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Ground Water Recharge Mapping in Iraqi Western Desert

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ABSTRACT

Local climate change and water shortage led it essential to assess the amounts and locations of groundwater recharge. To keep the Iraqi Western Desert's groundwater system sustainable. A model was developed to estimate soil moisture using artificial neural networks (ANN), geographic information systems (GIS), and remote sensing (RS). The soil needed approximately 26.54% of the total amount of rainfall to saturate voids before groundwater was recharged during the study years. The amount of recharge of groundwater was estimated depending on the water balancing method. The results showed that approximately 455,306,884 m^3 of rainwater during the study years was infiltrated for groundwater recharge, nearly half of the total amount of rainfall. Sandy loam soils were most leached to recharge groundwater, while loam soils were of medium rates for groundwater recharge, and silty loam soils were the lowest rates in groundwater recharge rates.

1. INTRODUCTION

Groundwater is the principal source of potable water for the human race [1]. Groundwater is responsible for providing 30% of the world's supply of fresh water. Because easily accessible aquifers have been over-exploited, water resource managers in many regions must now resort to ancient deep groundwater sources for an appropriate supply of clean, drinkable water [2-4]. Long-term water supply reliability is dependent on precise scientific evaluations of aquifer sources and recharge rates. This assessment is essential. Groundwater recharge may occur in a variety of methods to replenish the groundwater reservoir, including precipitation penetration, surface water leakage, and human-caused activities like irrigation and urban drainage [5]. Water flows downhill during recharge until it reaches the water table in the unsaturated zones [6].

The exact estimation of groundwater recharge is critical for good groundwater resource management, as is any assessment of groundwater flow or pollutant transfer. The downward movement of water to the saturation zone and water table, which increases the amount of stored groundwater, is what is meant by recharge [7]. Many variables influence groundwater recharge and outflow dynamics, including climate, land cover, land use, sedimentology, and the thickness of the unsaturation zone (vadose zone) [8, 9].

Although groundwater recharge is essential for present and future groundwater extraction, little is known about the conversion of rainfall into recharge. The lack of data on groundwater storage changes in this area is mostly to blame for this knowledge gap.

Climate and land cover have a major role in precipitation and evapotranspiration [10], while the underlying soil and geology decide whether a water surplus (precipitation minus evapotranspiration) can be transported and stored in the subsurface [11, 12].

Western Sahara has had much less precipitation than normal. Groundwater supplies are vulnerable to variations in recharge, and this led to a period of drought. One of the principles of controlling groundwater extraction is that "The overall extraction of any groundwater resource region does not exceed the long-term average yearly replenishment rate" [13]. This decrease in precipitation, coupled with a rise in water demand, implies that many groundwater resources are nearing the point at which they can no longer maintain themselves. As a result, groundwater recharge predictions must be made more accurate and reliable.

Since 1969, groundwater recharge has been estimated using simple water balance models as those developed by Grindley [14] and Hough & Jones [15]. In order to arrive at the real recharge water volumes, these models integrate a surface runoff model with a soil moisture and evaporation model. With this method, one can obtain sequential estimates of direct groundwater recharge from readily available meteorological data and then, using simple spatial aggregation procedures [16], produce true recharge estimates that can be used in a complete watershed water balance model [16, 17].

Groundwater recharge controls and climate change implications were the focus of this research which aims to determine (1) what role does Western Sahara play in the replenishment of groundwater? Groundwater recharge has been experimentally approximated by empirically measuring the quantity required to saturate the soil thoroughly and then calculating how much water will evaporate and flow off. (2) How will climate change affect groundwater recharge due to changes in precipitation variability and quantity? So, we looked at years' rainfall trends to get a handle on the problem. Groundwater recharging is influenced by rainfall throughout the years by climate change estimates for increased precipitation variability and reduced precipitation quantity. (3) The groundwater recharge quantity was then calculated based on the water balance relationship.

