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# Climatic Water Balance and Groundwater Recharge in Abu-Jir Village, Al-Anbar Governorate, Western Iraq

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**Abstract**

The study area is located in Al-Anbar Governorate, western Iraq. The climatic data were collected from Al-Ramadi Meteorological Station for the period 1990 to 2020 and used to assess the climatic condition of the study area. The total annual rainfall, relative humidity, monthly average temperature, evaporation, wind speed and sunshine duration are 108 mm, 52.7 %, 22.6˚C, 2814.3 mm, 2.2 m/s and 8.8 h/day, respectively. The climate of the study area is described as an arid to sub arid and relatively hot in summer and cold with low rain in winter. During the data used, the highest potential evapotranspiration was 217.1 mm in July, while the lowest value was 10.7 mm in January, with a total amount of 1170.07 mm. The highest and lowest corrected evapotranspiration becomes 264.2 mm in July and 9.4 mm in January, with 1310.3 mm. water Surplus (WS) is 2.1mm, 10.71mm, and 5.65mm in December, January and February, respectively. The WS was 18.46mm, forming 17.09 % of the total annual rainfall. The groundwater recharge (18.46 mm) with a rate of 17.09% represents the recharge from the total rainfall zero surface runoff. It has been found that the low amount of rain and sandy soil are among the most important factors causing the absence of surface runoff.

**Keywords:** Classification of climate; Water balance; Potential evapotranspiration; water surplus. water deficit

# الموازنة المائية المناخية والتغذية للمياه الجوفية في منطقة ابو الجير في محافظة الانبار –غربي العراق

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**الخلاصة**

تقع منطقة الدراسة في محافظة الانبار غربي العراق. جمعت البيانات المناخية من محطة الرمادي للأرصاد الجوية للفترة 1990 – 2020 ، واستخدمت في تقييم الحالة المناخية لمنطقة الدراسة. إجمالي هطول الأمطار السنوي والرطوبة النسبية والمتوسط الشهري لدرجة الحرارة والتبخر وسرعة الرياح ومدة سطوع الشمس هي (108) ملم ، (52.7) ٪ ، (22.6) درجة مئوية ، (2814.3) ملم ، (2.2) م / ث و (8.8). ) ساعة / يوم على التوالي. يوصف مناخ منطقة الدراسة بأنه جاف إلى شبه جاف وحار نسبيًا في الصيف ، وباردًا مع

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انخفاض هطول الأمطار في الشتاء. خلال فترة المقارنة التي دامت 30 عامًا ، كانت أعلى قيمة تبخر نتح محتملة 217.1 ملم في شهر يوليو ، بينما كانت أدنى قيمة 10.7 ملم في يناير ، بينما كانت الكمية الإجمالية 1170.07 ملم. وكذلك كانت أعلى قيمة للتبخر النتح المصحح 264.2 ملم في يوليو بينما أدنى قيمة كانت 9.4 ملم في يناير والكمية الإجمالية 1310.3 ملم. الفائض المائي في منطقة الدراسة (2.1 ملم) ، (10.71 ملم) ، (5.65 ملم) في كانون الاول وكانون الثاني وشباط على التوالي. بلغ الفائض المائي 18.46 ملم أي حوالي 17.09٪ من إجمالي هطول الأمطار السنوي. تمثل قيمة التغذية الجوفية (18.46 ملم) بنسبة (17.09٪) تمثل النسبة المئوية لتغذية المياه الجوفية من إجمالي هطول الأمطار عندما تكون قيم الجريان السطحي في منطقة الدراسة صفرًا ، وذلك من أهم العوامل المسببة لغياب المياه الجوفية. الجريان السطحي هو كمية الأمطار المنخفضة وكذلك نوع التربة الرملية

## Introduction

Iraq's climate is hot, dry in summers and rainy-cold in winters. Almost 90% of the yearly rainfall occurs from November to April. Temperature ranges from 53°C in July and August to below freezing in January. Water resource systems must be managed to cope with climate change variability. Because of the expected fluctuations in temperature and precipitation, there is a considerable need for emergency plan practices to manage water resources in an emergency [1]. Water resources systems have traditionally been designed to assume that the statistical characteristics of hydro-meteorological processes are almost predictable annually and over time. It is critical to consider that all these parameters are expected to change in lockstep with the changing climate [2]. Climate change is one of the most important environmental issues to be studied and evaluated because of its significant impact on several factors such as water, agriculture, marine resources and others. Climate is an important environmental factor since it influences by other factors including water quality, weathering and erosion, transportation, sedimentation, and the relationship between geochemical variables and living organisms [3]. Rainfall events come in various types and sizes depending on latitude, temperature, terrain, and meteorological conditions [4]. Water scarcity afflicts a significant portion of the developing globe. The climate significantly impacts groundwater quality and changes in its levels [5]. The increased rainfall participates in recharging groundwater leading to improve quality [6], whilst, drought intensification, increased flood risk. Water scarcity and insecurity afflict a major portion of the developing globe. The most important climate elements are latitude, height, terrain, proximity to significant water bodies, and atmospheric circulation [7]. The Abu- Jir Village has located 50 km to the west of Ramadi in the Western Desert of Iraq between latitudes 33º.5′15″ -33°28′ 0″N and longitudes 42°.38′30″ - 42°.59′15″ E (Figure 1).

This study aims to determine climatic water balance by analyzing the climatic parameters of Al-Ramadi Meteorological Station from 1990 to 2020 and groundwater recharge from the total rainfall. Several studies on climate in Al-Anbar, such as [8] and [9] were published.

