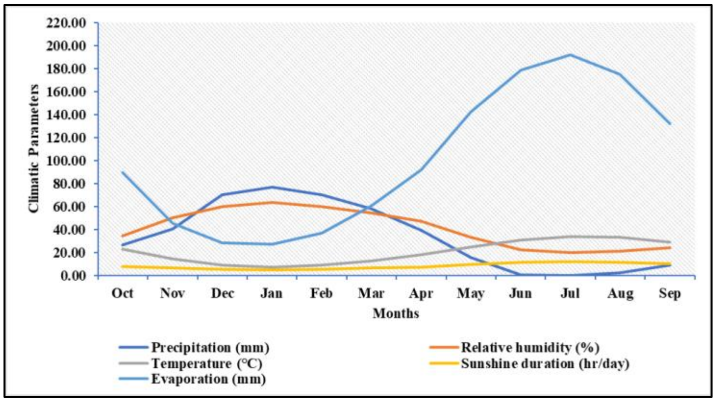
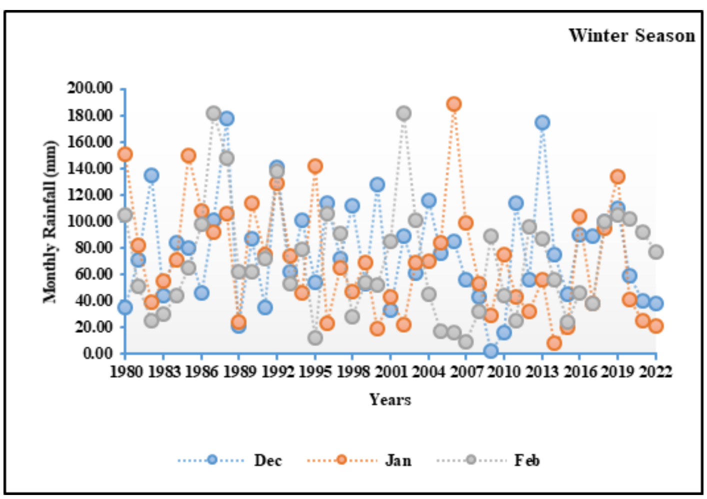
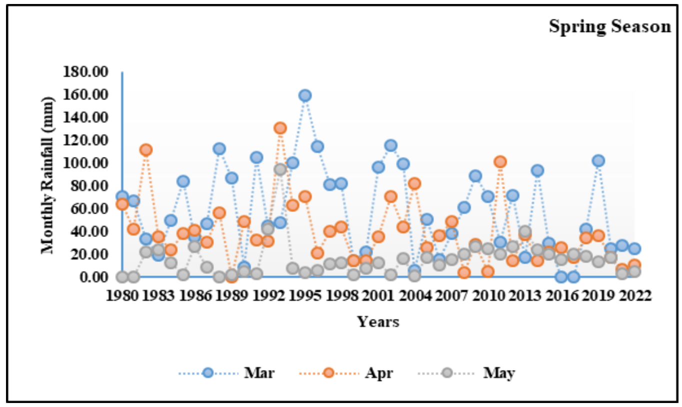


Figure 3: Correlation between mean monthly climatic parameters for the period (1980-2022) in the study area.

Table 2: Seasonal rainfall variation during (1980-2022) in the study area.

Years/Seasons	Months	Total mean	Standard Deviation	Coefficient variation (%)
	Sep			
Autumn	Oct	77.04	69	90
	Nov			
	Des			
Winter	Jan	217.49	79	36
	Feb			
	Mar			
Spring	Apr	113.12	52	46
	May			





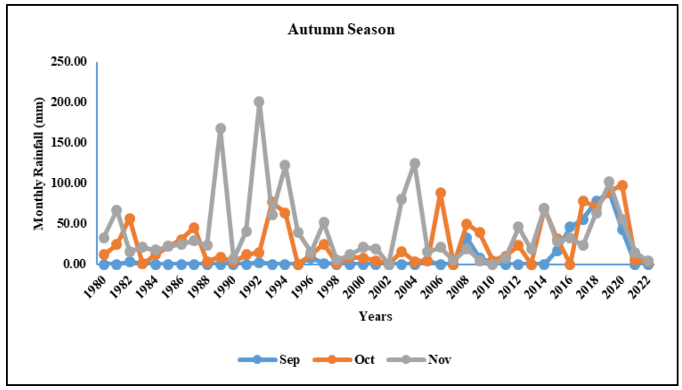


Figure 4: Seasonal rainfall variation of Erbil meteorological station for the period 1980-2022.