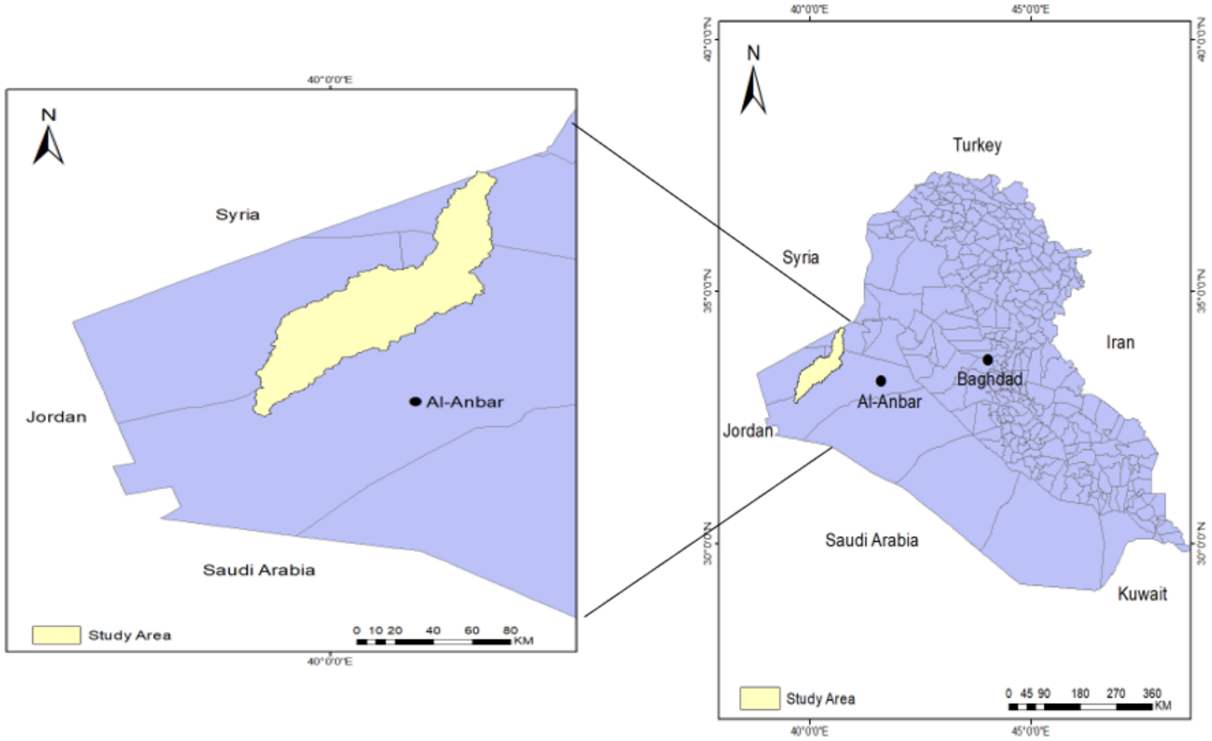

Figure 1. Location of the study area

2. STUDY AREA

The Al-Ratga valley basin, represented in Figure 1. as one of the key valleys in Iraq's western desert, is the site of the current investigation. Euphrates River in Syria the near Iraqi-Syrian border is fed by this valley. Longitude 39° 38' 11″ to 40° 46' 46″ E; Latitude 32° 47' 7″ to 34° 17' 41″ N define the research area in western Al-Anbar province. The research area covers a total of 5579 km^2.

This region's climate varies from hot and arid in summer to cold and damp in winter with brief transitions. Seasonal climate shifts may be extreme in this area of the country. Precipitation also varies significantly from year to year. There are many years of low or high annual precipitation rates that have a significant impact on these places, and it is especially challenging to manage the region's limited water supplies during dry years [18]. In Iraq's Western Desert, yearly precipitation typically starts in September and lasts until May. Precipitation tends to be concentrated and only lasts a short time when it does. Runoff from this occurs for months at a time, although most of the year is dry [19, 20]. At Al-Rutbah station, the average annual precipitation is just 143 mm, and the average temperature is 31.6 degrees Celsius, while at Al-Qaim station, the average annual precipitation is 146.7 mm, and the average temperature is 33.8 degrees Celsius in July [21, 22]. The study area's minimum annual temperatures are typically recorded in January at Al-Rutbah station and at Al-Qaim station, respectively, at 7.5 degrees Celsius and 7.8 degrees Celsius, respectively. Average yearly evaporation of 3300 mm is recorded in the research region. From the lowest elevation to the highest, the research area's altitude ranges from 268 to 836 meters above sea level. The basin's average slope is 0.0095; the stream's longest length is 220 km; the form factor is 3.73.