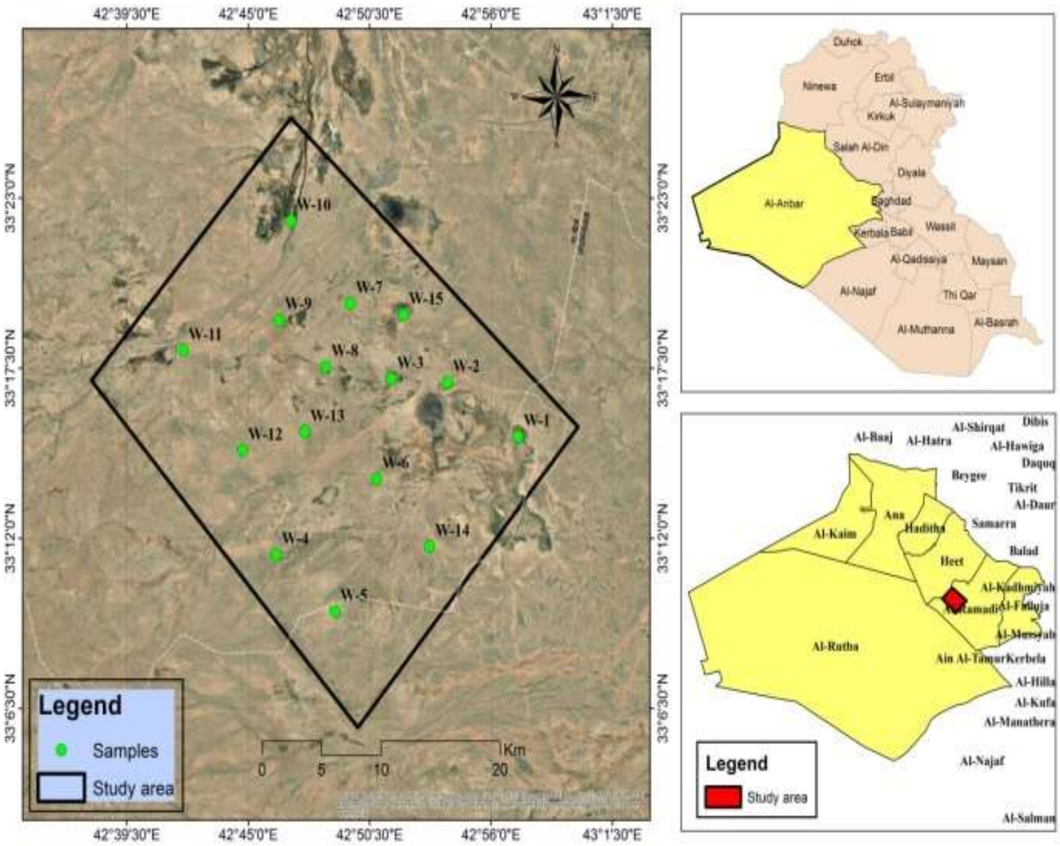


**Figure 1:** Location map of the study area.

## Materials and Methods

The meteorological data were collected from the Iraqi Meteorological Organization based on Ramadi meteorological station from 1990 to 2020. The evapotranspiration was monthly calculated by using the [10] Two methods were used to determine the prevailing climate type,[11] [12],and [13] was used to compute the water balance. The six climate elements are temperature, rainfall, evaporation, sunshine duration, wind speed and relative humidity. The average monthly values for each parameter were measured for the studied period. The soil conservation service method (SCS) used the runoff curve number (CN) method to estimate runoff from storm rainfall. Later the value of groundwater recharge was also calculated.

**Results and Discussion**

**Table 1:** Mean monthly records of climatic elements at Al-Ramadi meteorological m station for the period (1990-2020) Rainfalls (p) 1.

| Month | Rainfalls )mm( | Relative Humidity (%) | Temperature )C°( | Evaporation )mm( | Wind Speed )m/s( | Sunshine Duration )h/day( |
|---|---|---|---|---|---|---|
| **Oct.** | 6.1 | 52.1 | 24.7 | 209.4 | 1.8 | **8.4** |
| **Nov.** | 14.5 | 67.3 | 16 | 117.8 | 1.8 | **6.5** |
| **Dec.** | 14.1 | 75.8 | 10.8 | 73.8 | 1.8 | **5.4** |
| **Jan.** | 20.2 | 78 | 9.7 | 61.2 | 1.9 | **5.7** |
| **Fab.** | 20 | 67.2 | 11.8 | 91.7 | 2.2 | **7.4** |
| **Mar.** | 14.1 | 55.2 | 16.2 | 157.2 | 2.4 | **8.1** |
| **Apr.** | 15 | 50.1 | 22.6 | 203.2 | 2.5 | **8.8** |
| **May.** | 3.7 | 42.2 | 28.1 | 292.6 | 2.5 | **9.4** |
| **Jun.** | 0 | 34.1 | 32.7 | 385.4 | 2.7 | **11.9** |
| **Jul.** | 0 | 33.2 | 35 | 451.8 | 2.7 | **12** |
| **Aug.** | 0 | 35.9 | 34.1 | 433.2 | 2.2 | **11.6** |
| **Sept** | 0.3 | 41.5 | 29.9 | 337.3 | 1.9 | **10.6** |
| **Total** | 108 | …….. | …….. | 2814.3 | ……. | **…….** |
| **Average** | ……… | 52.7 | 22.6 | ……… | 2.2 | **8.8** |

A significant water supply for many parts of the world is distinguished by its intensity, quantity, and distribution over time [14]. The precipitation includes snow, rain, hail, drizzle, fog, mist, and sleet; and varies naturally in time and space [15]. The total annual average of rainfall recorded by the Ramadi station is 108.2mm; the average monthly precipitation ranges from 0.3 mm in September to 20.2 mm in January, concentrated in October to May, while it is dry from June to June September (2).