4.3 Evapotranspiration

Evapotranspiration (ET) is the releasing of water into the atmosphere caused by a combination of soil and plant surface evaporation and plant transpiration (Mohammed et al., 2022; Wang et al., 2021). According to climatic parameters available for the region that is being examined, potential evapotranspiration could be assessed by using the Thornthwaite (1948) technique and the results was shown in (Table 3 & Fig 5):

$$PET = La\ 16\ (10t / J)^{a} \quad \text{(Eq. 1)}$$

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

$$j = (t/5)^{1.514}$$

$$a = 0.016\ J + 0.5$$

Where: PET: is potential evapotranspiration in mm; La: is mean monthly correction constant function of latitude; j: is a monthly factor related to temperature; J: is a heat index annually; and t: is mean monthly temperature (°C).

Table 3: Calculation of potential evapotranspiration in Erbil sub-basin during 1980-2022.

Months	P (mm)	T (℃)	j	J	La	PET(mm)
Oct	27.0	22.9	10.01	111.01	0.94	108.66
Nov	40.9	14.8	5.15	111.01	0.85	36.16
Dec	70.2	9.4	2.59	111.01	0.81	12.23
Jan	77.1	7.7	1.90	111.01	0.83	7.92
Feb	70.3	9.1	2.46	111.01	0.91	12.72
Mar	58.2	12.9	4.21	111.01	1.00	31.40
Apr	39.2	18.4	7.22	111.01	1.09	77.02
May	15.7	24.9	11.39	111.01	1.18	165.59
Jun	0.6	30.7	15.61	111.01	1.22	275.07
Jul	0.3	34.2	18.40	111.01	1.20	346.40
Aug	2.7	33.5	17.83	111.01	1.13	311.24
Sep	9.1	28.9	14.25	111.01	1.04	204.53
Total	411.3		111.01			1588.94
a	2.28					

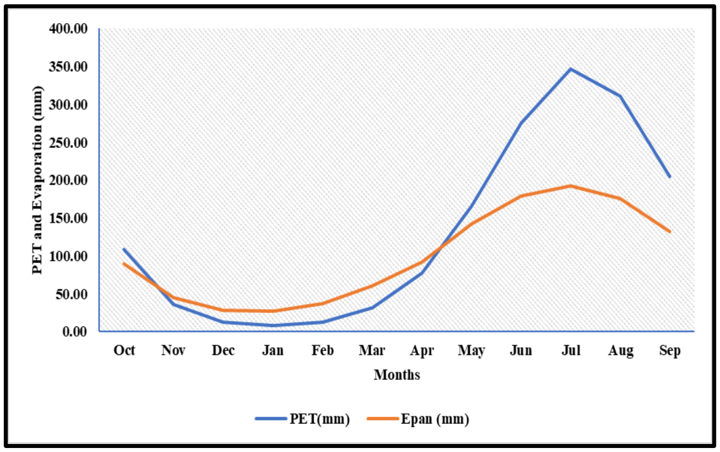


Figure 5: Relationship between evaporation and PET during (1980-2022) in the study area.

4.4 Water Surplus and Water Deficit

Water surplus is referred to as an excess of the amount of rainfall values (p in mm) greater than the potential evapotranspiration values (PET in mm) during specific months of the year, however water deficit is definite the excess of potential evapotranspiration values greater than the rainfall values throughout the other months of the year. Table 4 and Fig 6 show the mean monthly value of the WS and WD. The equations show that the WS, WD, WS% and WD% as follows:

$WS = P - PET \quad \text{if} \quad P > PET$ .... (Eq. 2)
$WD = PET - P \quad \text{if} \quad PET > P$ ....(Eq. 3)
$WS\% = (WS / P) * 100$ ....(Eq. 4)
$WD\% = 100 - WS\%$ .... (Eq. 5)

Where WS is water surplus, WD is water deficit, P is rainfall, and PE is potential evapotranspiration.

