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Assessing the Groundwater Recharge with Water Balance in Ameriat Al-Falluja City, Al-Anbar Governorate, Western Iraq

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Abstract

This study aims to figure out how to calculate water recharge using the soil conservation service method, one of the most widely used methods for calculating runoff volume following rainfall. The research is being conducted in Ameriat Al-Falluja City, Al-Anbar Governorate. The Iraqi meteorological organization's Baghdad Airport and Al-Ramadi stations provided data on the research area from 1989 to 2020 as total annual rainfall (123.1 mm), the RH% (43%), the mean monthly T (23.6 °C), total evaporation (3169.61 mm), the wind speed (3.1 m/s), and the sunshine duration (9 h/day). The climate of the study area is described as arid. The total evapotranspiration value quantity is 1137.38 mm for the 32-year comparison period, while the total amount of correct evapotranspiration was 992.3 mm.

Water surplus is 36.7% of total rainfall, which equals 45.2 mm. Groundwater recharge is 45.2 mm, with a rate of 36.7%, showing the groundwater recharge (%) from total rainfall. The value of groundwater recharge throughout a year is about equivalent to 23.6848* 10^5 m^3/year.

Keywords: Ameriat Al-Falluja, climate, Water balance, Groundwater recharge.

تقييم إعادة تغذية المياه الجوفية مع الموازنة المائية في مدينة عامرية الفلوجة ، محافظة الأنبار ، غرب العراق

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الخلاصة

الغرض من البحث هو تحديد كيفية حساب إعادة تغذية المياه باستخدام تقنية Soil Conservation Service ، والتي تعد واحدة من أكثر الطرق شيوعًا لتحديد حجم الجريان السطحي بعد هطول الأمطار. تقع منطقة الدراسة في مدينة عامرية الفلوجة بمحافظة الانبار. المعلومات المناخية تم الحصول عليها من محطتي مطار بغداد و الرمادي التابعين لهيئة الأرصاد الجوية العراقية خلال الفترة (1989-2020) . بلغ إجمالي هطول الأمطار السنوي 123.1 ملم ونسبة الرطوبة النسبية 43٪ ، بينما المتوسط الشهري للحرارة كان 23.6 درجة مئوية ، والتبخر الكلي 3169.61 ملم ، وسرعة الرياح 3.1 م / ث ، ومدة السطوع الشمسي 9 ساعات / يوم. صنف مناخ منطقة الدراسة بأنه جاف. بلغ إجمالي قيمة التبخر- النتح 1137.38 ملم خلال 32 عامًا ، بينما كانت الكمية الإجمالية للتبخر- النتح المصحح 992.3 ملم. في منطقة الدراسة ، بلغ مقدار الزيادة

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المائية 36.7 % من إجمالي هطول الأمطار ، أو 45.2ملم. ونتيجة لذلك ، بلغت قيمة إعادة تغذية المياه الجوفية 45.2 ملم ، بمعدل 36.7 % ، مما يوضح النسبة المئوية لإعادة تغذية المياه الجوفية من إجمالي هطول الأمطار. في المنطقة المدروسة ، تبلغ قيمة تغذية المياه الجوفية على مدار العام حوالي 23.6848 * 105 م ^{3} / سنة.

1. Introduction

Climatological change is the differences between average climatic measurements or subsequent climatological periods [1]. The interplay of rainfall and evaporation, which contribute to groundwater recharge, is significantly influenced by climate. Climate factors substantially impact surface and groundwater resources, varying throughout the year and year. The studies which address the whole hydrological cycle show likely changes in the hydrochemical characteristics and the hydraulic properties of the Iraqi groundwater [2, 3, and 4]. Climate change may cause dryness intensity, increase soil salinity, increase flood risk, liquid waste, decrease groundwater level, etc. [5]. This research aims to determine how to compute water recharge using the soil conservation service technique and calculate climatic water balance by examining climatic characteristics at the Baghdad Airport and Al-Ramadi meteorological stations (1989–2020).

2. Study area

The study area is located in Ameriat Al-Falluja City, bounded from the eastern part by the Euphrates River and Al-Razzaza, Al-Habaniya Lakes from the south and north, respectively. The study area is about 524 km^{2} with an elevation range of 96–44 m (a.s.l.). Ameriyat AL-Fallujah lies in the center of Iraq within the Mesopotamian Plain. The study area is restricted to latitudes (32º 59′ -33º 14′N) and longitudes (43º 39′- 44º3′E) (Figure1a). The Injana Formation (Upper Miocene) is an exposed formation characterizing the study area together with Quaternary sediments (Pleistocene and Holocene) (Figure1b).