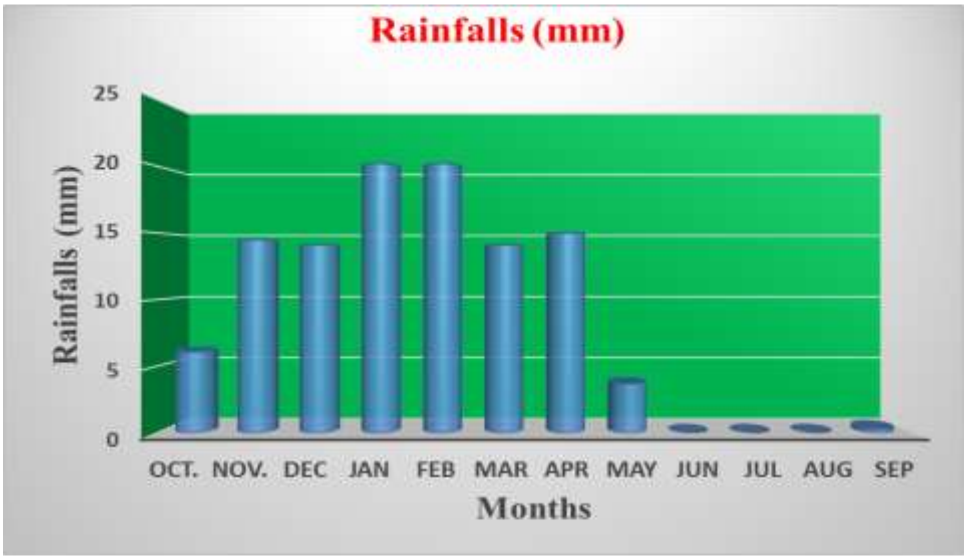


**Figure 2:** The mean monthly rainfall for the period 1990-2020 in the Ramadi meteorological station Relative Humidity (RH%) 2.

The ratio of the actual water vapour pressure in the air to saturated vapour pressure at the same temperature is relative humidity [16]. It is related to precipitation and temperature, as it rises in winter due to higher rainfall and lower temperatures but decreases in summer due to lower precipitation and higher temperature [17]. In the study area, the maximum monthly mean was 78% in January, and the minimum was 33.2% in July, while the average relative humidity was 52.7% (Figure 3).

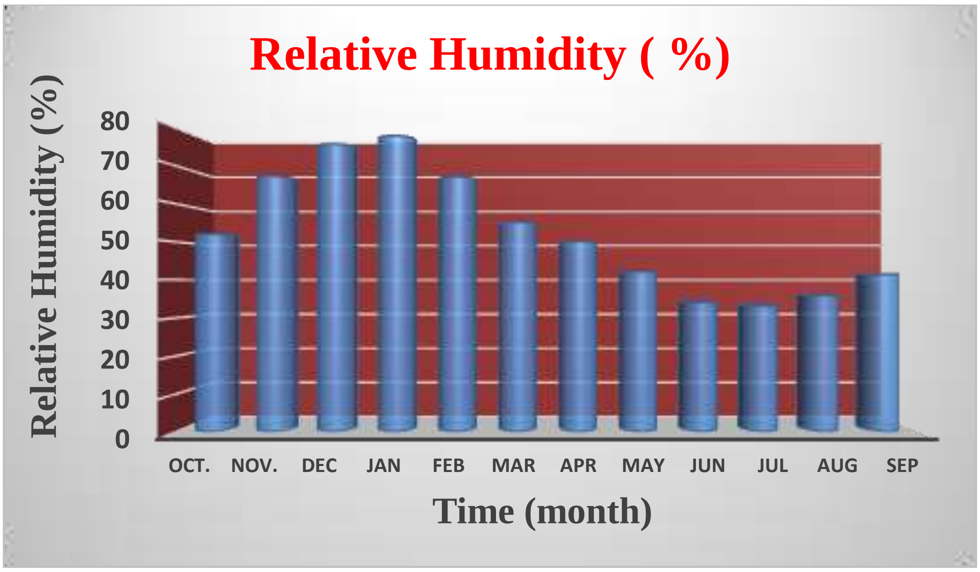


**Figure 3:** The mean monthly relative humidity for the period (1990-2020) for Ramadi meteorological station Temperature (T) 3.

Temperature is an essential component of climate, playing a significant role in rainfall, pressure, and evaporation [18]. It influences rainfall, which affects evaporation and evapotranspiration, resulting in an increase that has a detrimental impact on groundwater recharge sources. The maximum mean monthly temperature is 35 °C in July, and the minimum is 9.7 C in January. The mean annual mean temperature is 22.6 C° as shown in Figure 4.