Table 4: Estimation of water surplus & water deficit during (1980–2022) in the study area.

Months	P (mm)	PET(mm)	W.S (mm)	W.D (mm)
Oct	27.04	108.66	0	81.61
Nov	40.89	36.16	4.73	0
Dec	70.15	12.23	57.92	0
Jan	77.06	7.92	69.14	0
Feb	70.27	12.72	57.55	0
Mar	58.20	31.40	26.80	0
Apr	39.22	77.02	0	37.79
May	15.70	165.59	0	149.89
Jun	0.63	275.07	0	274.44
Jul	0.31	346.40	0	346.09
Aug	2.68	311.24	0	308.56
Sep	9.10	204.53	0	195.43
Total	411.26	1588.94	216.14	1393.81
WS%	52.56	WD%	47.44	

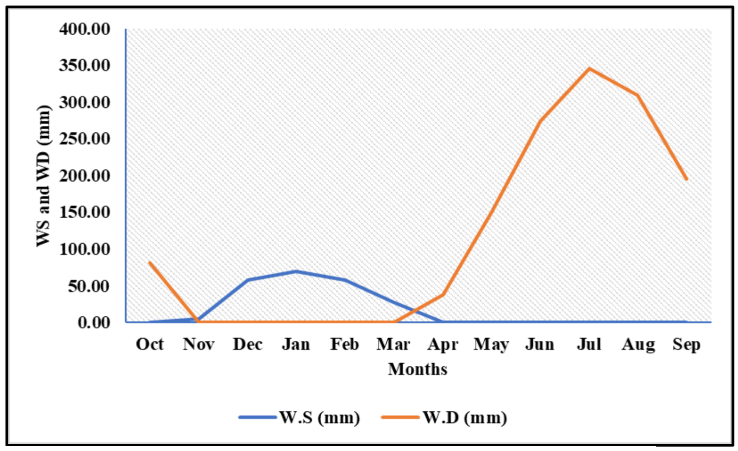


Figure 6: The association between water surplus (WS) and the water deficit (WD) during (1980-2022) in the study area.

4.5 Surface Runoff (Rs) Estimation

Precipitation from a basin is discharged throughout its natural drainage system, such as surface runoff or overland flow (Anderson and Mc Donnell, 2005). According to Singh et al., (2021), soil moisture is a critical factor in determining how much rainfall will infiltrate into the soil versus how much will become surface runoff. Different soil types and landscape positions (e.g., hillslopes vs. flat areas) respond differently to rainfall. For example, soils with high clay content may become saturated quickly and produce more runoff compared to sandy soils (Singh et al., 2021; Song and Wang, 2019). Surface runoff is calculated according to the soil conservation system (SCS) approach according to rainfall data that is currently available (Hammer et al., 1981;

Jirjees et al., 2020). The empirical rainfall-runoff relationship is as follows:

Q = (P – 0.2S)2 / P + 0.8 S ………… (Eq. 6)

Where; Q: is runoff (mm) of depth; P: is monthly rainfall (mm); S: is retention including the initial abstraction [S = 1000/CN – 10]; CN: is Curve number. Calculation the CN from precise information on the soil and plant cover is available. The SCS approach was implemented with four soil classes (hydrologic soil groups) (Maidment, 1993Therefore, using the Watershed Modelling System (WMS) software to estimate the soil type and curve number for the Rawanduz sub-basin is based on soil, rainfall, global vegetation, and land use (Rafaat and Hameed, 2023; Jirjees et al., 2023). The average weighted curve number for Erbil sub-basin is about (CN=75.40), and the soil group is type (B (Silty clay to clay loam)). according to the zonation in the (WMS) model (Table 5 and Fig 7). The surface runoff determination is summarized in Table 6 and Fig 8.

Table 5: Curve number calculate by (WMS) Software in the study area.