3. Materials and methods

The meteorological data were collected from Baghdad Airport and Al-Ramadi stations from 1989 to 2020. The Thornthwiat technique was used to compute evapotranspiration on a monthly basis. Two approaches were utilized to establish the prevailing climate in the study area. The water balance was calculated using the Lerner technique. The runoff from storm rainfall was computed using the soil conservation service method and the runoff curve number (CN). The value of groundwater recharge in the study area was then estimated throughout a water year.

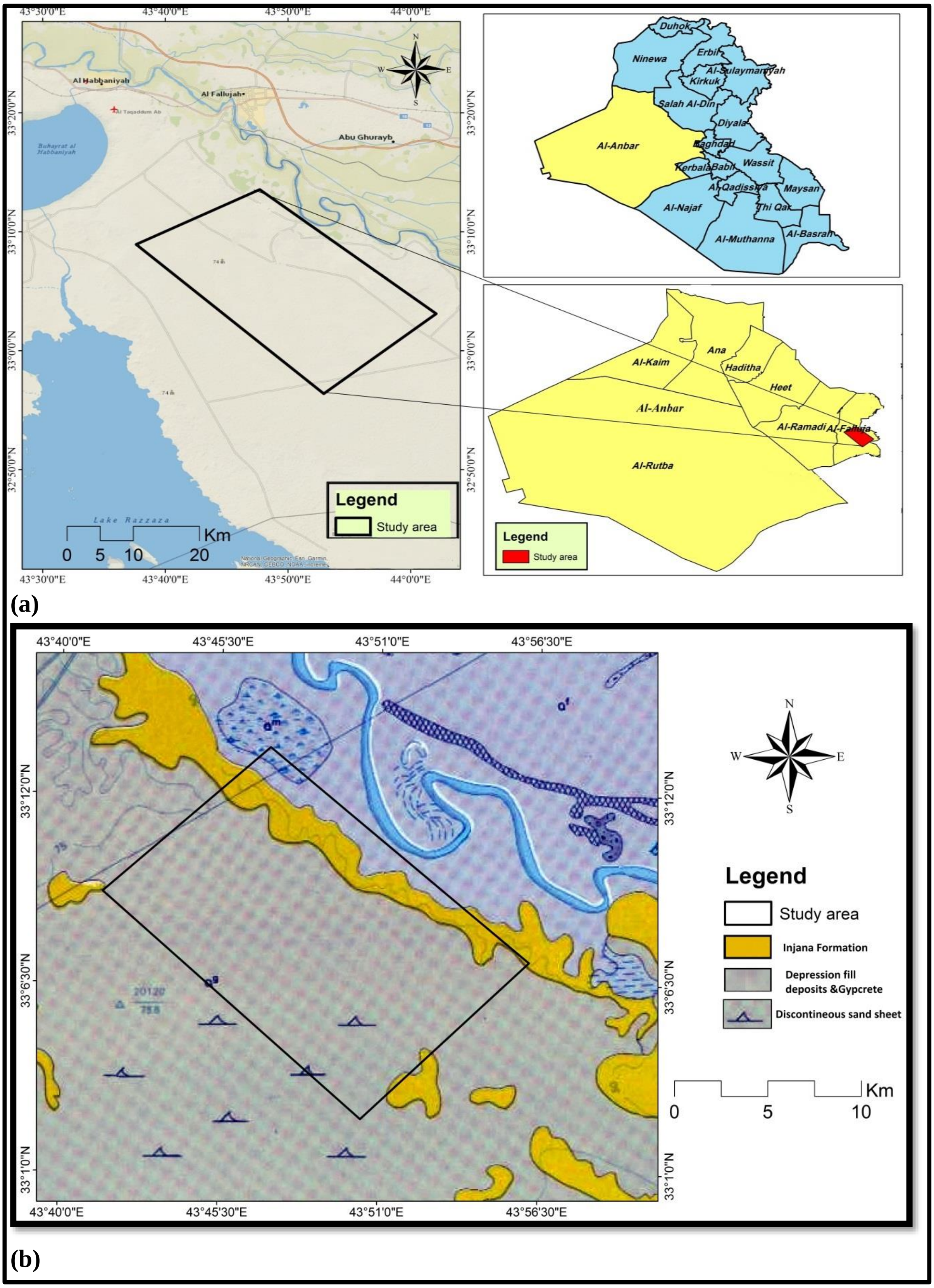


Figure 1: (a) Location of the study area. (b) Geological map of the study area [6].

4. Results and discussion

The following is a list of the variable climatic components that were used throughout the study period from 1989 to 2020:

3.1 Rainfall:

Precipitation plays a crucial role in groundwater recharge in arid and semi-arid environments. Rainfalls allude to the rivers' principal sources of flow or drought and lake expansion and development in some locations [7]. The wet season runs from May (3 mm) to October (6.9 mm), while the dry season is from June (0.0 mm) to September (0.1 mm) Table (1). The wetter month was January (24.7 mm) in Baghdad and Ramadi, The water years (1989-2020) are divided into dry years (below the average line = 15 years) and wet years (above the average line = 17 years) based on yearly average rainfall (Figure 2). After 1998, the number of dry years increased, as did the incidence of drought conditions, which impacted water resources, particularly groundwater recharge.