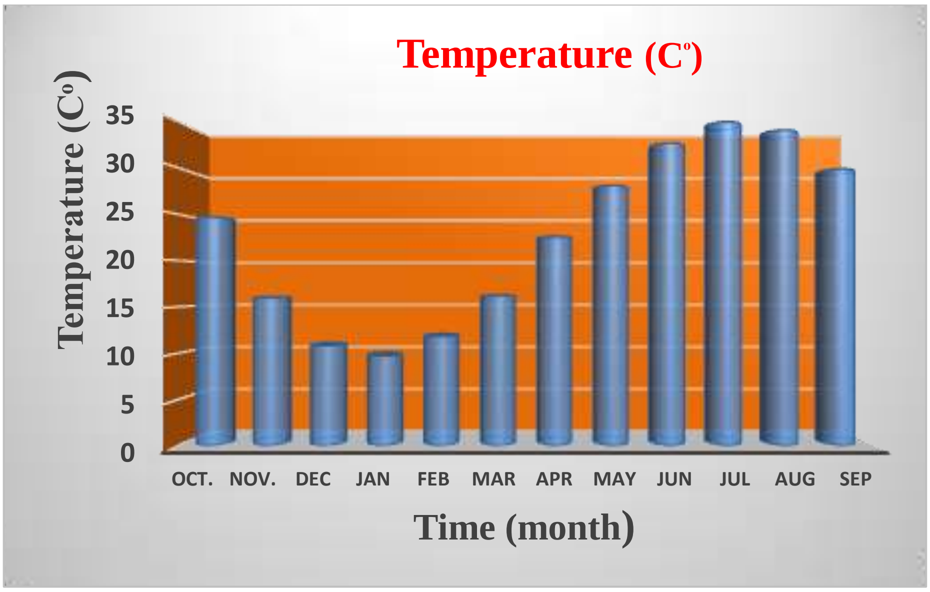


**Figure 4:** The mean monthly temperature for the period (1990-2020) for Ramadi meteorological station Wind Speed 4.

In dry and semi-arid locations, the wind is one of the most important elements of erosion that has a permanent effect on geomorphology. Evaporation is influenced by the wind, which is a climatic factor. Climatologists are primarily concerned with wind speed and direction.

In the study area, the mean monthly wind speed values vary from 1.8 to 2.7 m/sec. Minimum values were recorded in October, November and December, while the maximum values were in June and July. The mean annual wind speed is 2.2 m/sec (Figure 5).


**Figure 5:** The mean monthly wind speed from Ramadi meteorological station for the period 1990-2020 Sunshine duration **5.**

Sunshine duration means the number of hours of sunshine in a day. It is thought to be the most critical component influencing the evaporation process. The sunshine time in a certain location impacts its temperature.

In the study area, maximum sunshine duration occurs in July with a mean monthly of (12) h/day while the minimum monthly average is 5.4 h/day occurs during December, and the mean annual is 8.8 h/day (Figure 6).

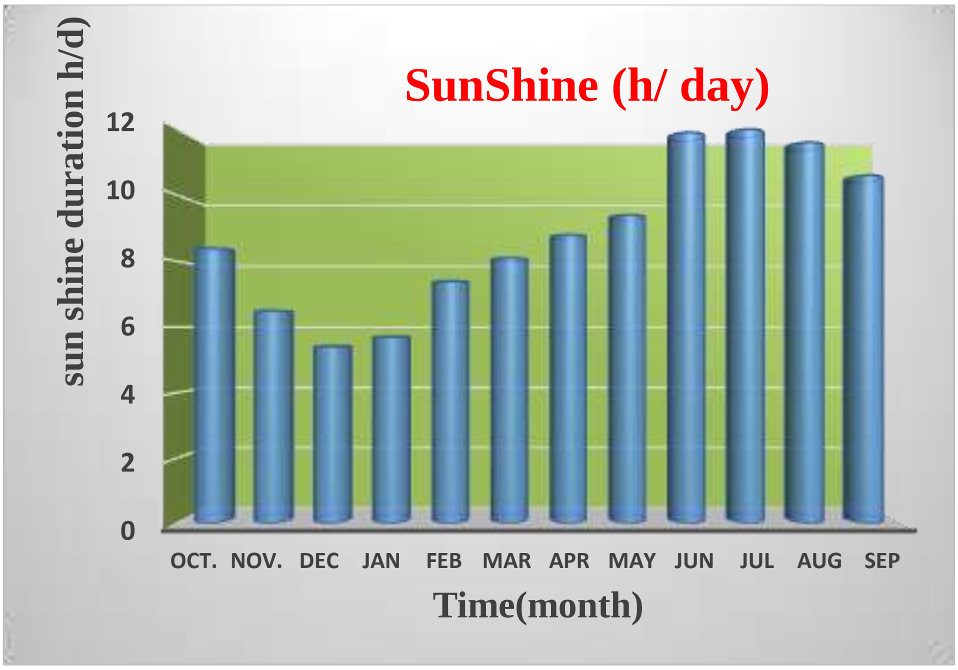


**Figure 6:** The mean monthly sunshine duration for Ramadi meteorological station for the period 1990-2020

**6. Evaporation**

Evaporation (E) is a crucial component of water balance and hydrogeology. Water is transferred from a liquid to a gaseous state [19]. A free water surface evaporates, such as lakes, rivers, soils, and moist vegetation. Evaporation is influenced by several factors, including relative humidity, air temperature, wind speed, and solar radiation. The minimum mean monthly evaporation is 61.2 mm in January, while the maximum monthly is 451.8 mm in July. The mean annual evaporation is 2814.3 mm (Figure 7).