Sub-basins	Weighted curve number (CN)	Area (km^2)	Average weighted curve number
Sub-basin 1	74.09	396.86	75.40
Sub-basin 2	76.11	414.67	
Sub-basin 3	75.85	255.87	

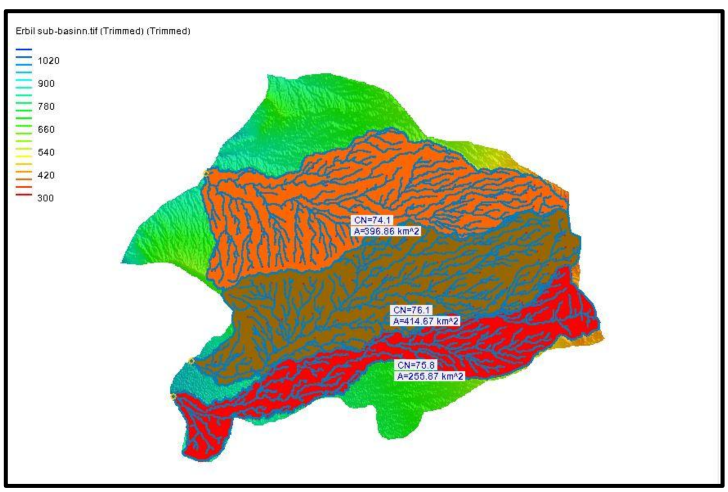


Figure 7: Dividing of study area depending on the soil group from (WMS) software zonation.

Table 6: Mean monthly rainfall and runoff according to soil conservation service (SCS) technique in study area.

Months	P (mm)	Rs (mm)
Oct.	27.04	0
Nov.	40.89	6
Dec.	70.15	19
Jan.	77.06	24
Feb.	70.27	20
Mar.	58.2	13
Apr.	39.22	4
May.	15.7	0
Jun.	0.63	0
Jul.	0.31	0
Aug.	2.68	0
Sep.	9.1	0
Total	411.26	86

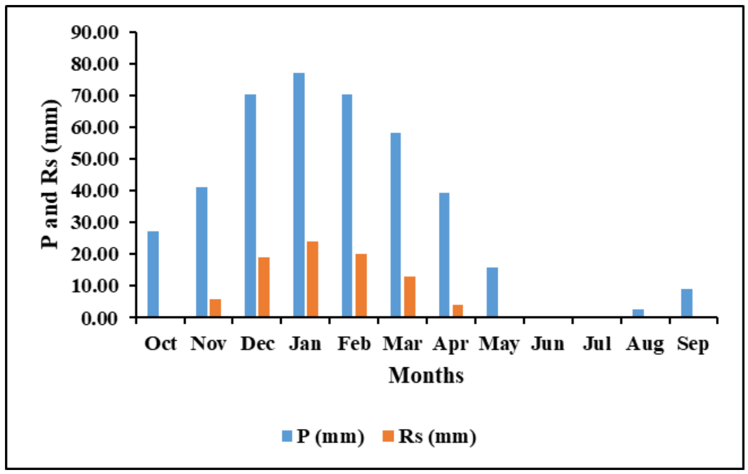


Figure 8: Relationship between mean monthly rainfall and runoff in (mm) which calculated by SCS method.

4.6 Groundwater Recharge (Re)

The space of the studied region and the amount of annual rainfall that falls influence groundwater recharging (Al-Kubaisi et al., 2022). According to Al-Kubaisi et al., (2022), groundwater recharging calculated depending on water surplus and surface runoff using the equation below:

WS = Re + Rs ………………… (Eq. 7)

Re = WS – Rs Re = 130.14 mm / Year

Re% = Re / P *100 Re% = 31.64 %

Rs% = Rs / P * 10 Rs% = 20.91 %

The annual water budget equation as follows:

Groundwater Budget = Re (mm) * Area (km^2) ………………. (Eq. 8)

Groundwater Budget= 187661880 m^3 / Year

4.7 Climate Classification

According to potential evapotranspiration (PET) result value, the category of climate in the research region will be determined using a variety of classifications, including the following:

4.7.1 Kettaneh and Gangopadhyaya (1974)

This kind of climate classification depended on humidity index (H.I), which calculated the proportion of rainfall to potential evapotranspiration (Table 7), and the formula as follows:

$$H.I. = P / PET \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 9)}$$

Where; H.I is a humidity index; P is a mean monthly rainfall (mm); PET is a potential evapotranspiration (mm).