Table 1: Mean monthly records of climatic parameters at Baghdad Airport and Al-Ramadi stations (1989-2020).

Month	Rain falls (mm)	Mean monthly Temp. C◦	Relative Humidity (%)	Mean Wind speed (m/s)	Evaporation (mm)	Sunshine duration (hours/day)
Oct.	6.9	25.6	42	2.7	221.15	**8.06**
Nov.	23.8	17.05	58	2.5	107.93	**6.94**
Dec.	16.4	11.9	68	2.6	74.63	**5.84**
Jan.	24.7	10.25	69	2.6	67.82	**6.05**
Feb.	16.5	12.7	59	2.9	98.98	**7.13**
Mar.	16.8	17.5	49	3.3	176.45	**7.7**
Apr.	15	23.15	41	3.2	250.78	**8.57**
May.	3	29.05	31	3.4	365.73	**9.86**
Jun.	0.0	33.5	24	4	475.68	**11.56**
Jul.	0.0	35.7	24	4.2	522.97	**11.51**
Aug.	0.0	35.25	26	3.5	463.93	**11.31**
Sep.	0.1	31.15	31	2.9	343.56	**10**
Mean annual		23.6	43	3.1		**9**
Total	123.1				3169.61	

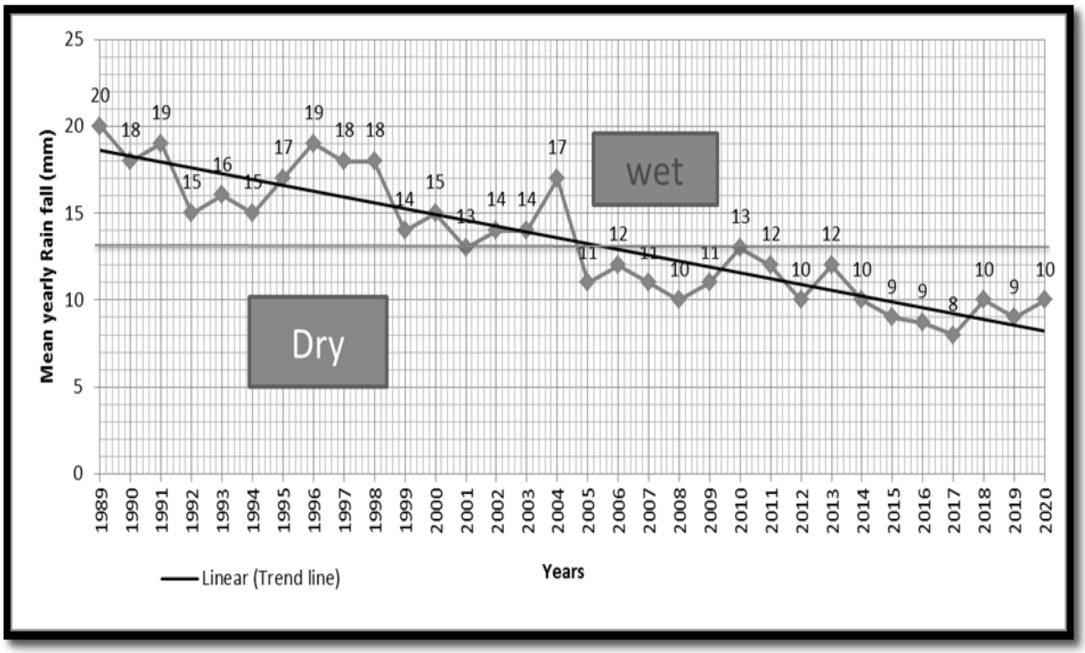


Figure 2: Water years were classified into dry and wet years depending on Annual rainfall (1989-2020) at Baghdad Airport and Al-Ramadi Meteorological stations.

3.2 Temperature:

One of the climatic elements that has a considerable influence on the hydrological cycle is temperature. Its fluctuations occur regularly during any water year, causing rainfall to behave unfavorably [8]. Table (1) displays the mean yearly temperature from 1989 to 2020. The Mean annual temperature is (23.6 ˚C), with a mean monthly temperature of (10.25°C). January is the coldest month, while July is the warmest, with a mean monthly temperature of (35.7°C) in Baghdad and Ramadi. The water years are categorized by the mean monthly temperature, which shows that most years since 1998 have increased temperature over the mean monthly value (Figure 3). The trend line shows that the mean temperature has risen by around 2°C in the last thirty years, indicating climate change in the area.