A large amount of rain falls in the Western Desert region every year, which makes it ideal for water harvesting projects because of the flatness and amount of rain, as well as the region's soil, which aids water penetration into the ground as a recharge of groundwater and allows for future investment of water [23].

The amount of rain varies in the study area according to the data of the meteorological stations in the area as shown in Figure 2.

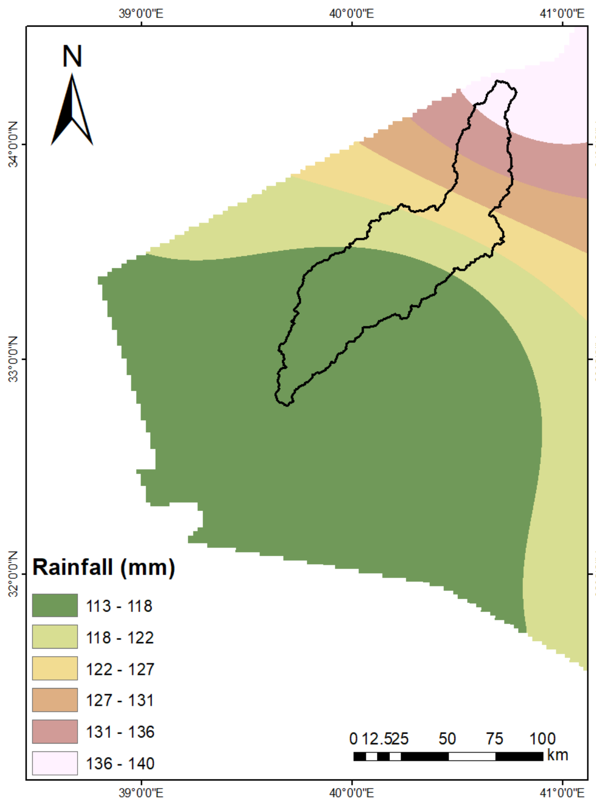

Figure 2. Rainfall map of study area

3. METHODOLOGY

This study explains how to estimate the amount and location of groundwater recharge using remote sensing data, GIS, and artificial neural network systems (ANNs). In order to attain this aim, several procedures have been implemented, as illustrated in Figure 3.

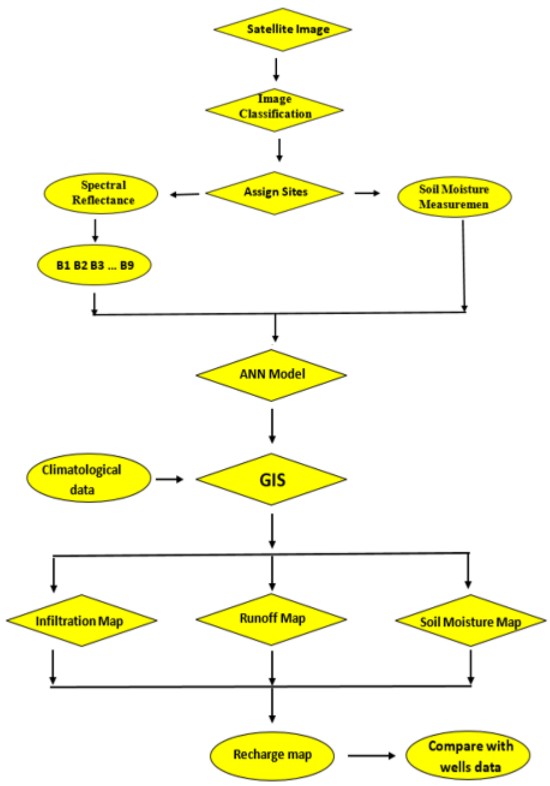

Figure 3. A diagrammatic representation of the suggested technique

Landsat 8 satellite picture of the research region and a DEM produced from information from the Radar Topographic Mission are used to calculate the catchment basin. WGS 84 and UTM Region 37 were used to make engineering adjustments to these images in ArcGIS 10.7. The Digital Elevation Model (DEM) with a spatial resolution (30×30 m) were acquired from United States Geological Survey (USGS). Unsupervised classification is used to classify pixels into a small number of categories based on their data value [24].