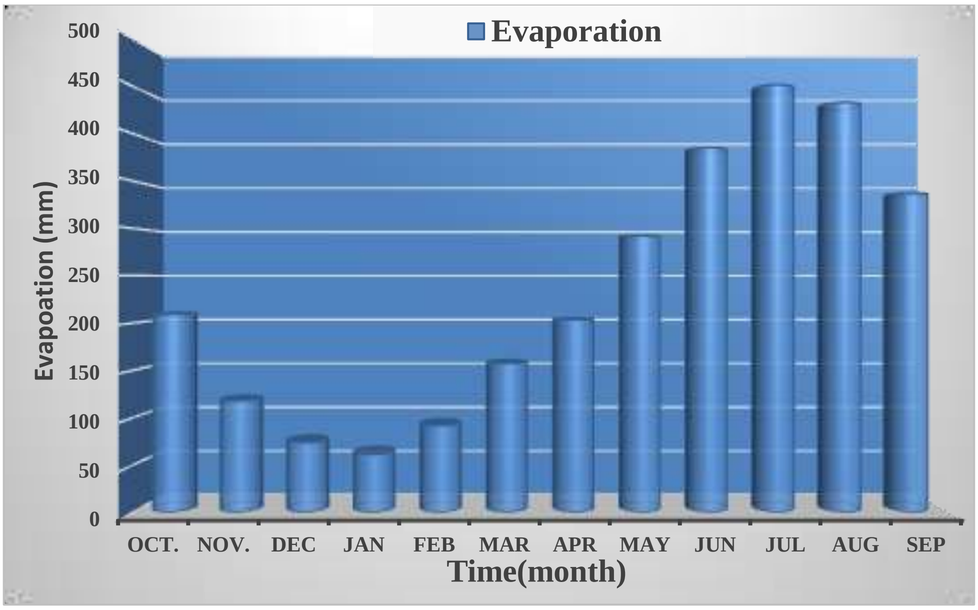


**Figure 7:** The mean monthly evaporation for Ramadi meteorological station for the period 1990-2020

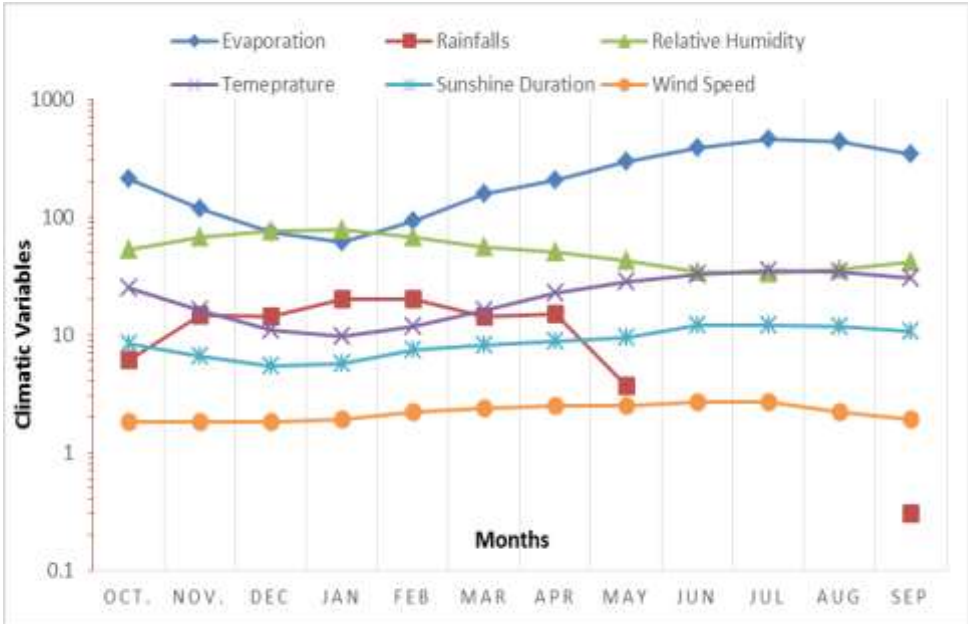


**Figure 8:** Relation between the climate elements in the study area for the period (1990-2020).

**Classification of climate**

According to Al-Kubaisi [11], the climatic data of the study area for the period 1980–2020 was classified as arid, sub-arid, humid, and moist using Al-1 and Al-2 (equations 1&2).

$$Al\ -1= (1.0 *P)/(11.525 * t) \quad ..............................(1)$$

AI: aridity index, P: Total rainfall (mm) , t: average temperature (ºC) ...$t \neq 0$
Al -1=(1×108) / (11.525× 22.6) = 0.41

$$AI\text{-}2= 2*\sqrt{p/t} \quad ........................(2)$$

Al -2= 2 *√ 108 / 22.6 =0.91
According to the total rainfall and average temperature of the study area, AI-1 is 0.41 and AI-2 is 0.91.
The climate of the study area was classified as sub arid to arid for both modes 1 and 2

**Table 2:** Climate classification according to [11]

| 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≤ Al-2<2.5 | Moist |
| | | 1.5≤ Al-2< 1.5 | Moist to sub arid |
| AI- 1<1.0 | Sub arid To arid | 1.0 < Al -2< 1.5 | sub arid |
| | | Al -2 < 1.0 | Arid |

according to Mather [12]. This is determined by the Aridity Index (AI), the ratio of rainfall to evapotranspiration (equation 3). The results are shown in Table 3. The Aridity index is given as follows:

$$AI= \{(P/PEc) -1\}*100 \quad ........................ (3$$

Where:
AI = Aridity Index AI on Studied area
P = rainfall (mm
PEc = Corrected evapotranspiration (mm)
The values of the aridity index (AI) becomes as follows
AI = {(108/1310.2) -1}*100 = - 91.75

**Table 3**: Climate classification according to (Mather, 1974)

| Climate type | Range of Al | AI on Study area |
|---|---|---|
| dry –sub humid | 0.0 to -33.3 | -91.75 |
| semi –arid | -33.3 to -66.6 | |
| arid | -66.6 to -100 | |

Depending on the classification suggested by Mather, 1974. The aridity index is **-91.75,** so the study area is an arid region.

## Evapotranspiration

The evapotranspiration was measured every month using Thornthwaite's (1948) equation [10].

