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Climatic water balance for AI-Ruhba District in Najaf Governor – Iraq

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Abstract
The study area is situated in the southwest of the governorate of Najaf, underwent a climatic analysis using data from Al-Najaf Meteorological Station spanning from 1980 to 2022. Findings reveal an annual rainfall of 134.2 mm, a relative humidity of 40.32%, an average temperature of 25.6°C, a wind speed of 1.52 m/sec, 8.45 hours of daily sunshine, and an evaporation rate of 5470.4 mm. Notably, The total amount of corrected evapotranspiration was 1038.75 mm. Water Surplus (WS) varies across months, with values of 6.59 mm (November), 30.11 mm (December), 11.93 mm (January), and 4.72 mm (February). The water surplus amounted to 53.35 mm, about 39.75% of the annual rainfall. This value represents the portion of rainfall that recharges groundwater, assuming no surface runoff in the study area. However, factors such as evaporation and plant uptake can reduce the actual amount of water that infiltrates the soil. The silty sand soil type and low rainfall contribute to limited surface runoff.

Keyword: Classification of climate, Water balance, Potential evapotranspiration, Water surplus, Water deficit.

الموازنة المائية المناخية لقضاء الرحبة في محافظة النجف – العراق

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الخلاصة
خضعت منطقة الدراسة الواقعة في الجزء الجنوبي الغربي من محافظة النجف الأشرف إلى تحليل مناخي باستخدام بيانات محطة أرصاد النجف الأشرف للفترة الممتدة من عام 1980 إلى عام 2022. وتشير النتائج إلى هطول أمطار سنويه قدرها 134.2 ملم، ورطوبة نسبية 40.32%، ومتوسط درجة الحرارة 25.6 درجة مئوية، وسرعة الرياح 1.52 م/ث، و8.45 ساعة من ضوء الشمس يوميا، ومعدل التبخر 5470.4 ملم. ان اجمالي كمية التبخرالنتح المصححه كانت 1038.75 ملم. وتختلف الزياده المائيه عبر الأشهر، حيث تبلغ قيم 6.59 ملم (تشرين الثاني)، و30.11 ملم (كانون الاول)، و11.93 ملم (كانون الثاني)، و4.72 ملم (شباط). بلغ الفائض المائي 53.35 ملم، أي حوالي 39.75% من هطول الأمطار السنوي. وتمثل هذه القيمة نسبة هطول الأمطار التي تغذي المياه الجوفية، على افتراض عدم وجود جريان سطحي في منطقة الدراسة. ومع ذلك، فإن عوامل مثل التبخر وامتصاص النباتات يمكن أن تقلل الكمية الفعلية للمياه التي تتسرب إلى التربة، ويساهم نوع التربة الرملية الغرينية وقلة هطول الأمطار في الحد من الجريان السطحي.

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1. Introduction

Throughout the past century, the Middle East has grappled with the significant challenge of climate change. Numerous aspects of life, such as agriculture, environment, economics field, social dynamics, and public health, have been significantly impacted by this phenomenon [1]. Its effects are connected to the accessibility of water supplies in both urban and rural areas [2]. Except for the hilly regions, the climate of Iraq is classified as continental, subtropical, and semi-arid regions. [3]. Iraq experiences hot, dry summers and wet, freezing winters. The months of November through April see around 90% of the annual rainfall [4]. Systems of water resources need to be managed to adapt to the unpredictability of climate change. Practices for emergency plans are crucial for managing water resources in an emergency because of the predicted variations in temperature and precipitation [5]. Due to its significant effects on various sectors, including water, human health, agriculture, marine resources, and others, One of the most important environmental cases that must be investigated and evaluated is climate disparity change. Climate change may result in increased danger of flooding, drought intensity, reduced groundwater levels, and increased salinity of the soil, liquid waste, and other effects [6].The quality of groundwater and variations in its levels are significantly influenced by the climate. Heat waves in the summer cause water to evaporate, which raises salinity levels and lowers groundwater levels. Conversely, Rainfall increases allow water to seep through the layers of soil. Increasing groundwater levels and lowering certain chemical element concentrations in water [7].The primary factors that determine climate include latitude, height, topography, vicinity to major water bodies as well as air circulation [8].

This research aims to evaluate the climate by studying and assessing climate factors for the Al-Najaf city from 1980 to 2022 and determining the water surplus, deficit and the percentage of total rainfall that recharges the groundwater.