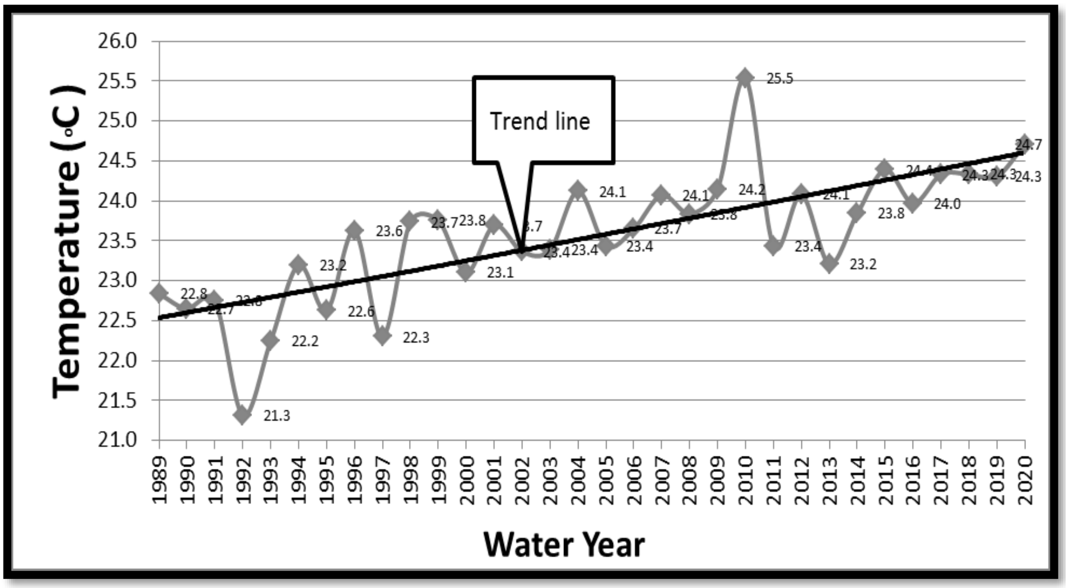


Figure 3: Classification of the water years based on the annual mean temperature (1989-2020).

3.3 Relative Humidity:

The percentage saturation of air with water vapor at 100% is known as relative humidity [9]. January has the most significant average RH% (69%) from 1989 to 2020, while June and July have the lowest mean monthly relative humidity (24%) (Table 1).

3.4 Sunshine duration:

The sunshine duration is the amount of time that direct solar energy is directed to the earth's surface [10]. One of the climatic elements that has considerably influenced the amount of water evaporated is the amount of sunshine. The maximum mean monthly sunshine duration is 11.56 hours/day in June, and the lowest is 5.84 hours/day in November, with a mean monthly of 9 hours/day (Table 1).

3.5 Wind speed:

Wind speed fluctuates from month to month, increasing between summer and spring and having an influence near the earth's surface. It increases in hot weather, evaporating more soil water [10]. The most significant monthly wind speed in July was 4.2 m/sec, while the lowest was 2.5 m/sec in November. The mean monthly speed is about 3.1 m/sec (Table 1). The analysis of wind direction data from the last thirty-two years (1989–2020) revealed that the general direction along the year is essentially N. NE to NW less, and the lowest order are S/SW and EE, SW/W.

3.6 Evaporation:

Evaporation is a characteristic that changes regularly and is influenced by several variables and physical causes [11]. Evaporation is affected by some elements, including solar radiation, wind speed, air temperature, and RH%. The total evaporation from the class (A) pan was 3169.61mm per year, with the highest mean monthly evaporation (522.97mm) in July and the lowest (74.63 mm) in December (Table 1). The evaporation started to increase after 1998 due to drought, which impacted water resources (Figure 4). Figure 5 depicts the varied relationships between all the climatic components. Temperature, evaporation, sunshine duration, and wind speed are inversely associated with rainfall. Wind speed is strongly associated with evaporation; as wind speed increases, so does the rate of evaporation, which has little effect on groundwater level fluctuations.