As part of the field moisture measurements, 75 samples of the study area's soil were measured for moisture content. Calculating how much water is needed to completely saturate the soil may be done with each sample by first adding a predetermined amount of water, and then measuring the volume of penetrating water that remains after 24 hours. The final moisture map for the study region was created by combining the GIS and GPS data received from soil samples in the area with the information from the research area map. Soil moisture requirements and the quantity of water evaporation in a study area and the amount of surface runoff [6] were used to determine the amount of water entering the soil to replenish groundwater. Soil moisture, evaporation, and runoff data were gathered using the search area map, and the resulting recharge map was created using GIS and GPS.

The quantity of recharging in each part of the research area was used to split the area into sections. Afterward, a comparison was made between the estimated amounts and the recharge map and the evidence of wells in the area acquired from Iraqi Ministry of Water Resources.

4. THE CONCEPT OF SPECIFIC YIELD

Once "saturated" with water, a rock or soil's specific yield is calculated by the ratio of how much water it can "given by gravity" [25]. As a general rule, this formula is employed:

$$S_y = \phi - S_r \tag{1}$$

where,

S_y= specific yield;

ϕ= the rock's ability to retain water as a percentage of its volume;

S_r= specific retention.

Specific yield (S_y) and specific retention (S_r) are used to describe this (the volume of water retained by the rock per unit volume of rock). In principle, the immediate release of water from storage may be accounted for by using the phrase "specific yield." The release of water is not immediate in actuality. Instead, the release might take a very long period, particularly for fine-grained sediments [26]. It required two and a half years of draining to arrive at the S_y. value of 0.20 for fine sand. Notes are made on the limits of this definition by Meinzer [25], furthermore, it ignores the effects of temperature and chemicals. Because of these issues, there is a broad range of values in the literature. According to Johnson [27], 17 studies were collected that employed different methods to determine S_y. and Table 1 shows the averages, Coefficient of variation, and the widest range. According to Muneer [6], in the Western Desert of Iraq, there exist varieties of soil like those listed in Table 1.

Table 1. Johnson compiled yield data from 17 studies [24]

Texture	Average specific yield	Coefficient of variation (%)	Minimum specific yield	Maximum specific yield	Number of determinations
Clay	0.02	59	0.0	0.05	15
Silt	0.08	60	0.03	0.19	16
Sandy clay	0.07	44	0.03	0.12	12
Find sand	0.21	32	0.10	0.28	17
Medium sand	0.26	18	0.15	0.32	17
Coarse sand	0.27	18	0.20	0.35	17
Gravelly sand	0.25	21	0.20	0.35	15
Fine gravel	0.25	18	0.21	0.35	17
Medium gravel	0.23	14	0.13	0.26	14
Coarse gravel	0.22	20	0.12	0.26	13

5. WATER BALANCE

The water budget approaches use a water budget equation as their foundation. A basin's water budget may be expressed as:

$$\Delta S = P - R_o - E - G_{off} \quad (2)$$

where,

P=The amount of rainfall (mm/day).

R_o=Runoff (mm/day).

G_{off}=Ground Moisture(mm/day).

E=Evapotranspiration (mm/day).

ΔS=Groundwater Recharge (mm/day).

This approach may be used at many different geographical and temporal scales. The accuracy of the recharge predictions, however, relies on how well other elements of the water balance equation are determined, which is a significant drawback of this technique [28].

6. RESULT AND DISCUSSION

In order to determine whether or not a model is credible, there are no widely agreed upon criteria. The model's application has a significant impact on this metric. As a consequence, the hysteresis argument for model evaluation is rather wide. Once the model provided in this study has been used to estimate soil moisture, the problems raised must be examined to determine the model's validity. Simultaneous testing is done to see whether the model can accurately predict system response (soil moisture) for the same region as observed samples [29]. Remote sensing data (spectral reflectance) from the specified locations was used to estimate the area's soil moisture content as shown in Figure 4.

