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Calculating Groundwater Recharge Using Water Balance in Mandaly City, Diyala Governorate, Eastern Iraq

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Abstract
Water balance approaches are strategies for resolving key theoretical and practical hydrological issues. The major goals of this study are to examine climatic elements and conditions to calculate groundwater recharge using the water balance approach. The study area is located in Mandaly city, Diyala Governorate, eastern Iraq. The metrological data was gathered between 1994 and 2020 to evaluate the study area's climate. The annual rainfall rate has been 248.61 mm, with a relative humidity of 43.89%, a temperature of 24.41 ^{o}C, a wind speed of 1.99 m/sec, sunshine of 8.32 hours per day, and evaporation of (268.09 mm). The total amount of corrected evapotranspiration was 1010.09 mm, with a peak value of 225.29 mm in July and the lowest value of 3.91 mm in January. the climate was classified into arid and sub-arid. The water surplus (WS) has been calculated to be 149.52 mm and 60.14 % annual rainfall. The surface runoff is 24.86mm, and the groundwater recharge value is 124.66 mm with a rate of 50.14 %. This shows the percentage of groundwater recharge from total rainfall.

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

استخدام الموازنة المائية لحساب تغذية المياه الجوفية في منطقة مندلي ، محافظة ديالى ، شرق العراق

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الخلاصة
تقنيات موازنة المياه هي استراتيجيات لحل القضايا الهيدرولوجية النظرية والعملية. تتمثل الأهداف الرئيسية لهذه الدراسة في فحص العناصر والظروف المناخية من أجل حساب إعادة تغذية المياه الجوفية باستخدام نهج الموازنة المائية. تقع منطقة الدراسة في منطقة مندلي بمحافظة ديالى شرقي العراق. تم جمع البيانات المترولوجية بين عامي 1994 و 2020 لتقييم الظروف المناخية لمنطقة الدراسة. يبلغ المعدل السنوي لهطول الأمطار 248.61 ملم ، مع رطوبة نسبية 43.89 في المائة ، ودرجة حرارة 24.41 درجة مئوية ، وسرعة رياح 1.99 م / ثانية ، وسطوع شمس 8.32 ساعة في اليوم ، وتبخر (268.09 ملم). بلغ إجمالي كمية التبخر النتح المصحح 1010.09 ملم ، وبلغت ذروة قيمته 225.29 ملم في يوليو وأدنى قيمة بلغت 3.91 ملم في يناير. وتشير نتائج التصنيفات إلى تصنيف المناخ كان شبه جاف و جاف. بلغ الفائض

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المائي 149.52 (WS) ملم ، وبنسبة 60.14٪ من الأمطار السنوية. بلغت كمية الجريان السطحي في منطقة الدراسة 24.86 ملم ، وقيمة التغذية الجوفية (124.66 ملم) بمعدل (50.14٪) وهذا يوضح نسبة تغذية المياه الجوفية من إجمالي هطول الأمطار.

Introduction

The relationship between rainfall and evaporation, which contribute to groundwater recharge, is influenced by climate.. Rainfall and evaporation are the primary components in the hydrological cycle, and they fluctuate from season to season or year to year [1]. Climate change may intensify dryness, increase flood danger, increase soil salinity, liquid waste, and lower groundwater levels, among other things [2]. Increased rainfall causes water to filter through the soil layers, resulting in rising groundwater levels and lower concentrations of specific chemical components in water. In contrast, increased summer temperatures cause water to evaporate, lowering groundwater levels and raising salts [3] . Many studies have been done in Mandaly city, including Buringh has conducted research on the region's soil in 1960[4], concluding that the region's soils are mainly sedimentary, carried from the border areas by torrential rains. The Mendelian fan was studied geophysically by [5]. The study comprised the interpretation of vertical electric survey data using the electrical specific resistance method in 58 electric points throughout the study area. The contemporary sediments are composed of gravel, sand, and clay that change over time in numerous areas[6]. Hydrochemical and hydrogeochemical studies of the deep wells, hand-dug wells, and springs Mandaly district [7]. They studied the water balance of the Mandali basin, the east part of Iraq, based on the climate reality of the basin.