Where:
PE: Potential evapotranspiration for each month (mm / month
J: Annual heat index $(C^{\circ})$
t: Mean monthly air temperature, a: Constant

J =∑_(j=1 )^12j(for the 12 month) …………………..(4)

j = [tn / 5]1.514 (for each month) …………………(5)

where:
j: Monthly temperature parameter $(C^{\circ})$, n: Number of monthly measurement.

a =0.016 J+0.5 …………………. (6)

Correct evapotranspiration (PEc) values can be determined from the actual evapotranspiration (PE) are extracted

PEc = k*PE .. ………………… (7)

K= DT/360 ……………………(8)

Where:
PEc: Correct evapotranspiration (mm)
K: Correction coefficient for hours during the month between sunrise and sunse**t**

**Table 4:** Mean monthly evapotranspiration values by using the [10] for the period (1990-2020)

| Month | Temperature $(C^{\circ})$ | j | PE (mm) | K | PEc (mm) |
|---|---|---|---|---|---|
| Oct. | 24.7 | 11.2 | 95.8 | 0.98 | **94.2** |
| | 16 | 5.8 | 34.8 | 0.87 | **30.5** |
| Dec. | 10.7 | 3.2 | 13.9 | 0.86 | **12** |
| | 9.7 | 2.7 | 10.7 | 0.88 | **9.4** |
| Fab. | 11.8 | 3.6 | 17 | 0.85 | **14.5** |
| | 16.2 | 5.9 | 35.6 | 1.03 | **36.8** |
| Apr. | 22.6 | 9.8 | 77.9 | 1.08 | **84.5** |
| | 28.1 | 13.6 | 129.4 | 1.19 | **154.6** |
| Jun. | 32.7 | 17.1 | 184.1 | 1.19 | **219.4** |
| | 35 | 19 | 217.1 | 1.21 | **264.2** |
| Aug. | 34.1 | 18.2 | 203.1 | 1.15 | **234.4** |
| | 29.9 | 15 | 135.8 | 1.03 | **155.4** |
| Total | | J=125.5 | 1170.07 | | **1310.3** |

The maximum potential evapotranspiration value was 217.1 mm in July, while the lowest potential evapotranspiration value was 10.7 mm in January, resulting in 1170.07 mm. The total amount was 1310.3 mm, with the highest corrected evapotranspiration value of 264.2 mm in July and the lowest corrected evapotranspiration value of 9.4 mm in January. The relationship between corrected evaporation, potential evaporation, and evapotranspiration over the period (1990-2020) is shown in Figure 9**.**

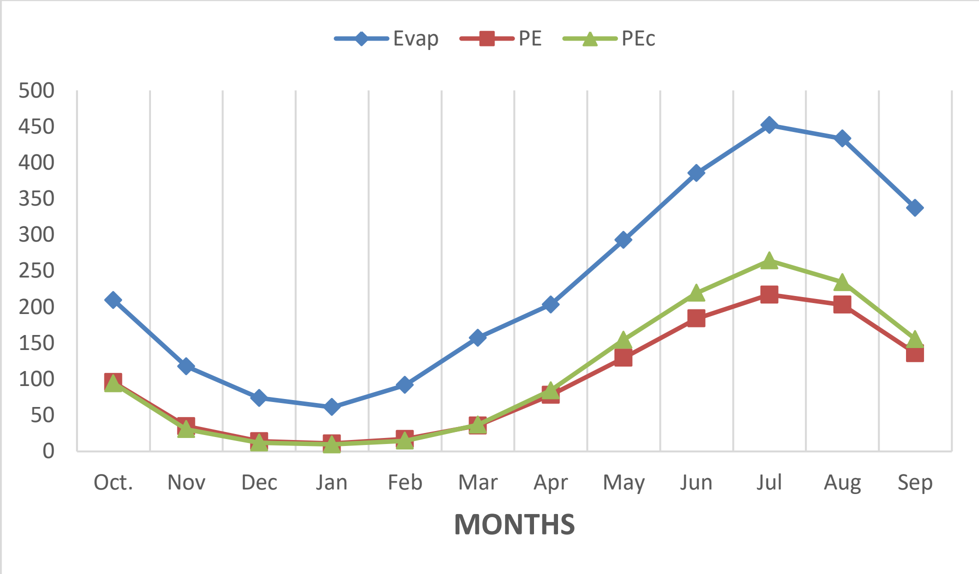


**Figure 9:** Relationship between evaporation, potential and corrected evapotranspiration for the period (1990-2020).

**Water Balance**

used the Lerner et al. (1990) method to compute the water balance of the study area.

**Water Surplus (WS)**

$$WS = P - PEc \qquad \ldots\ldots 9$$

PEc = APE, when P > PEc

Where (WS) Water Surplus (mm). (P) Rainfall (mm). (PEc) Corrected evapotranspiration (mm). (APE) Actual Evapotranspiration (mm).

• **Water Deficit (WD)**

$$WD = PEc - P \qquad \ldots\ldots 10$$

P = APE, when P < PEc.

Where (WD) Water Deficit (mm).

The total annual value of WS was 18.46 mm from total rainfall, which was recorded in December, January and February due to the rainfall exceeding PEc. The WS ratio from the yearly rainfall can be represented as:

$$WS\ \% = WS/P \times 100 \qquad \ldots\ldots 11$$

WS % = 18,46 /108 ×100 = 17.09%

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

$$WD\ \% = 100 - WS\ \% \qquad \ldots\ldots 12$$

WD % = 100 – 17,09 = 82.91%

Table 5 shows the monthly averages of APE, WS and WD and Figure 4 shows the relationship between the mean monthly rainfall (P) and corrected evapotranspiration (PEc), which shows the water surplus (WS) and water deficit (WD) periods.