Figure 4. Field humidity measurements

The correlation between the estimated soil moisture and the actual soil moisture for samples (shown in Figure 5). Comparing actual and anticipated soil moisture rates for each sample during a test session was used to evaluate the model's qualitative performance. model's ability to predict soil moisture rate is shown by the fact that the model's predicted basic soil moisture rate episodes closely match the actual basic soil moisture rate episodes.

The prediction model's accuracy was tested during the testing period using an easy-to-use approach for finding the appropriate error (MAPE) [30]. The Nash-Sutcliffe efficiency may be used to evaluate how well an ANN model performs (ME). This measure is often used in the evaluation of hydrological models, and it may be used to compare the performance of two techniques [31]. Spatial analysts employed RBF-NNs output and reflectance data from 1000 locations throughout our study region to map soil moisture rates in ArcGIS. This data was used to build a computerized soil moisture map for the whole area.

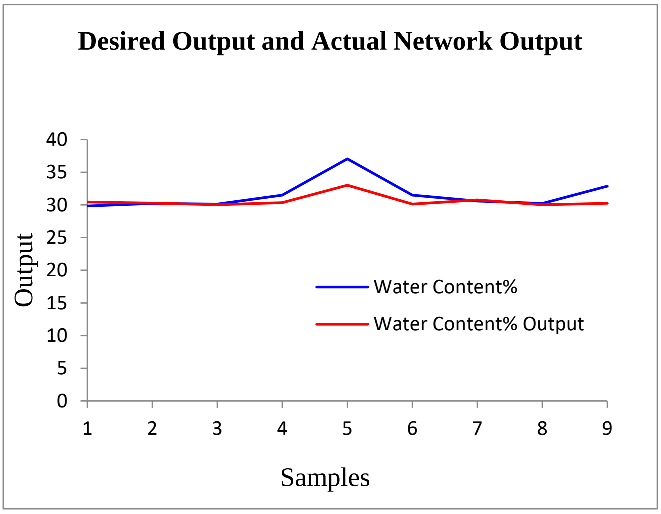

Figure 5. Observed and simulated percentages of soil moisture for the testing stage

Evaluation of the model's performance was done by comparing the model's output with the model's predictions for each training sample. A variety of statistical performance indicators (MAE) are used to assess the ANN model's performance over time, including the correlation coefficient (r), root mean square error (RMSE), lowest and greatest total absolute errors, and the mean absolute error [32] shown in Table 2.

Table 2. ANN model performance indices

Performance	Water Content%
RMSE	1.722727283
NRMSE	0.055121288
MAE	1.142511736
NMAE	0.036556406
Min Abs Error	0.030155022
Max Abs Error	4.033616895
R^2	0.877283824
Score	90.55133166

The study site is surrounded by sandy loam and silt loam soils, as shown in Figure 6. Regular connections to calcareous layers at various depths make soil typically permeable and well-drained. The study area's soils have strong latent productivity when they are in the USDA's third classification (medium to excellent quality for agricultural application) and have easy access to sufficient water earnings, proper soil management methods are put in place [33].

Soil moisture values ranged between (30% to 37%) of the infiltration, where the study area was divided into six areas, including a range of high water absorption to low absorption. The soil absorbed approximately 26.54% of the total rainfall during the study years to achieve complete saturation. as shown in Figure 7.