Study area and Geological setting

The study area is located at Mandaly city, east of Diyala governorate, along the Iraqi-Iranian borders. It is bordered to the south by Qazaniya district, to the north by Khanaqin district, and to the west by Baladrouz district, between the latitudes 33° 40′ 17.3″ -33° 54′ 14.3″ N, longitudes 45° 24′ 55.2″ - 45° 38′ 51.5″ E. The total area is expanded over about 334 km^2 with an elevation of (58m -168m) m.a.s.l (Figure 1). The Quaternary and Tertiary sediments that emerge along the margin of the Hamrin Mountains range cover the study region. The incompatible geological layer structures characterize the quadrilateral and Tertiary periods. It is notably prominent at the Iraqi-Iranian border, where Miocene and Pliocene sediments have been represented by the Euphrates, Fatha, Mukdadiyah, and Bai Hassan formations. Quaternary sediments, both current and ancient, encompass the research region in general, each represented by multiple units that differ based on geomorphological and lithological characteristics, by Pleistocene Deposits sediment, alluvial fans, and terraces.

This research aims to evaluate the climate by studying and evaluating climate factors for the Mandaly city from 1994 to 2020, as well as determining the water surplus, deficit and the percentage of total rainfall that recharges the groundwater.

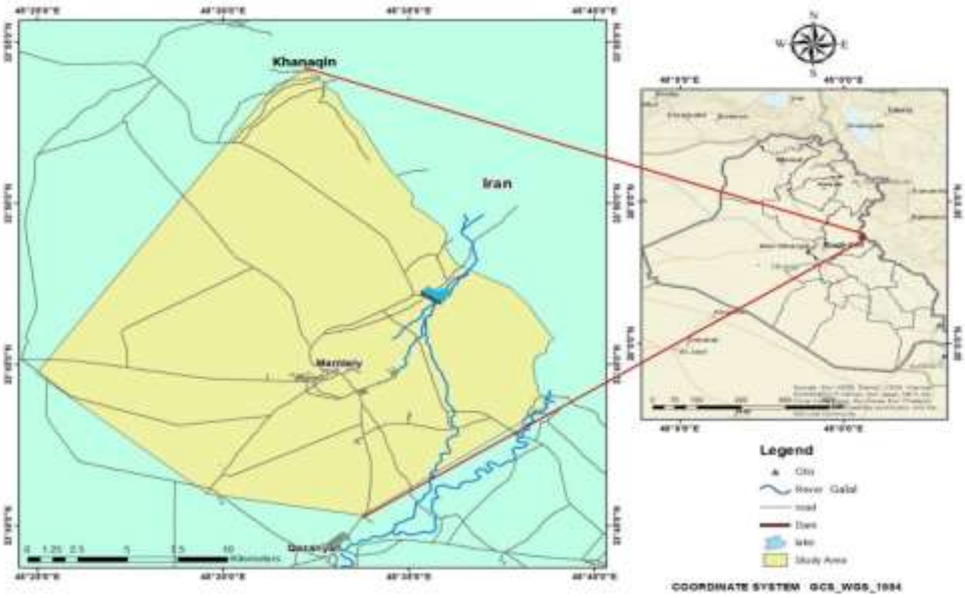

Figure 1: Location of the study area

Methods and Materials

The climate data of study area has been determined using meteorological data from the stations Badra (Ba) (E 45° 57' 00" - N 33° 06' 00")and Khanaqin (Ka) (E 45° 26' 00" - N 34° 18' 00") for the period (1994-2020) . The arithmetic mean is utilized to derive the monthly values of several climatic aspects of the proposed station Mandaly due to the presence of Mandaly city between Badra and Khanaqin stations [7] (Table 1). [8] developing an equation to compute the values of potential evapotranspiration (PE) and evapotranspiration correct (EPc) for each month based on latitude. [9], Furthermore, [10] techniques were used to classify the climate. The water surplus and deficit have been determined by using the Thornthwait method and estimating runoff from the Runoff coefficient method [11]

Table 1: Monthly averages of rainfall, temperature, relative humidity, sunshine, wind speed, and evaporation derived for the station Mandaly (Ma) suggested for the period (1994-2020).