**Table 5:** The monthly averages of water surplus and water deficit in the study area

| Month | P (mm) | PEc (mm) | APE (mm) | WS (mm) | WD (mm) |
|---|---|---|---|---|---|
| Oct | 6.1 | 94.2 | 6.1 | 0 | **88.1** |
| | 14.5 | 30.57 | 14.5 | 0 | **16.07** |
| Dec. | 14.1 | 12 | 12 | 2.1 | **0** |
| | 20.2 | 9.49 | 9.49 | 10.71 | **0** |
| Fab. | 20.2 | 14.55 | 14.55 | 5.65 | **0** |
| | 14.1 | 36.82 | 14.1 | 0 | **22.72** |
| Apr. | 15 | 84.5 | 15 | 0 | **69.5** |
| | 3.7 | 154.6 | 3.7 | 0 | **150.9** |
| Jun. | 0 | 219.42 | 0 | 0 | **219.42** |
| | 0 | 264.2 | 0 | 0 | **264.2** |
| Aug. | 0 | 234.42 | 0 | 0 | **234.42** |
| | 0.3 | 155.42 | 0.3 | 0 | **155.12** |
| Total | 108 | 1310.17 | | 18.46 | **1220.45** |

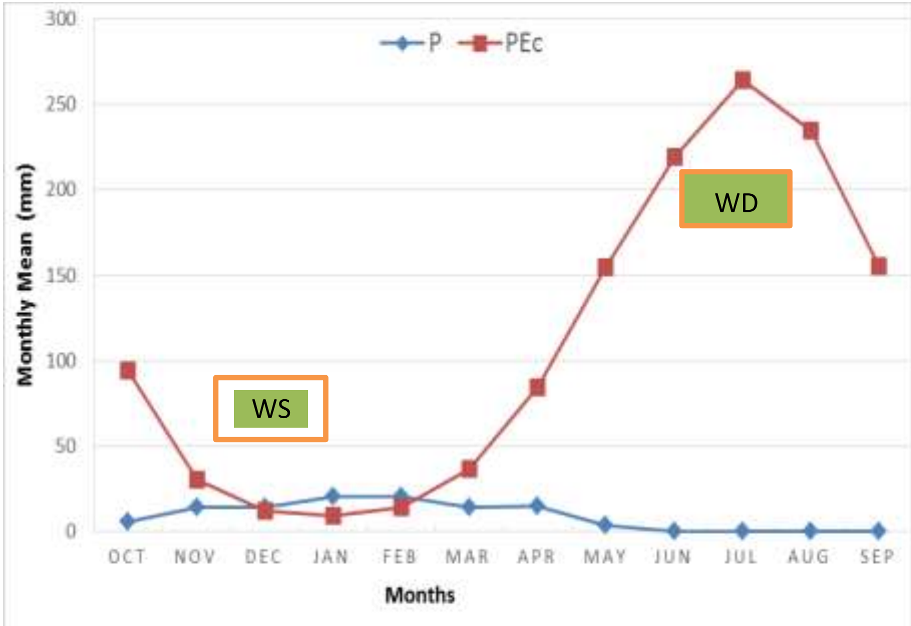


**Figure 10:** show the relationship between the mean monthly rainfalls (P) and corrected evapotranspiration (PEc), showing water surplus (WS) and water deficit (WD) for period

The result of Ramadi station was compared with Karbala due to the locations (Table 6).

**Table 6:** Monthly Average of climate elements for Karbala meteorological station for the period 1982-2015 [20]

| climate elements | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RH% | 3.8 | 10.4 | 15.1 | 16.3 | 13.4 | 14.5 | 12.1 | 3.1 | 0 | 0 | 0 | 0.3 | 89∑ |
| Monthly Rainfall(mm) | 46 | 62 | 72 | 74 | 61.2 | 55.1 | 43 | 34 | 30 | 29 | 32 | 36 | 47.9 |
| MeanTemp.c° | 26.6 | 17.1 | 12.5 | 10.4 | 12.3 | 18 | 24 | 30.6 | 34.3 | 36.3 | 35.4 | 31.3 | 24.1 |
| Monthly Evaporation (mm) | 206 | 107 | 65.4 | 64 | 98 | 175 | 251 | 348 | 452 | 472 | 426 | 319 | ∑2984 |
| Monthly Sun day/ h / shine | 8.2 | 7.2 | 6.3 | 6.2 | 7.2 | 8 | 8,4 | 9.4 | 11.2 | 11.8 | 11.1 | 10.2 | 8.8 |
| Wind speed s/m | 2.2 | 2.1 | 2 | 2.3 | 3.1 | 3.1 | 3.2 | 3.2 | 4.1 | 4.3 | 3.4 | 2.5 | 3 |

**Soil Conservation Service Method (SCS)**

The SCS uses the runoff curve number (CN) approach to measure runoff from storm rainfall., (CN) can be calculated depending on cover conditions and watersheds soil. This model represents hydrologic soil group, cover type, vegetation type and hydrologic condition. By United States' Natural Resources Conservation Service (NRCS), the curve-number model was developed by the Department of Agriculture. The most common method for estimating runoff.

Where:

$$Rs = \frac{(P - Ia)2}{(P + Ia) + S} \quad P > 0.2\ S \qquad \text{……………………………(13)}$$

Runoff (mm), P: Total rainfall (mm) United States' Natural Resources Conservation Service (NRCS). The Department of Agriculture developed the curve-number model. The most common method for estimating runoff is to utilize the calculation below.