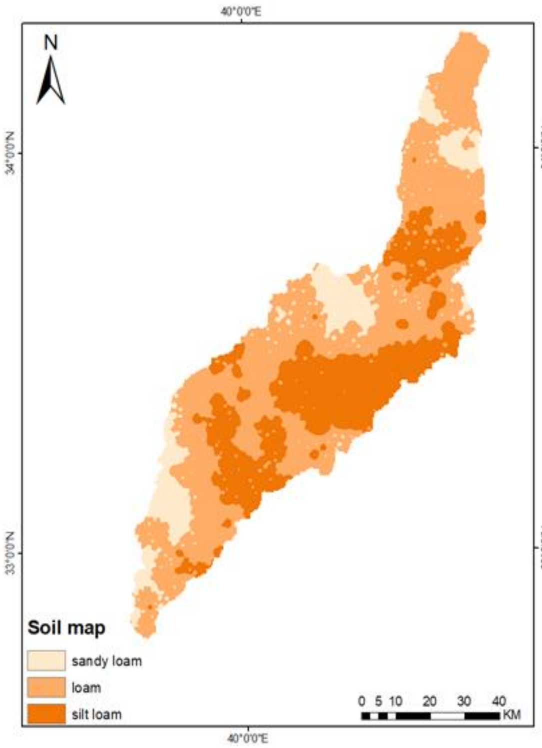

Figure 6. Soil map for Al-Ratga valley

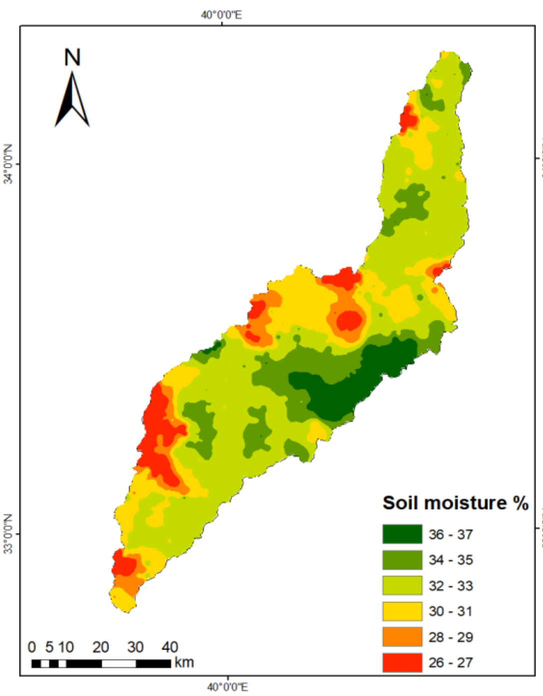

Figure 7. Soil moisture map for Al-Ratga valley

The observed value of average soil moisture at 75 locations after 24 hours of adding water to the soil samples shows that Silty Loam soil is the most water absorbing type, where the water absorption rate was 37%, and the soil samples and required a too-long drainage period of approximately 18 hours. As for loam soil, it was medium water absorption, where the water absorption rate of the soil was roughly 32%, and it took a long period, about 8 hours, as a rate for drain the water given to the soil samples. Sandy Loam soil was the lowest among the soil types in the research region, as it absorbed roughly 30% of the water applied to the soil samples and it took a short time to drain the existing water supply to the samples within two hours on average.

According to Muneer [6], the infiltration rates for the study area ranged from (6 to 22) mm/hr shown in the Figure 8.

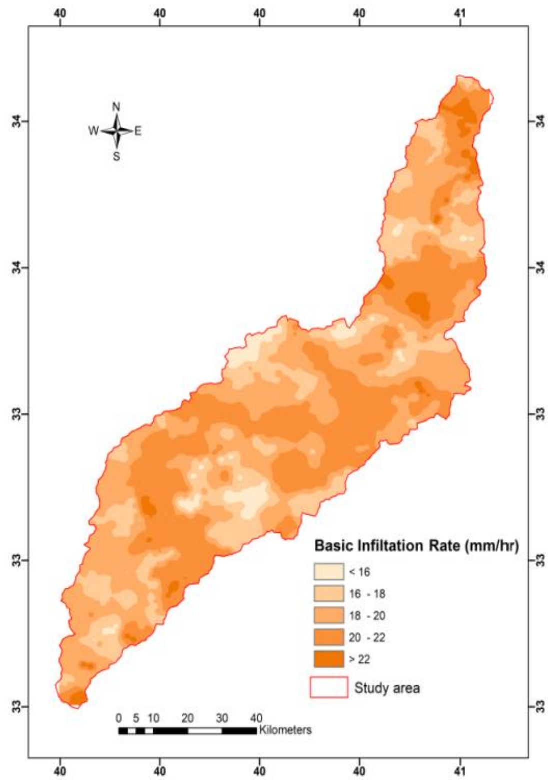

Figure 8. Infiltration rate map in the wet season [4].