Months	Rainfall (mm)	R.H.%	Temperature (◦ C)	Wind Speed (m/sec)	Sunshine (h./day)	Evaporation (mm)
Oct.	17.72	36.66	26.20	1.74	8.01	258.95
Nov.	48.25	57.68	17.29	1.47	6.80	119.62
Dec.	35.25	68.21	12.17	1.50	5.65	69.33
Jan	46.85	72.85	10.85	1.73	5.77	62.00
Feb.	32.89	64.18	12.98	1.91	6.58	95.11
Mar.	36.18	53.35	17.41	2.16	7.30	175.27
Apr.	23.02	45.16	23.81	2.29	7.87	240.59
May.	7.67	31.67	30.40	2.12	9.14	335.40
Jun.	0.15	23.99	35.17	2.47	11.16	462.12
Jul.	0.00	22.54	37.50	2.45	11.02	524.90
Aug.	0.00	22.97	36.94	2.19	10.80	496.95
Sep.	0.63	27.43	32.21	1.93	9.75	376.95
Total	248.61					3217.19
Monthly Mean		43.89	24.41	1.99	8.32	268.09

Results and Discussion:

The total rainfall (248.61), average relative humidity (43.89 %), average temperature (24.41° C), wind speed average (1.99 m/sec), sunshine time average (8.32 h/day), and average evaporation are the monthly average values of climate parameters in the study region for the period (1994-2020). (268.09mm). The climatic variables have a variety of correlations (Figure 2). When comparing the rates of rain and temperature in this research with the previous study by Hassan 2007[6] in the Mandaly city, it is found that the total rainfall was 264mm and the average temperature was 23.8 ° C, as the temperature rates increased and the total rains decreased.

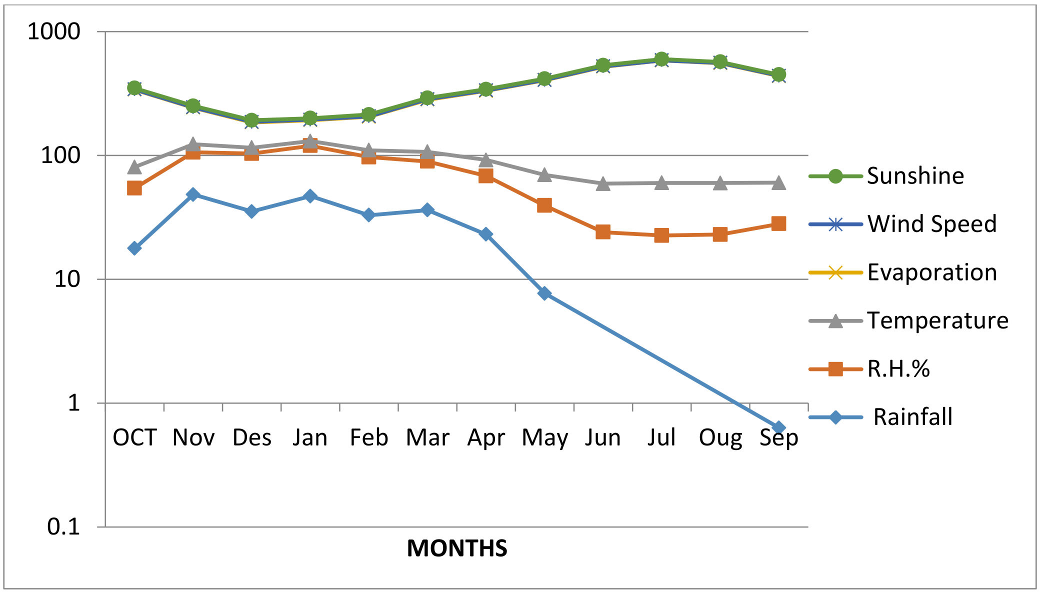

Figure 2: Relationships of climatic variables for the period (1994-2020).