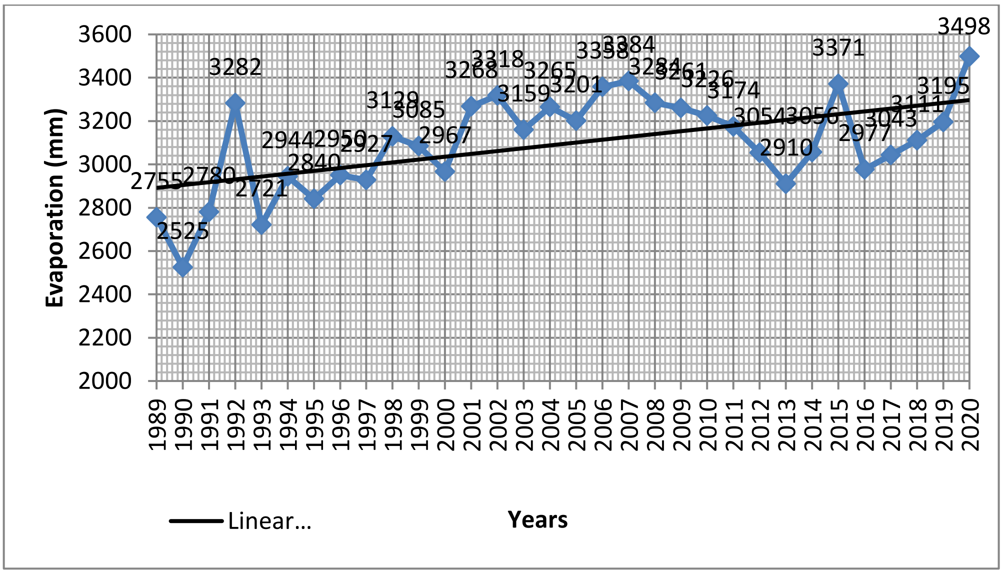


Figure 4: Classification of the water years based on the evaporation for the period (1989-2020).

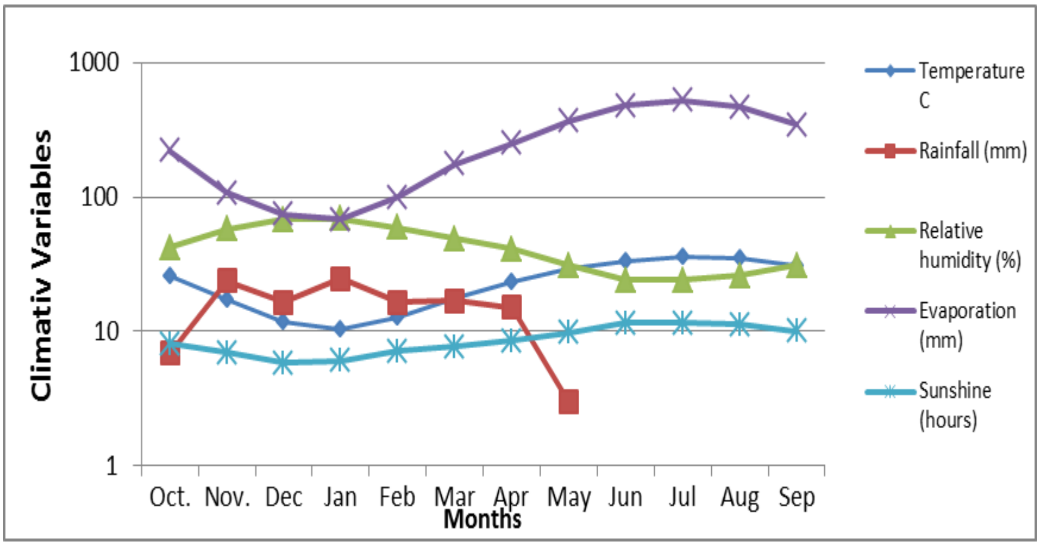


Figure 5: The link between climatic characteristics in the research region from 1989 to 2020. At Baghdad Airport and Al-Ramadi Meteorological Stations

5. Climate classification

A climate index (CI) value reflects a dry climate, and a positive value represents a humid climate [13]. Therefore, since the CI of the study area is equal to -89.176, so the climate type is arid (Table 2)

Table 2: Climate classification depending on Mather,1974 [13].

Climate type	Range of CI	CI on the study area
Dry-Sub Humid	0.0 to -33.3	
Semi-Arid	-33.3 to 66.6	
Arid	-66.6 to -100	-89.176

Determine the type of the climate and the aridity index by using the yearly dryness treatment depending on the amount of rainfall and temperature [14]. The value of type 1 = 0.452, and accordingly, the climate is classified as sub-arid to arid, while type 2 = 4.567 so that it is classified as a sub-arid climate (Table 3).

Table 3: Climate classification depending on Al-Kubaisi (2004) [14]

Type 1	Evaluation	Type 2	Evaluation
AI-1 >1.0	**Humid to moist**	**AI-2 > 4.5**	**Humid**
		2.0 < 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-2 < 1.5	**Sub arid**
AI-1 <1.0	**Sub arid to arid**	**AI-2 > 1.0**	**Sub arid**
		AI-2 < 1.0	**Arid**

6. Potential Evapotranspiration (PE)

The most significant factor in water balance is this variable. It's a computation that can be done in a variety of ways. In the lack of devices to assess PE, empirical equations are sufficient, and climatic conditions are the primary determinant. The most widely used formulas were produced by devising a connection for determining the crop's consumptive usage using the mean of daily temperatures, the zone's latitude, and the month of the year [10]. It is assumed that the mean temperature and other factors such as moisture, wind speed, and sunlight have a favorable relationship; they describe the link as follows [7]:

$$PE = 16\ (10\ t\ /\ J)^{a} \text{mm/month} \quad (1)$$

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

$$j = (t\ n\ /\ 5)^{1.514} \quad (3)$$

$$a = (675*10\text{-}9)\ J3\text{-}\ (771*10\text{-}7)\ J2 + (179*10\ \text{-}4)J + 0.492 \quad (4)$$