Table 7: Monthly climate classification from (Kettaneh and Gangopadhyaya, 1974) during (1980-2022) in the study area.

Months	P (mm)	PET(mm)	H.I	Climate Types
Oct	27.04	108.66	0.25	Moderate to Dry
Nov	40.89	36.16	1.13	Humid
Dec	70.15	12.23	5.73	Humid
Jan	77.06	7.92	9.73	Humid
Feb	70.27	12.72	5.52	Humid
Mar	58.20	31.40	1.85	Humid
Apr	39.22	77.02	0.51	Moist
May	15.70	165.59	0.09	Dry
Jun	0.63	275.07	0.00	Dry
Jul	0.31	346.40	0.00	Dry
Aug	2.68	311.24	0.01	Dry
Sep	9.10	204.53	0.04	Dry

4.7.2 Al-Kubaisi (2004)

This classification depends on the annual dryness treatment according to precipitation and temperature value. the (AI-1) and (AI-2) result values representing the dryness in the area (Table 8). The result value of (AI-1) is about 1.73 shows Humid to Moist and (AI-2) is 2.55 also shows Humid to Moist climate types in the study area. The formulas as follows:

$$AI - 1 = (1.0 \times P) / (11.525 \times t) \quad \ldots\ldots\ldots\ldots \text{(Eq. 10)}$$

$$AI - 2 = 2\sqrt{p} / t \ (13) \quad \ldots\ldots\ldots\ldots \text{(Eq. 11)}$$

Where: AI is aridity index; P: is annual rainfall (mm); t: is mean monthly temperature (C°).

Table 8: Classification of the climate according to (Al-Kubaisi, 2004) in Erbil sub-basin for period (1980-2022).

Climatic Type -1	Evaluation	Climatic Type -2	Evaluation
AI-1 > 1.0		AI-2 > 4.5	Humid
	Humid to Moist	2.5 < AI-2 < 4.0	Humid to Moist
		1.85 < AI-2 < 2.5	Moist
		1. 5 < AI-2 < 1.85	Moist to Sub-Arid
AI-1 < 1.0	Sub-Arid to Arid	1.0 < AI-2 < 1.5	Sub-Arid
		AI < 1.0	Arid
Study area			
AI-1 = 1.73	Humid to Moist	AI-2 = 2.55	Humid to Moist

4.8 Drought Indices Analysis

The Standardized Precipitation Index (SPI) being one of the more popular drought indicators, is a frequently used measure for describing meteorological droughts (Deo, 2018). SPI may be defined across a variety of periods, including 1, 3, 6, 12, 24, and 48 months (Livada and Assimakopoulos, 2007). According to (McKee et al., 1993), the standardized precipitation indices (SPI) and the frequency of probability event happen show in (Table 9). Also, the SPI result value and the probability event show in (Table 10 and Fig 9). The SPI formula calculating as:

$$SPI = (P - P^{-}) / S.D \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 12)}$$

Where: SPI is standardized precipitation index; P: is annual rainfall (mm); P-: is Mean annual rainfall (mm); S.D: Standard deviation.

Table 9: Frequency and probability events of drought classification based on the SPI value (McKee et al., 1993).

SPI value	Category	Frequency	Probability event (%)
≥ 2	Extremely wet	3	6.97
1.50 to 1.99	Severely wet	0	0
1 to 1.49	Moderately wet	3	6.97
0 to 0.99	Mildly wet	14	32.56
0 to -0.99	Mildly drought	16	37.21
-1 to -1.49	Moderate drought	6	13.95
-1.50 to -1.99	Severe drought	1	2.33
≤ -2	Extreme drought	0	0

Table 10: Drought indices analysis in the Erbil sub-basin for the period 1980-2022.