Potential Evapotranspiration (PE):

The difference between the quantity of actual evaporation and the evaporation capacity is prospective evapotranspiration (PE), which is the water loss that will occur if there is a deficit of water in the soil for the use of vegetation [8]

Thornthwiate (1948)[8] devised a formula for determining the crop's consumptive consumption based on the mean daily temperature, zone latitude, and month of the year. It is assumed that the mean temperature and the other factors have a strong relationship. The relationship is shown in the following equations :

$$PE_X = 16[10tn/J]^a \qquad \text{.......... (1)}$$

$$J = \sum j \text{ for the 12 months} \qquad \text{.......... (2)}$$

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

a= 0.016J+0.5

Where:

PEx = Evaporative potential for each month (mm / month)

t = Average monthly air temperature (C°).

n = Number of monthly measurements.

J = Annual heat index (C°).

j = Monthly temperature parameter (C°).

a = Constant

The adjusted potential evapotranspiration (PEc) values might be calculated using the equation below:

$$PEc = PE *(DT/360) \qquad \text{………….(4)}$$

Where: PEc: Potential evapotranspiration has been corrected (mm). PE: potential evapotranspiration (mm). D: Number of days in the month. T: Mean month sunshine.
The monthly potential evapotranspiration values are higher during the period (May- October) and have moderate values from November to April (Table 2). The years are characterized in all months by the following relation: E pan > PE > PEc. Where; the evaporation from the ground EA pan is (3217.19 mm). and the corrected potential evapotranspiration (PEc) rate of evaporation is (1010.09mm), while the rate of potential evapotranspiration (PE) is (1199.54 mm) Table 2. The observed difference between the three numbers demonstrates the disparity in the methods of measurement. (field values and calculated values).

Table 2: Potential evapotranspiration (PE) mm for Mandaly city by Thornthwiate

Months	t ◦ C	t/5	$j=(t/5)^{1.514}$	$(10t/J)^a$	PE (mm)	DT/360	PEc (mm)
Oct.	26.20	5.24	12.27	5.541	88.65	0.68	61.15
Nov.	17.29	3.458	6.54	1.769	28.30	0.56	16.03
Dec.	12.17	2.434	3.84	0.674	10.78	0.48	5.24
Jan	10.85	2.17	3.23	0.491	7.87	0.49	3.91
Feb.	12.98	2.596	4.23	0.804	12.87	0.51	6.59
Mar.	17.41	3.482	6.61	1.803	28.84	0.62	18.13
Apr.	23.81	4.762	10.62	4.260	68.12	0.65	44.71
May.	30.40	6.08	15.37	8.336	133.38	0.78	104.98
Jun.	35.17	7.034	19.17	12.441	199.06	0.93	185.12
Jul.	37.50	7.5	21.12	14.838	237.42	0.94	225.29
Aug.	36.94	7.388	20.65	14.237	227.80	0.93	211.86
Sep.	32.21	6.442	16.78	9.772	156.35	0.81	127.03
Total			140.47		1199.54		1010.09

CLASSIFICATION OF CLIMATE

Various techniques (methods) are used to classify climate, including the different elements of climate, and it is difficult to collect them in one classification.
Two classifications will be used to define the kind of climate in Mandaly city :
The classification was proposed by (Mather, 1974)[9]. The climate type is determined by the value of the climate index, which yields three classes related to rainfall and evapotranspiration, as shown in the equation below:

$$AI= \{(P/PEc) -1\}*100 \qquad \text{…………………….. (5)}$$

Where:
AI = Aridity Index AI on Studied area
P = rainfall (mm)
PEc = Corrected evapotranspiration (mm)
The aridity index (AI) values are as follows::
AI = {(248.61 /1010.09) -1}*100 = - 75.38