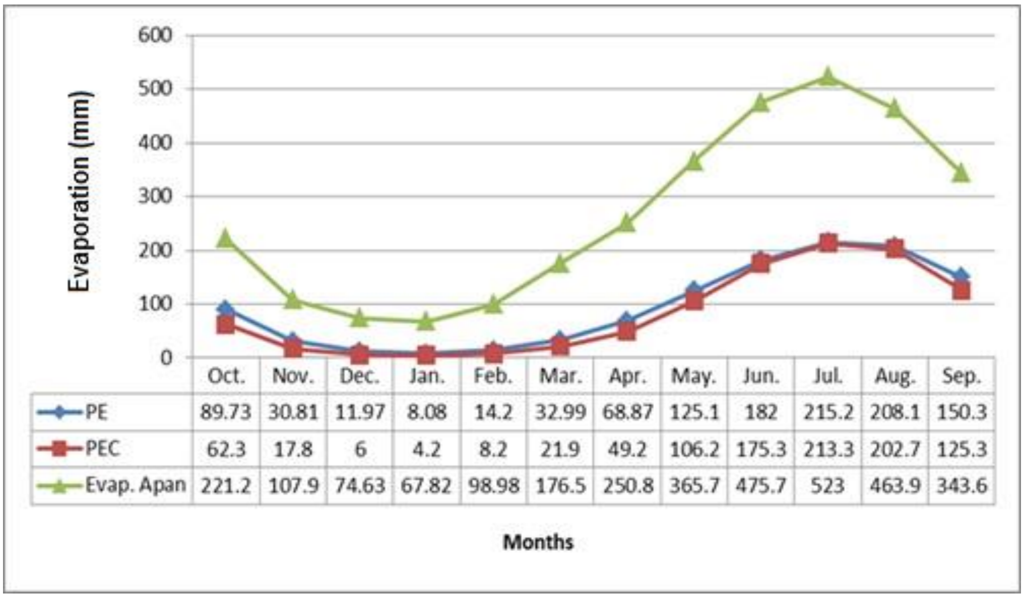
$$a = 0.016\ J + 0.5$$

PE = evapotranspiration potential for each month (mm/month).t = Mean monthly air temperature (°C). n = Countdown to the month, J = Annual heat index (°C). j = Temperature averaged throughout a month (°C)
a = Constant → a = 0.016 * J +0.5 = 2.63

However, it is a theoretical quantity because (PE) is a monthly estimate based on thirty days and twelve hours of sunshine each day. Wilson (1971)[7], proposed the following equation to determine the corrected potential evapotranspiration (PEC) (Table 4):

$$PE_{C} = PE*\ DT\ /360 \quad (5)$$

Where: PE_C : Corrected potential evapotranspiration (mm).
PE: potential evapotranspiration(mm). D: The month's total number of days. t: average No. of hours between sunrise and sunset in the month. As shown in (Table 4) and (Figure 6), monthly potential evapotranspiration varies from 8.08 to 215.16 mm, with an annual total of (1137.38) mm. In contrast, corrected evapotranspiration ranges from (4.2 to 213.3) mm, with an annual total of (992.3) mm.



	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.
PE	89.73	30.81	11.97	8.08	14.2	32.99	68.87	125.1	182	215.2	208.1	150.3
PEC	62.3	17.8	6	4.2	8.2	21.9	49.2	106.2	175.3	213.3	202.7	125.3
Evap. Apan	221.2	107.9	74.63	67.82	98.98	176.5	250.8	365.7	475.7	523	463.9	343.6

Figure 6: Evaporation, potential evapotranspiration (PE) and corrected potential evapotranspiration (PEc) correlation line graph at Baghdad Airport and Al-Ramadi Meteorological Station (1989-2020).

Table 4: Potential Evaporation transpiration values calculated using Thornth-Waite method 1989 to 2020.