Materials and Methods

Al-Rahba is situated in the governorate of Najaf's southwest. AI-Rahba is currently 35 kilometers from the holy city of Najaf; Figure 1 illustrates this area's position within the Northerly latitude range of (31°55′30″– 31°40′30″) and the Easterly longitude range of (44°12′00″– 44°28′30″). Examining the climatic data of the AI-Najaf Meteorological Station from 1980 to 2022, as provided by the Iraqi Meteorological Organization [9]. The examination of climatic factors has shown six main factors, including temperature (°C), wind speed (m/s), sunshine length (h/day), rainfall (mm), relative humidity (%), and evaporation (mm) [4]. Developing an equation to calculate to calculate the values of potential evapotranspiration (PE) and corrected evapotranspiration (PEc), as well as actual evapotranspiration (APE) for each month based on latitude [10]. Additionally, climate classification techniques from [11]and [12]were employed. The water balance, as determined using [13], identified surplus and deficit. The Runoff Curve Number (CN) approach was employed by the Soil Conservation Service (SCS) to estimate runoff following severe rainfall. Folk [14] used the pipette analysis method to determine the kind of soil. Subsequently, a groundwater recharge value calculation was made [15].

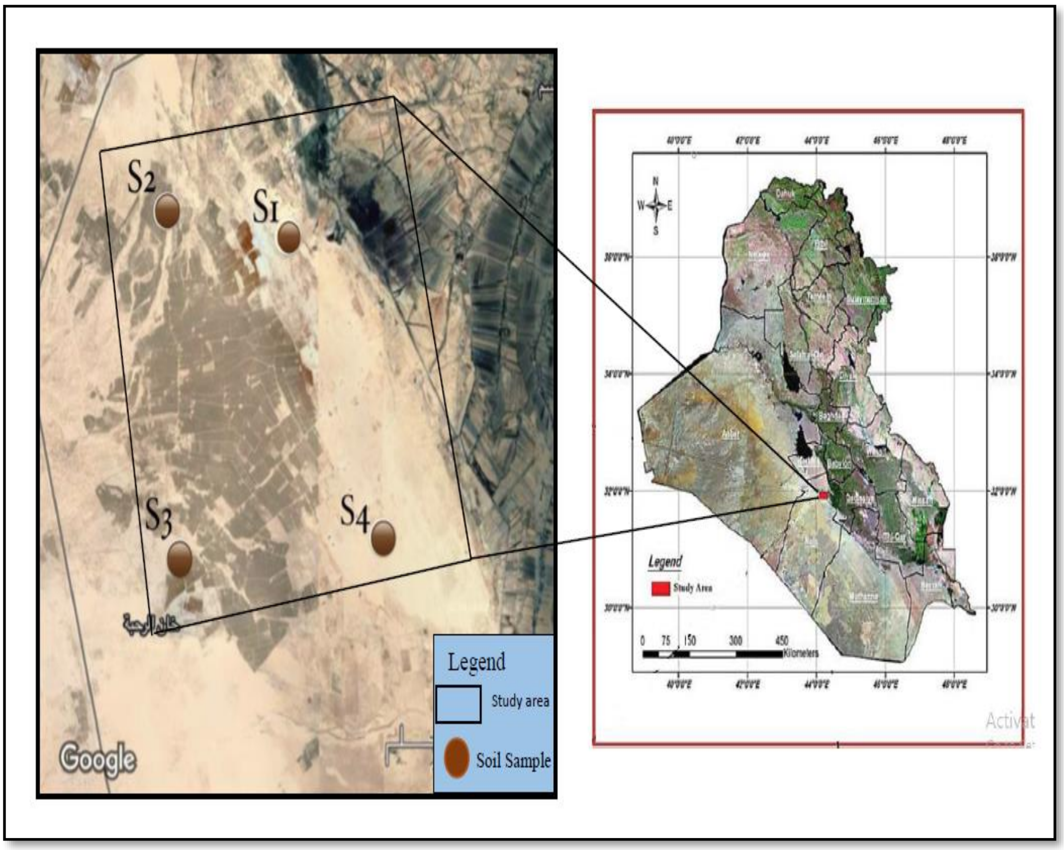

Figure 1: shows the study area and soil sampling locations.

Results and Discussion

The following is an explanation of the weather variables that were used throughout the 1980-2022 study period:

Table 1: Mean monthly records of climatic parameters at Al_ Najaf meteorological station from 1980 – 2022 (Iraqi Meteorological Organization, 2023).