S: maximum potential retention after runoff (mm). Ia = initial abstraction (mm).

Ia can be an approximated by the following empirical equation:

$$Ia = 0.2\ S \qquad \text{……………………………(14)}$$

By Compensation value Ia, the equation becomes as follows:

$$Rs = \frac{(\mathbf{P - 0.2\ S})\mathbf{2}}{(\mathbf{P + 0.8\ S})} P > 0.2\ S \qquad \text{…………………………..(15)}$$

S : related to soil and cover condition, of the watershed during CN,

where CN represents range between (0 to 100), and S is related to CN by:

$$CN = \frac{1000}{10 + \frac{S}{25.4}} \quad \text{(S) in (millimeter)} \qquad \text{………………………16)}$$

Soil infiltration rates vary greatly and are influenced by both surface and subsurface permeability. The soils are classified by soil scientists into four Hydrologic Soil Group A, B, C, and D according to their minimum infiltration rate or in another meaning based on the soil runoff potential (Table 7).

**Table 7:** Definition of four SCS hydrologic soil groups [21]

| Hydrologic Soil Group | Definition |
|---|---|
| A | Soils have low runoff potential, high rate of water transmission and high infiltration rates even when thoroughly wetted., well to excessively drained sand or gravel. |
| B | soils with moderately fine to moderately coarse textures , and moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. |
| C | soils have a low rate of water transmission and have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. |
| D | That soil has very low infiltration rates and has high runoff., soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, These soil with a very low rate of water transmission. |

CN was determined (Tables 7 and 8). Table 9 defines the four groups and provides a list of most of the soils and their group classification [21].

**Table 8:** Classification of HSG according to the texture of the new surface soil [21]

| HSG | Soil textures |
|---|---|
| **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** |

soils in the study area consist of sandy loam [22 & 23]. The soil in the study area is of class (A) type. Most parts of the study area are covered by shrubs and grass. According to the classification proposed by the method, the curve number (CN) for this soil condition is equal to 68 (Table 9). The surface runoff values (Rs) in the study area are zero, and one of the most important factors causing the absence of surface runoff is the amount of low rain, as well as soil type (sandy soil). This reflects that soil has high infiltration rates even when thoroughly wetted and low runoff potential (Table 7).

**Table 9:** Curve Number for Various Urban Land Uses [21]

| 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 (town houses) | 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** |
| 1 acre (4046.86 m2) | 51 | 68 | 79 | **84** |
| 2 acres (8093.72 m2) | 46 | 65 | 77 | **82** |

**Table 10**: Mean monthly values of surface runoff in the study area.

| Months | P (mm) | WS (mm) | Weighted CN | S | P > 0.2 S | Rs (mm) |
|---|---|---|---|---|---|---|
| **Oct.** | 6.1 | 0 | | | | **0** |
| **Nov.** | 14.5 | 0 | | | | **0** |
| **Dec.** | 14.1 | 2.1 | | 119.53 | NO | **0** |
| **Jan.** | 20.2 | 10.71 | | 119.53 | NO | **0** |
| **Feb.** | 20.2 | 5.65 | | 119.53 | NO | **0** |
| **Mar.** | 14.1 | 0 | 68 | | | **0** |
| **Apr.** | 15 | 0 | | | | **0** |
| **May** | 3.7 | 0 | | | | **0** |
| **Jun.** | 0 | 0 | | | | **0** |
| **Jul.** | 0 | 0 | | | | **0** |
| **Aug.** | 0 | 0 | | | | **0** |
| **Sep.** | 0.3 | 0 | | | | **0** |
| **Total** | 108 | 18.46 | | | | |

## Groundwater Recharge (Re)

Because the soil is sandy loam and very thin, the groundwater recharge in the study region can be calculated using the equation below.:

$$WS = Rs + Re \qquad \text{……………………………(17)}$$

Where (WS) water Surplus (mm). (Rs) surface runoff (mm). (Re) groundwater recharges (mm) record of Al-Ramadi meteorological station for the period (1990 – 2020). The amount of rainfall is shown below, and when the soil type is sandy loam, the surface runoff will be absent in the study area

$Re = WS - Rs$

Re = 18.46 – 0 = 18. 46mm.
Re %= (18.46 /108) *100 = 17.09%,

The following equation were used to calculate the value of groundwater recharge in the studied area during average water years.

$$\text{Re annual} = A \times \text{Re} \quad \text{-------------------------------------} \ (18)$$

Where; A: Area of study (241) km2.
Re annual = 241 * $10^6$ ($m^2$) * 18.46 *$10^{-3}$ (m)
Re annual = 4.448* $10^3$ $m^3$/year.

The following equation can be used to compute the value of groundwater recharge in the research region during typical water years

**Conclusions**

The following findings were concluded:

▪ Total annual rainfall is 108 mm, evaporation is 2814.3 mm, temperature 22.6◦C, wind speed 2.2 m/sec, sunshine 8.8 h/day, and relative humidity is 52.7%.

▪ In December, January, and February, water surplus values of 2.1mm, 10.71mm, and 5.65mm, respectively, indicate that the study area's climate is arid, with WS representing 17.09% of total annual rainfall.

▪ There was a large water deficit due to high temperature and thus increased evaporation rate and the climate in the study area is dry.

▪ Global warming and climate change have a remarkable effect even on the close geographical location of the meteorological stations such as Ramadi Karbala. it is evident that all the studied climate parameters have their print on the water surplus or deficit and minor changes within each geographical location.

▪ The groundwater recharge (18.46) with a 17.09% indicates a recharge 108 from total rainfall.

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