Month	Mean Temp.°C	$j=(tn/5)^{1.514}$	PE(mm)	PE_C=PE *DT/360 (mm/month)	Evaporation Class(A) pan (mm)
Oct.	25.6	11.9	89.73	62.3	221.15
Nov.	17.05	6.4	30.81	17.8	107.93
Dec.	11.9	3.7	11.97	6.0	74.63
Jan.	10.25	3.0	8.08	4.2	67.82
Feb.	12.7	4.1	14.20	8.2	98.98
Mar.	17.5	6.7	32.99	21.9	176.45
Apr.	23.15	10.2	68.87	49.2	250.78
May.	29.05	14.4	125.12	106.2	365.73
Jun.	33.5	17.8	182.02	175.3	475.68
Jul.	35.7	19.6	215.16	213.3	522.97
Aug.	35.25	19.2	208.10	202.7	463.93
Sep.	31.15	16.0	150.33	125.3	343.56
Total		J=132.9	1137.38	992.3	3169.61

7. Water Balance

Water balance is one of the most important roles in understanding a specific area's water system. The constituents of water balance include rainfall, evapotranspiration, and groundwater recharge [12]. Calculate the study region's water balance based on the methodology of [16].

7.1 Water Surplus (WS):

$$PEC=PE \qquad \text{When } P \geq PEC \tag{9}$$

$$WS = P - PEC \tag{10}$$

Where:

PE_C = corrected potential evapotranspiration
P = Rain fall (mm)
PE = potential evapotranspiration
WS= Total water surplus

The results of utilizing this method with the evapotranspiration data in Table 5, which were previously obtained using the Thornthwaite method, show that water surplus is recognized in four months: November, December, January, and February, with an annual value of (45.2 mm). The water surplus as a percentage of rainfall is discovered to be:

WS% = (45.2/123.1) ×100= 36.7 %, and WD % = 63.3%.

7.2 Water Deficit (WD) :

A water deficit occurs when the amount of corrected prospective evapotranspiration values exceeds the amount of rainfall for the rest of the year. However, in this situation, it is equal to the rainfall values written as follows:

$$WD = PEC - P; \text{ when } P < PEC \text{ where } P = PE \tag{11}$$

The months of March to October are considered a water deficit period, with an annual value of (869.2mm) when applying this calculation (Table 5). Figure (7) depicts the (WS) and (WD) periods by plotting the connection between mean monthly rainfall (P) and corrected evapotranspiration (PEC).

Table 5: The mean monthly water surplus and deficit for the study area

Month	P (mm)	PEc (mm)	WS(mm)	WD(mm)
Oct.	**6.9**	**62.3**	**0**	**55.4**
Nov.	**23.8**	**17.8**	**6**	**0**
Dec.	**16.4**	**6.0**	**10.4**	**0**
Jan.	**24.7**	**4.2**	**20.5**	**0**
Feb.	**16.5**	**8.2**	**8.3**	**0**
Mar.	**16.8**	**21.9**	**0**	**5.1**
Apr.	**15**	**49.2**	**0**	**34.2**
May	**3**	**106.2**	**0**	**103.2**
Jun.	**0.0**	**175.3**	**0**	**175.3**
Jul.	**0.0**	**213.3**	**0**	**213.3**
Aug.	**0.0**	**202.7**	**0**	**202.7**
Sep.	**0.1**	**125.3**	**0**	**125.2**
Total	**123.1**	**992.3**	**45.2**	**869.2**

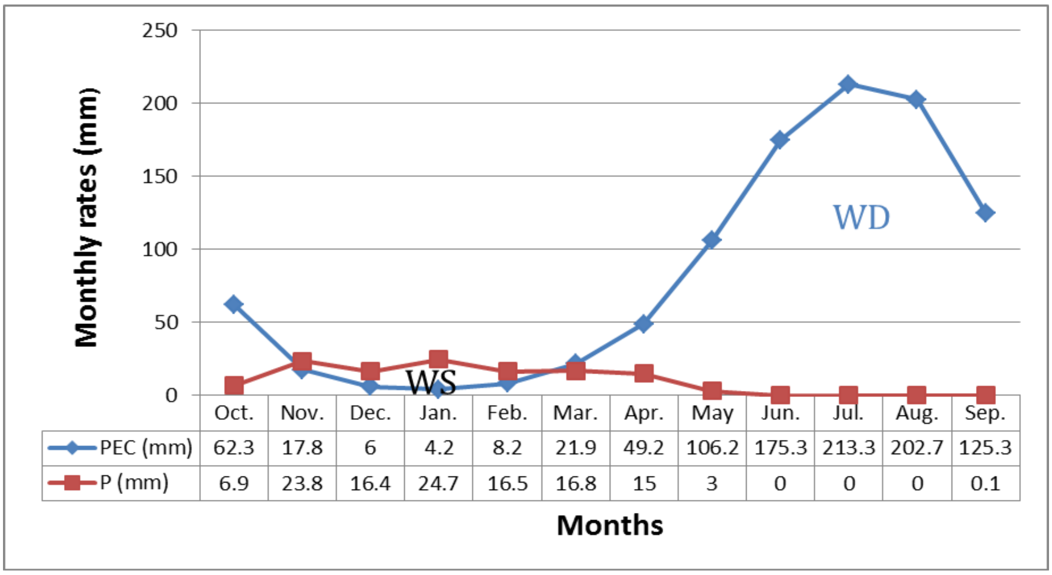


Figure 7: Relationship between mean monthly rainfall and PEc shows water surplus and water deficit.