Months	*Temperature (C°)*	*Rainfall (mm)*	*Evaporation (mm)*	*Relative humidity (%)*	*Sunshine (hr)*	*Wind speed (m/sec)*
Oct.	28.1	4.7	425.1	29.45	8.5	1.2
Nov.	19.35	25.7	202.03	57.05	6.85	0.95
Dec.	13.75	36.7	133.9	69	6.1	0.97
Jan.	11.25	15.9	136.1	63.75	6.65	1
Feb.	14.85	13.9	200.4	53.95	7.67	1.3
Mar.	18.1	12	325.7	44.15	7.15	1.95
Apr.	25.6	21.9	443.3	38.95	7.1	1.85
May.	30.6	3.4	614	30.55	8.9	1.8
Jun.	36.15	0	772.8	25.45	10.7	1.95
July.	37.8	0	845.5	20.85	11.75	2.1
Aug.	37.9	0	792.2	23.2	11	1.7
Sep.	33.8	0	579.4	27.45	9	1.45
Total	…….	134.2	5470.4	……..	……...	……
Average	25.6	………	………	40.32	8.45	1.52

1. Precipitation (p)
Rainfall, particularly in dry and semiarid regions, is essential to the hydrological cycle. In certain areas, it is the primary factor influencing the growth or lack thereof of agriculture [16]. The water source, vital to numerous regions globally, stands out due to its strength, volume, and temporal-spatial distribution [4]. Snow, rain, hail, drizzle, fog, mist, and sleet are all considered forms of precipitation, and they naturally vary in both time and space [6]. The Najaf station records an average annual rainfall of 134.2 mm (Table 1), as shown in Figure 2.

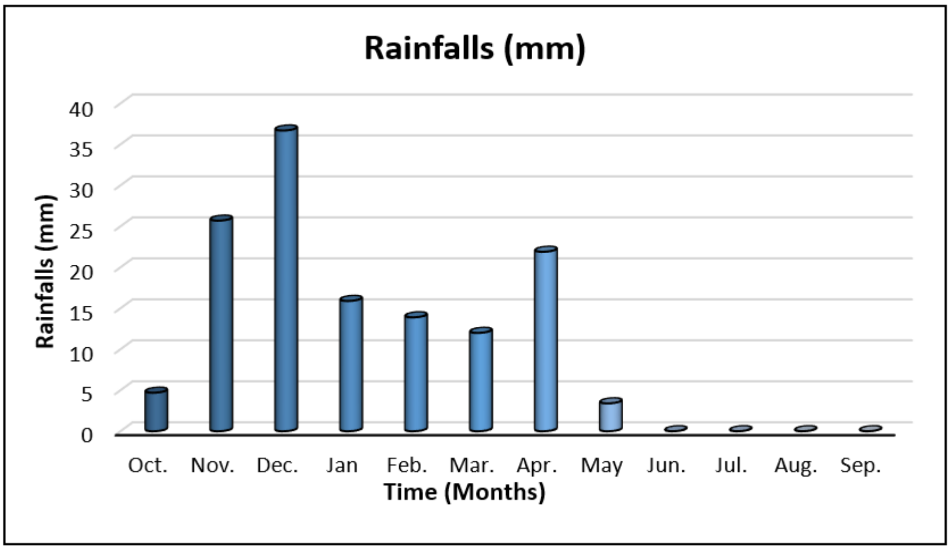

Figure 2: shows the average monthly rainfall from 1980 to 2022 at the Najaf meteorological station.

2. Relative Humidity (RH%)
The definition of relative humidity is the ratio of the current water vapor pressure in the air to its saturated vapour pressure at a specific temperature [11]. Its correlation with precipitation and temperature is evident as it increases during winter with elevated rainfall and lower temperatures, while it decreases in summer with reduced rainfalls and higher temperatures [10]. The monthly average relative humidity recorded was 40.32% (Table 1). Relative humidity data showed that months (November, December, January, February, and March) exceeded the average, as depicted in Figure 3.