Table 3: According to the classification of climate (Mather, 1974)

Climate type	Range of Al	AI on Study area
Dry –sub-humid	0.0 to -33.3	-75.38
Semi-Arid	-33.3 to -66.6	
Arid	-66.6 to -100	

According to the classification proposed by Mather in 1974. The aridity index is (-75.38), indicating that the study area is arid. The second classification is for (Al-Kubaisi, 2004)[10] to determine the climate type by using the annual dryness treatment, which is based on temperature and rainfall amounts, as the following equations:

$$\mathrm{Al}\ -1=(1.0 * P) / (11.525 * t) \qquad \text{..............................(6)}$$

AI: aridity index , P: Total rainfall (mm) , t: average temperature (ºC) ...$t \neq 0$
Al -1=(1×248.61) / (11.525×24.41) = 0.88

$$\mathrm{AI}\text{-}2= 2*\sqrt{p}/t \qquad \text{.........................(7)}$$

Al -2= 2 *√ 248.61 / 24.41 =1.29
According to the Total rainfall and average temperature of the study area, where AI-1 = 0.88 and AI-2 = 1.29. The climate of the study area can be categorized into two types: Sub-arid to arid in type 1 and sub-arid in type 2.

Table 4: Climate classification according to Al-Kubaisi, (2004)

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

water balance

The term "water surplus" refers to when rainfall exceeds potential evapotranspiration during specified months. In other months of the year, the water deficit, defined as the values of potential evapotranspiration, is more significant than rainfall [12].
Used the Lerner et al. (1990) [12] method to compute the water balance of the study area.
Water Surplus (WS)

$$WS = P - PEc \qquad \text{..................................... (8)}$$

PEc = APE, when P > PEc
Where (WS) Water Surplus (mm).
(P) Rainfall (mm).
(PEc): Corrected evapotranspiration (mm).
(APE): Actual Evapotranspiration (mm).
Water Deficit (WD**)**

$$WD = PEc - P \qquad \text{..................................... (9)}$$

P = APE, when P < PEc.
Where (WD): Water Deficit (mm)

Table 5: Water surplus of the study area for the period (1994-2020).

Months	P (mm)	PEc (mm)	APE (mm)	WS (mm)	WD(mm)
Oct.	17.72	61.15	17.72	0	43.43
Nov.	48.25	16.03	16.03	32.22	0
Dec.	35.25	5.24	5.24	30.01	0
Jan	46.85	3.91	3.91	42.94	0
Feb.	32.89	6.59	6.59	26.3	0
Mar.	36.18	18.13	18.13	18.05	0
Apr.	23.02	44.71	23.02	0	21.69
May.	7.67	104.98	7.67	0	97.31
Jun.	0.15	185.12	0.15	0	184.97
Jul.	0.00	225.29	0	0	225.29
Aug.	0.00	211.86	0	0	211.86
Sep.	0.63	127.03	0.63	0	126.40
Total	248.61	1010.09		149.52	910.97