8. Soil Conservation Service (SCS):

The SCS-CN methodology is one of the most widely used methods for calculating runoff volume after precipitation. It's popular because it's straightforward, easy to comprehend and use, and it accounts for the bulk of runoff-producing watershed characteristics such as soil type, land use, hydrologic condition, and antecedent moisture condition. The approach has received much attention in the hydrologic literature in recent years. The Natural Resources Conservation Service (NRCS) of the US Department of Agriculture came up with the curve-number model [17]. It is the most comprehensive approach for determining rainfall surplus based on the formula:

$$Q = (P - Ia)2/(p + Ia) + S \qquad P > 0.25 \tag{11}$$

Where: (Q): Runoff (mm). (P) Total rainfall (mm).

(S) maximum potential retention after a runoff (mm). (Ia) = initial abstraction (mm). (Ia) was found to be approximated by the following empirical equation:

$$Ia = 0.2\ S \qquad (12)$$

CN was calculated using Tables 6 and 7, which were given by [17]. CN was estimated using the following formula:

$$CN = R1CN1 + R2CN2 + \text{-----} + Rn\ CNn \ / \ R1+R2+\text{----} +Rn \qquad (14)$$

Where:

R1 + ----- + Rn are the areas of various urban land use

CN1,----, CNn is the curve numbers

Because the soils in the research region are made mostly of sand, the soil type is class A. As indicated in Table 8, the CN for this soil condition is equivalent to 62, according to formula (14). The amount of Rs was low, implying that the soils have little runoff potential and high infiltration rates even when entirely saturated (Table 9). As a result, the total WS represents groundwater recharges based on the data gathered using this approach.

Table 6: HSG classification based on the fresh surface soil texture [17]

HGS	Soil Texture
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Table 7: CN for a variety of land uses in urban areas [17]

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% to 75%)	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 or less (town houses)	77	85	90	92
1/4 acre	61	75	83	87
1/3 acre	57	72	81	86
1/2 acre	54	70	80	85
1 acre	51	68	79	84
2 acres	46	65	77	82

Table 8: A CN for various urban land uses for the study area

Cover type and hydrologic condition	Area Km^2	CN	CN*Area
Natural desert landscaping	210	63	13230
Fair conditions: grass cover on 50% to 75% of the area	122	49	5978
Poor conditions: grass cover on 50% or less of the area	180	68	12240
Urban area	12	77	924
Total	524		32372
CN			62

Table 9: Surface runoff values in the research region on a monthly basis

Month	P(mm)	WS(mm)	CN	S	P>0.2S	RS (mm)
Oct.	**6.9**	**0**	62	0		0
Nov.	**23.8**	**6**		163	No	0
Dec.	**16.4**	**10.4**		163	No	0
Jan.	**24.7**	**20.5**		163	No	0
Feb.	**16.5**	**8.3**		163	No	0
Mar.	**16.8**	**0**		0		0
Apr.	**15**	**0**		0		0
May.	**3**	**0**		0		0
Jun.	**0.0**	**0**		0		0
Jul.	**0.0**	**0**		0		0
Aug.	**0.0**	**0**		0		0
Sep.	**0.1**	**0**		0		0
Total	**123.1**	**45.2**				0

The soil moisture assumption may be discarded in calculations (soil moisture is assumed to be zero) since the soil is sandy and relatively thin, and the value of groundwater recharge in the research area can be calculated using the equation:

$$WS = Rs + Re \tag{15}$$

Where:

Rs: Surface runoff (mm). Re: Groundwater recharges (mm).

The quantity of rainfall is seen to be minimal. According to the Baghdad Airport and Al-Ramadi meteorological station data (1989–2020), surface runoff will not be present in the study area due to the soil type.

$Re = 45.2 – 0$, $Re = 45.2$ (mm).

$Re\% = (45.2/123.1) *100 = 36.7\%$, which reflects the proportion of total rainfall that recharges the groundwater. The following calculation can be used to compute the value of groundwater recharge in the research region throughout a water year:

$$Re\ annual = A*Re \tag{16}$$

Where (A) Area of study (524) Km^2

$Re\ annual = 524 * 10^6\ m^2 * 45.2 *10^{-3}\ m$

$Re\ annual = 23.6848* 10^5\ m^3/year$

Conclusions:

- From total rainfall, WS has a total yearly value of 45.2 mm. The WS ratio is 36.7% based on annual precipitation, whereas the WD ratio is 63.3%, which is a clear indicator of the water scarcity in groundwater recharge from rainfall.
- In the research region, the value of groundwater recharge throughout a year is about equivalent to 23.6848* 10^5 m^3/year.

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