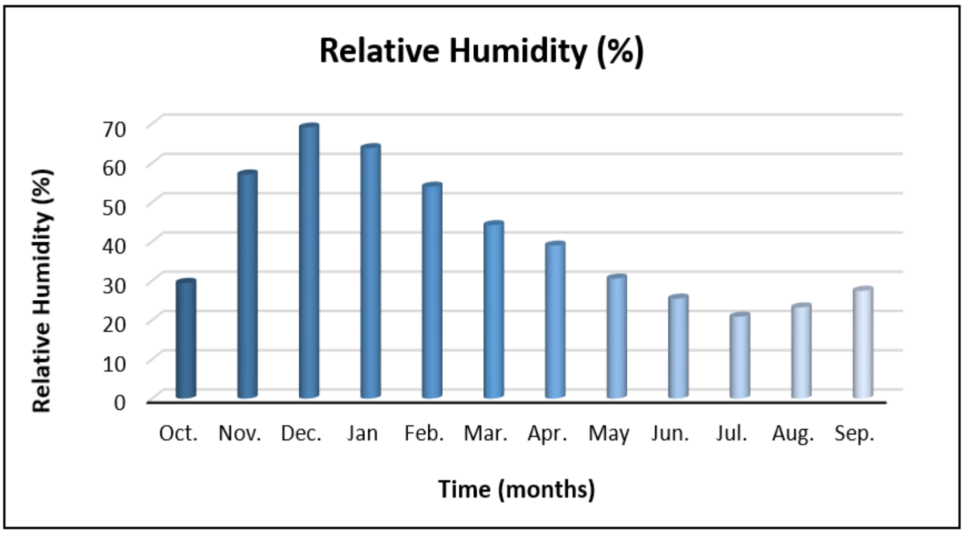

Figure 3: shows the monthly average relative humidity for 1980–2022 at the Najaf meteorological station.

3. Temperature (T)

Temperature, the primary determinant of climate, is influenced by latitude, surface characteristics, altitude, and dominant winds. Temperature degradation is caused by variables, including the rise of industry, population, and greenhouse gas emissions [17]. At the Najaf station, the average temperature from 1980 to 2022 was highest in the summer months of October, May, June, July, August, and September, exceeding the average, as shown in Figure 4. The monthly average recorded temperature was 25.6% (Table 1).

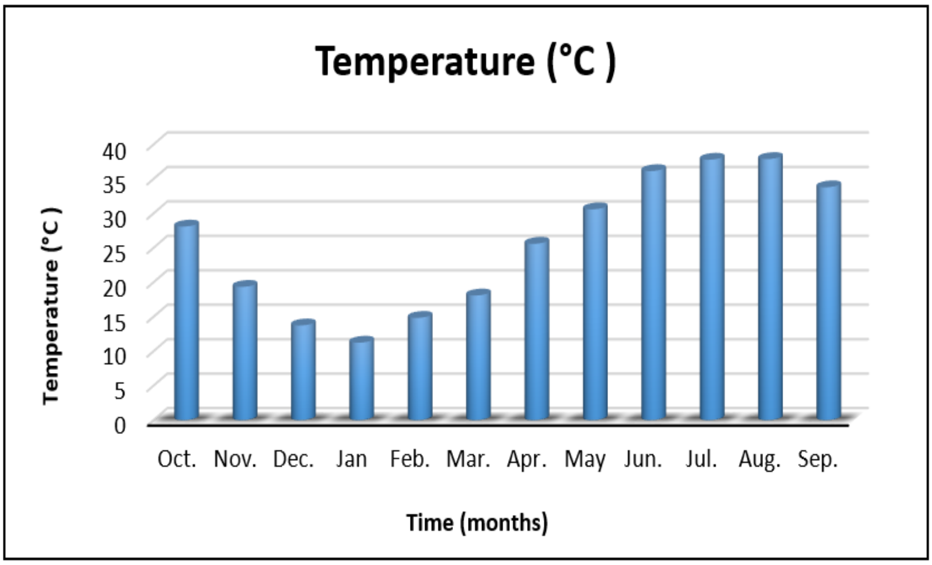

Figure 4: shows the Monthly average temperature for the Najaf meteorological station, 1980-2022.

4. Wind Speed

High temperatures cause the wind to speed up, which accelerates the evaporation of soil water [18]. In level terrain, the wind **speed** is higher, and wind direction is influenced by Earth's rotation [4]. The monthly average recorded relative wind speed was 1.52 m/sec (Table 1). Data showed that (March, April, May, June and July) wind speeds were higher than average, as depicted in Figure 5.

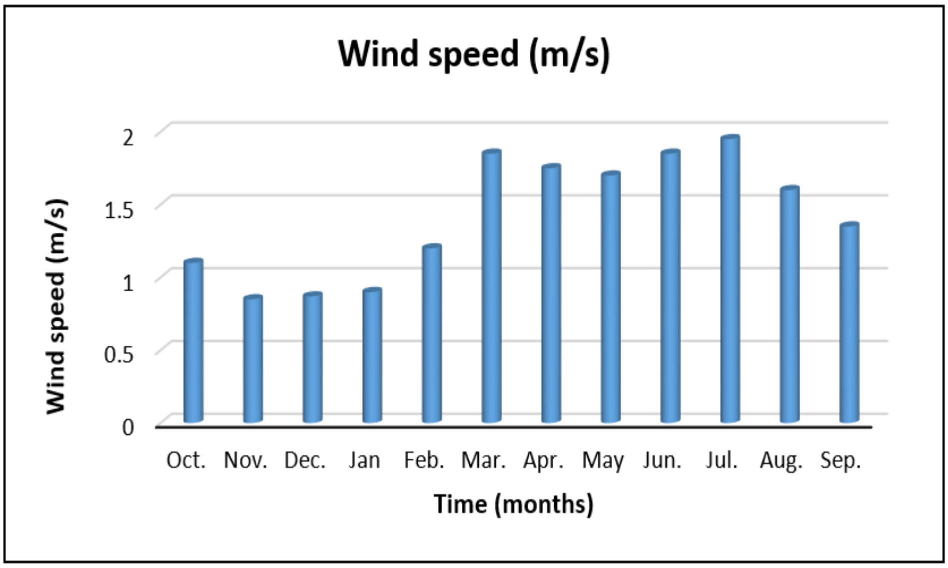

Figure 5: shows the monthly average wind speed for 1980-2022.