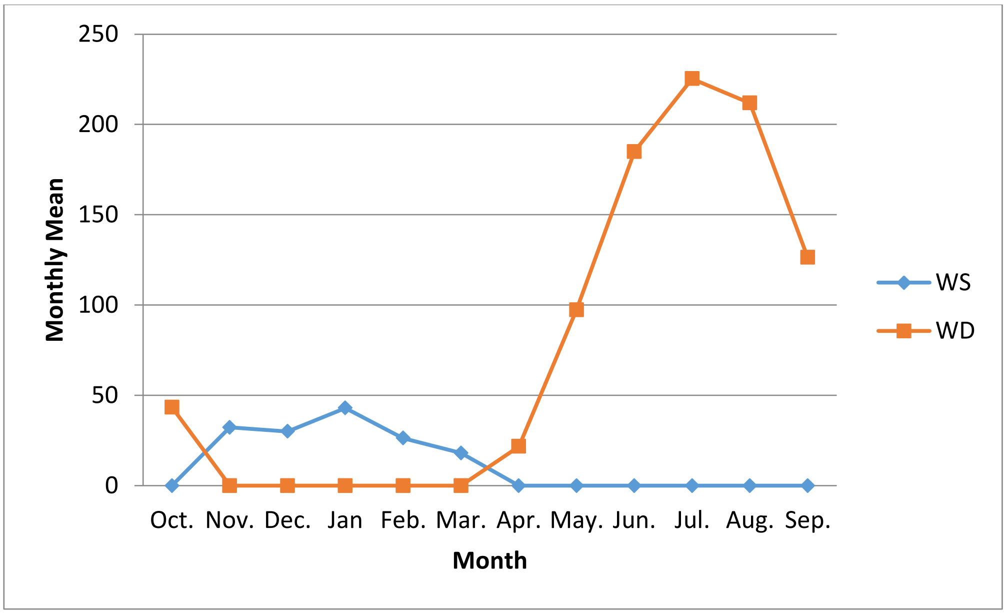

Figure 3: Water surplus (WS) and water deficit (WD) for a period 1994-2020

The entire annual value of WS was 149.52 mm due to total rainfall exceeding PEc in December, January, and February. The WS ratio calculated from yearly rainfall is:

$$WS\ \% = WS/P \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

WS % = 149.52 /248.61×100 = 60.14%

The water deficit (WD) ratio is calculated as follows:

$$WD\ \% = 100 - WS\ \% \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

WD % = 100 – 60.14 = 39.86%

Groundwater Recharge

One of the most challenging aspects of the hydrological cycle to quantify is groundwater recharge. To calculate the recharge firstly calculates runoff. The runoff coefficient method [11] was used to calculate runoff by applying the following formula:

$$Q = KP \qquad \text{-------------------------------(12)}$$

Where, Q: Runoff, P: Rainfall and K: A constant having a value less than (1) or at most equal to (1).

The value of K depends upon the imperviousness of the drainage area. Its value increases with the imperviousness of the catchments area and may approach unity (1.0) as the area becomes fully impervious. The value of K was estimated as (0.1) depending on [13; 14].

Q= 0.1*248.61= 24.86 mm

The groundwater recharge in the research area was calculated using the following method based on water surplus and surface runoff:

$$Re = WS – Q \qquad \ldots\ldots\ldots\ldots\ldots \quad (13)$$

Where (WS) Water Surplus (mm).
(Q) Runoff (mm).
(Re) Groundwater recharges (mm).
Re = WS – Q
Re = 149.52 – 24.86 = 124.66 mm.
Re %= (124.66 /248.61) *100 = 50.14%

During average water years, the following equation can be used to compute the value of groundwater recharge in the examined area.

$$Re\ annual = A \times Re \qquad \text{------------------------------------- (14)}$$

Where; A: Area of study (334) km^2.
Re annual = 334 $*10^6$ (m^2) * 124.66 $*10^{-3}$(m)
Re annual = 41.63* 10^6 m^3/year.

Conclusions

The different climatic transactions account for the proposed station Mandali of climate information obtained through the stations of Khanaqin and Badra period (1994-2020) as follows: By conducting analyzes and calculating the annual averages of the climatic parameters, it is shown that the total annual rainfall was 248.61 mm and relative humidity was 43.89%, while the monthly average temperature was 24.41 °C, evaporation was 3217.19 mm, the wind speed was 1.99 m/s, and sunshine duration was 8.32 h/day. In general, the study area's climate is located in the region of sub-arid and arid, which was described as relatively hot in summer and cold with low rain in winter. The overall yearly value of water surplus (WS) is (149.52 mm), so when we calculate The percentage of groundwater recharge from total rainfall is represented by the value of groundwater recharge (124.66 mm) with a rate of 50.14%.

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