Years	Annual rainfall (mm)	SPI	Standard interpretation
1980	471.50	0.442	Mild Wet
1981	404.40	-0.045	Mild Drought
1982	444.10	0.243	Mild Wet
1983	229.90	-1.313	Moderately Drought
1984	315.90	-0.688	Mild Drought
1985	463.90	0.387	Mild Wet
1986	412.00	0.010	Mild Wet
1987	536.90	0.917	Mild Wet
1988	626.90	1.571	Moderately Wet
1989	373.30	-0.271	Mild Drought
1990	335.00	-0.549	Mild Drought
1991	376.50	-0.248	Mild Drought
1992	751.74	2.477	Extremely Wet
1993	601.70	1.388	Moderately Wet
1994	583.40	1.255	Moderately Wet
1995	494.40	0.608	Mild Wet
1996	418.89	0.060	Mild Wet
1997	441.60	0.225	Mild Wet
1998	333.90	-0.557	Mild Drought
1999	232.50	-1.294	Moderately Drought
2000	272.30	-1.005	Moderately Drought
2001	328.70	-0.595	Mild Drought
2002	481.40	0.514	Mild Wet
2003	487.30	0.557	Mild Wet
2004	448.50	0.275	Mild Wet
2005	295.20	-0.838	Mild Drought
2006	462.40	0.376	Mild Wet
2007	273.50	-0.996	Mild Drought
2008	315.20	-0.693	Mild Drought
2009	321.20	-0.650	Mild Drought
2010	241.20	-1.231	Moderately Drought
2011	351.70	-0.428	Mild Drought
2012	366.40	-0.321	Mild Drought
2013	431.80	0.154	Mild Wet
2014	410.10	-0.004	Mild Drought
2015	243.70	-1.212	Moderately Drought
2016	369.90	-0.296	Mild Drought
2017	363.90	-0.339	Mild Drought
2018	681.50	1.967	Extremely Wet
2019	789.10	2.749	Extremely Wet
2020	474.40	0.463	Mild Wet
2021	215.50	-1.417	Moderately Drought
2022	184.00	-1.646	Severe Drought

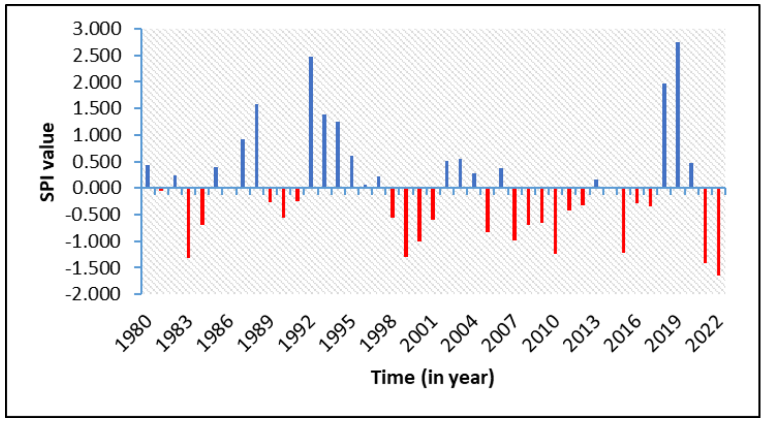


Figure 9: SPI indices result during 1980-2022 in the study area.

According to SPI result such as (Table 9), demonstrating the moderately drought in years (1983, 1999, 2000, 2010, 2015, and 2021) with probability event (13.95%). Also, representing severely in year (2022) with probability event (2.33%) in the study region.

5. Conclusions

If the sub basin's meteorological conditions and climatic parameters are identified, the water balance model is a useful concept that could potentially use properly. The studied area is a part of the region influenced by the Mediterranean climatological system. Water balance model calculated for the period (1980-2022). The mean annual rainfall is 411.30 mm/year and the average monthly relative humidity is 41.12%, the mean monthly temperature is 20.62°C, mean monthly sunshine duration 8.35 hrs./day and annual pan evaporation is 1200.96 mm / year. Potential evapotranspiration considered by Thornthwaite method is 1588.94 mm. The water surplus and water deficit are 216.14 mm and 1393.81 mm, respectively. The surface runoff calculating from soil conservation system (SCS) approach which is about 86 mm / year and groundwater recharge is about 130.14 mm / year. The groundwater Budgets is about 187661880 m^3 / year. The draught index according to SPI analysis show that the drought was observed during Moderately drought in (1983, 1999, 2000, 2010, 2015, and 2021) to severely drought in (2022).

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