5. Sunshine duration

The number of hours of sunshine in a day is referred to as the sunshine duration [6], is a crucial element of climatic parameters since it influences temperature, evapotranspiration, and relative humidity. In addition to impacting real evaporation rates, the sunshine period and rising temperatures can cause excess evaporation, which in turn can affect the amount of reclaimed water below the surface [13]. The monthly average recorded sunshine duration was 8.45 hours/day (Table 1). Data showed that (October, May, June, July, August and September) with sunshine durations exceeding the average, as depicted in Figure 6.

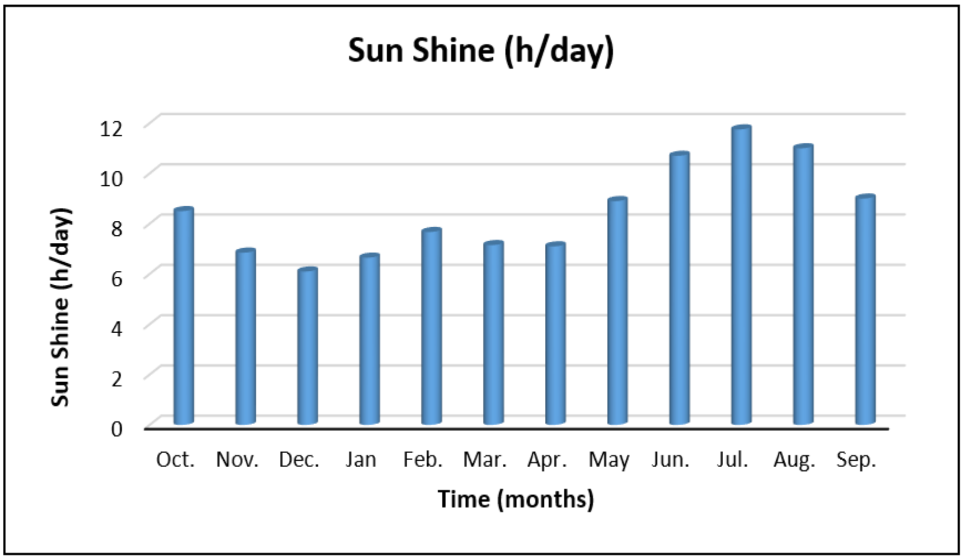

Figure 6: shows the average monthly sunshine length from 1980 to 2022.

6. Evaporation (E)

A key element of hydrology and water balance is evaporation [19]. Evaporation occurs on free water surfaces like lakes, rivers, soils, and damp vegetation. A few factors that influence evaporation are air temperature, relative humidity, wind speed, and sun radiation [20]. Table 1 shows that the average annual recorded evaporation was 5470.4 mm.

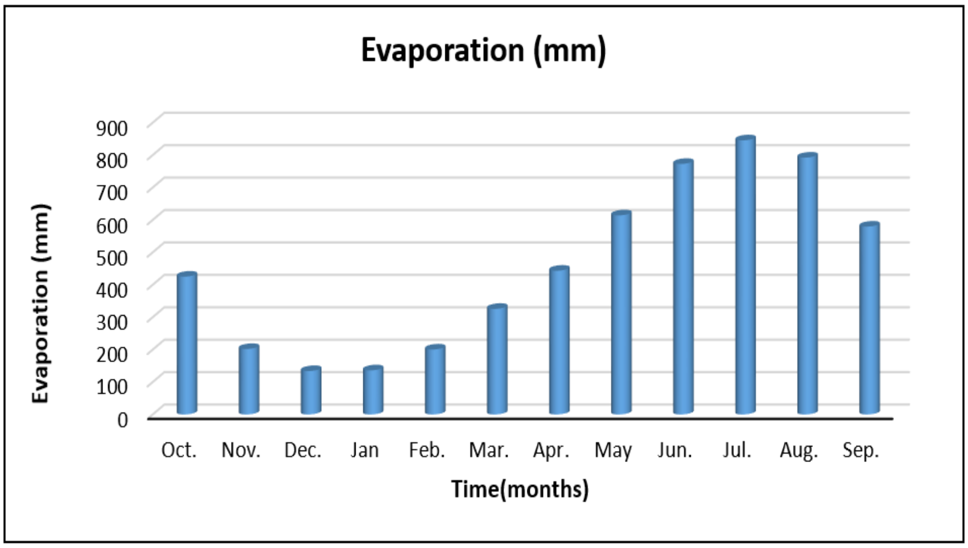

Figure 7: shows the average monthly evaporation for Najaf Meteorological Station (1980-2022).

7. Evapotranspiration (PE)

It is one of the most difficult components of the hydrologic cycle to estimate. The definition of it is the entire amount of water lost to evaporation from the earth's surface and transpiration from plants leaves [19]

Potential Evapotranspiration (PEc)

Together with transpiration and evaporation, the term " potential evapotranspiration" refers to the total amount of water lost from the soil-plant system [21]. An equation to compute the PE, PEc, was proposed by Thornthwiate [22] as shown in Table 2.

Table 2: Using the Thornthwaite method (1948), calculate the mean monthly evapotranspiration values for the 1980-2022 period

MONTH	*TEMPERATURE (c°)*	*$j=(tn/5)^{1.514}$*	*PE (mm)*	*T*	*D*	*K*	*PEc (mm)*
Oct.	28.1	13.65	98.85	8.5	31	0.73	72.16
Nov.	19.35	7.76	33.52	6.85	30	0.57	19.11
Dec.	13.75	4.63	12.45	6.1	31	0.53	6.59
Jan.	11.25	3.41	6.96	6.65	31	0.57	3.97
Feb.	14.85	5.2	15.56	7.67	28	0.59	9.18
Mar.	18.1	7.01	27.62	7.15	31	0.62	17.12
Apr.	25.6	11.85	75.45	7.1	30	0.59	44.52
May.	30.6	15.53	126.56	8.9	31	0.77	97.45
Jun.	36.15	19.99	205.18	10.7	30	0.89	182.61
July.	37.8	21.38	233.52	11.75	31	1.01	235.86
Aug.	37.9	21.47	235.31	11	31	0.95	223.54
Sep.	33.8	18.05	168.85	9	30	0.75	126.64
Total		J=149.93	1239.83				1038.75

Actual Evapotranspiration (APE)

The actual evapotranspiration (APE) represents the actual amounts of transpiration and evaporation that move upwards from soil and vegetation to the atmosphere under current conditions (climatic factors) [23].

1-APE = PEc …………. (1)

When: P ≥ PEc (With possible surplus after the soil is saturated)

P <PEc (without water surplus)

2-APE = P …………(2)

When: P <PEc

3- APE = 0 ………….(3)

When: P=0

Table 3 shows the actual evaporation values for each month.

Water Balance

Water surplus is defined as the excess of rainfall values over corrected evapotranspiration values during specific months of the year, while water deficit is the excess of corrected evapotranspiration values over rainfall values for the other months of that year [24]. The water balance of the study area was calculated using the Lerner et al. (1990).

Water Surplus (WS)

WS = P- PEc ..………... (4)

When P> PEc

Where: WS: Water Surplus (mm).

Water Deficit (WD)

$$WD = PEc - P \qquad \text{...............(5)}$$

When P< PEc.

Where WD: Water Deficit (mm).

The total yearly worth of WS was 53.35 mm due to total amount of rain surpassing PEc in the months (November, December, January and February) assuming that the soil moisture is (0). Based on annual rainfall, the WS ratio is:

$$WS\,\% = WS/P \times 100 \qquad \text{........... (6)}$$

WS% = 53.35/134.2× 100 = 39.75%

While the water deficit (WD) ratio can be represented as:

$$WD\% = 100 - WS\% \qquad \text{............(7)}$$

WD% = 100-39.75=60.25%

In Table 3, the APE,WS and WD monthly averages are shown. Additionally, Figure 8 illustrates the correlation between mean monthly precipitation (P) and corrected evapotranspiration (PEc), highlighting periods of water surplus (WS) and water deficit (WD).

Table 3: The research area's water surplus from 1980 to 2022

MONTH	*P (mm)*	*PEc (mm)*	*APE (mm)*	*WS (mm)*	*WD (mm)*
Oct.	4.7	72.16	4.7	0	67.46
Nov.	25.7	19.11	19.11	6.59	0
Dec.	36.7	6.59	6.59	30.11	0
Jan.	15.9	3.97	3.97	11.93	0
Feb.	13.9	9.18	9.18	4.72	0
Mar.	12	17.12	12	0	5.12
Apr.	21.9	44.52	21.9	0	22.62
May.	3.4	97.45	3.4	0	94.05
Jun.	0	182.61	0	0	182.61
July.	0	235.86	0	0	235.86
Aug.	0	223.54	0	0	223.54
Sep.	0	126.64	0	0	126.64
Total	134.2	1038.75		53.35	957.9

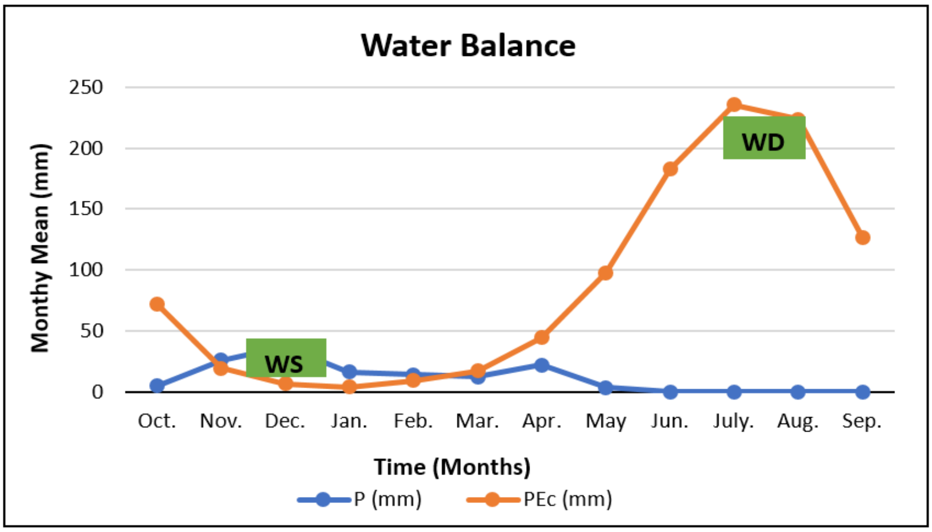

Figure 8: illustrates the relationship between the corrected evapotranspiration (PEc) and mean monthly rainfalls, Indicating water deficit (WD) and surplus (WS) for the years 1980-2022

Classification of Climate

Numerous scientists and researchers have devised various classifications to identify and categorize climate types [25]. Two of these categories will be used in this study to describe the climate in the chosen area in the following ways:

According to Thornthwaite 1948 [12], the study area's climate data from 1980 to 2022 was categorized. The dominant climate kind during the months of the year was discovered to be dry in the research region. In the Kubaisi (2004) classification, the type of climate dominated during the months of the year of the study area was found to be sub-arid to arid.

Soil Conservation Service Method (SCS): Calculates runoff from storm rainfall using the runoff curve number (CN) method. The curve-number model was created by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) [15], this is the technique for predicting rainfall surplus that is most frequently employed.

According to the results obtained from four samples calculating the soil type according to Folk [14], and as demonstrated in Table 3 by the pipette analysis method, it was discovered that the study area's soil is silty sand. Therefore, based on these specifications, the soil type of the study area belongs to class A, as shown in Table 4. By classification suggested by the curve number (CN) technique, this soil condition has a CN value of 68, as indicated in Table 5. In the research area, the surface runoff values (Rs) are zero as shown in Table 6,because of the low amount of rainfall, as well as the soil type being silty sand.

Table 4: The results of grain size analysis and type of texture of AL-Ruhba area soil.

Sample No.	*percentage %*			*Type of texture according to Folk (1974)*
	Sand	*Silt*	*Clay*	
X1	66	22	12	Loamy sand soil
X2	66	24.5	9.5	Loamy sand soil
X3	77.5	17.5	5	Loamy sand soil
X4	50	36	14	Loamy soil
Min.	50	17	5	
Max.	77.5	36	14	
Average	64.88	25	10.13	

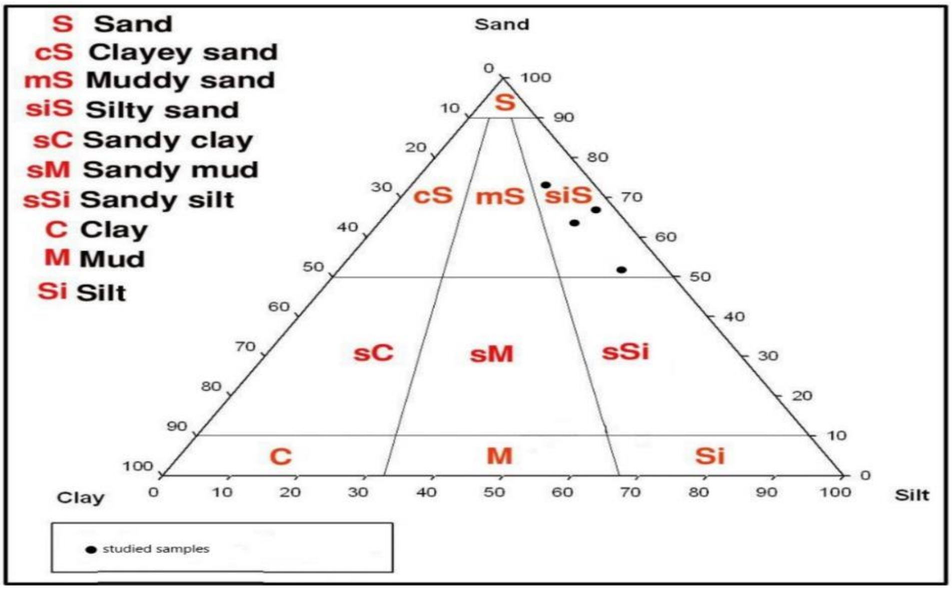

Figure 9: Folk classification of soil type in the study area.

Table 5: HSG classification based on the new surface soil's texture [15].

HSG	*Soil textures*
A	Sand, loamy sand, or sandy silt
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Table 6: Curve Number for Various Urban Land Uses [15].

Cover type and hydrologic condition	*Curve number for hydrologic soil group*			
	A	B	C	D
Poor condition (grass cover 50%)	68	79	86	89
Fair condition (grass cover 50%	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80
Paved parking lots, roofs, driveways, etc .	98	98	98	98
Paved; curbs and storm sewers	98	98	98	98
Paved; open ditches	83	89	92	93
Gravel	76	85	89	91
Dirt	72	82	87	89
Natural desert landscaping	63	77	85	88
Artificial desert landscaping	96	96	96	96
Commercial and business	89	92	94	95
Industrial	81	88	91	93
Residential districts by average lot size: 1/8 acre (505.86 m2) or less (townhouses)	77	85	90	92
1/4 acre (1011.72 m2)	61	75	83	87
1/3 acre (1348.95 m2)	57	72	81	86
1/2 acre (2023.43 m2)	54	70	80	85

Table 7: shows the research area's average monthly surface runoff data.

Months	*P (mm)*	*WS (mm)*	*Weighted CN*	*S*	*P > 0.2 S*	*Rs (mm)*
Oct.	4.7	0	68			0
Nov.	25.7	6.59		119.53	NO	0
Dec.	36.7	30.11		119.53	NO	0
Jan.	15.9	11.93		119.53	NO	0
Feb.	13.9	4.72		119.53	NO	0
Mar.	12	0				0
Apr.	21.9	0				0
May.	3.4	0				0
Jun.	0	0				0
July.	0	0				0
Aug.	0	0				0
Sep.	0	0				0
Total	134.2	53.35				0

Groundwater Recharge

Estimating groundwater recharge is crucial for groundwater system management [26]. The data from the Al-Najaf meteorological station spanning from 1980 to 2022 indicates consistently low rainfall. In areas with silty sand soil types, surface runoff is absent in the study area. To calculate groundwater recharge in this region, the following equation [14]can be applied:

$$WS = Rs + Re \qquad \text{…………. (8)}$$

Where:

WS: Water Surplus (mm), Rs: Surface runoff (mm), Re: Groundwater recharges (mm).

$$Re = WS - Rs \qquad \text{…………..(9)}$$

Re = 53.35- 0 =53.35 mm

Re%= (53.35/134.2)*100 = 39.75%

To ascertain the groundwater recharge during normal water years in the study area, the following equation is applicable under the assumption of zero soil moisture.

Re annual = A× Re …………(10)

Where: A: Area of study (79) Km^2

Re annual = $79\times 10^6(m^2)\times 39.75 10^{-3}(m)$

Re annual = $3140.25\times 10^3 m^3$/ year

Conclusions

-By conducting analyzes and calculating the annual average of the climatic parameters, it is shown that the total annual rainfall was 134.2 mm and relative humidity was 40.32%, while the monthly average temperature was 25.6 ° C, evaporation was 5470.4 mm, the wind speed was 8.45m/s

-In general, the climate of the study area is found to be located in a sub-arid to arid region, which is described as relatively hot in summer and cold with low rain in winter.

-53.35 mm of water surplus (WS) from total rainfall is the annual value. The annual rainfall yields a water surplus (WS) ratio of 39.75% and a water deficit (WD) ratio of 60.25%.

-Valu of groundwater recharge represent (53.35 mm) with a rate (of 39.75%) representing the percentage of groundwater recharge from the total rainfall.

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