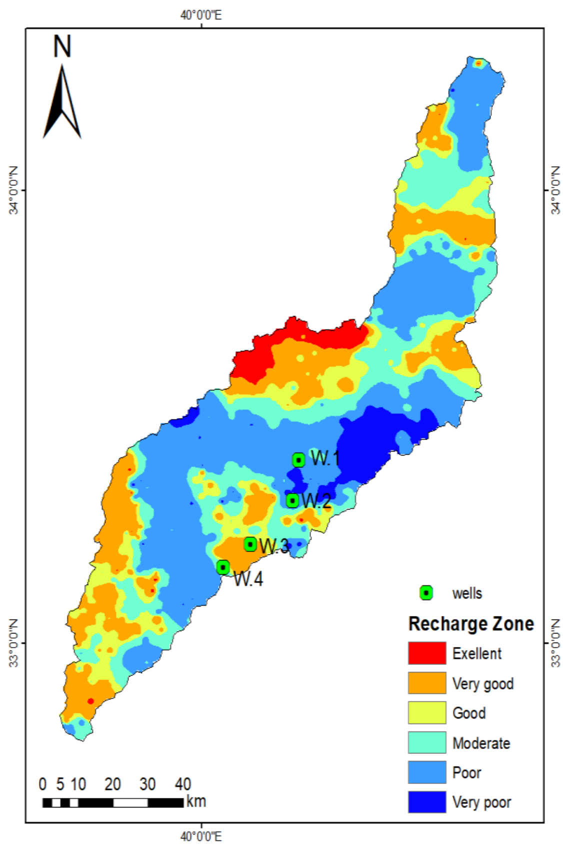

Figure 9. Recharging zone map for Al-Ratga valley with Wells position in study area

Based on rainfall and evaporation data gathered from the metrological station in the area, the water balance equation is used to determine the recharge volume in the studied area. Since the researchers were unable to install rain gauges and calculate the flow of surface throughout the 2018–2019 and 2019–2020 seasons, the data accuracy may be regarded as being rather good. Due to the conflict, much of the area still has mobility restrictions and is difficult to measure. Therefore, in addition to field observations of the people in the area, data analysis for measuring sites close to the research area is utilized. The calculation of the average rainfall for the regions is quite challenging because of the obvious variety in rainfall quantities on the area and the impact of the lack of Metrologic-stations spread throughout all the areas. The runoff and infiltration maps, as well as the information on rainfall and evaporation that was available, were used to create the recharging zones map that is seen in Figure 9. Where the land was split into six feeding regions, with the quality of the recharge of groundwater ranging from very poor to excellent.

The distribution of groundwater recharge and the estimated amounts for each region were compared with the well information provided from the Iraqi Ministry of Water Resources (shown in Figure 9). Well No. 1 was found to be inside the poor recharge area, pumping rate was 3 l/s, well No. 2, which was situated in the very poor recharge region, had a 1 l/s pumping rate, well No. 3 located the very good recharge region, it had a pumping rate of 5 l/s and the site of well No. 4 moderate recharge area, pumping rate was 1 l/s. Additionally, the salt levels in wells 1 and 3 were 965 and 473 ppm, respectively, indicating that the wells had good quality water, according to data on groundwater wells acquired from the Iraqi Ministry of Water Resources, while it was rather high in wells 2 and 4, as shown in Table 3.

The difficulty in estimating the average rainfall for the catchment regions is due to the area's obvious fluctuation in rainfall levels as well as the impact of the lack of Metrologic stations dispersed across all of the catchment areas. Due to the events that took place while ISIS controlled the majority of these regions before being freed by government troops, the majority of the territory is still impossible to go through and measure. Therefore, in addition to field observations of the people in the area, data analysis for measuring sites close to the research area is utilized.

The quantity of rain that permeated the soil was calculated using the rain data from the Iraqi Meteorological Authority for the years 2018-2020 displayed in Table 4, and the study area was divided into six regions based on the amount of recharge that infiltrated it.

Table 3. Wells data according to the Iraqi Ministry of Water Resources

Well No.	Depth (m)	Discharge (l/s)	TDS (ppm)
1	370	3	965
2	154	1	1868
3	198	5	473
4	187	3.5	2064

Table 4. Rainfall rate according to the Iraqi Meteorological Authority

Date	Rainfall (mm)
4-11-2018	18.6
6-11-2018	29.6
28-1-2019	24.4
25-3-2019	30.3
20-4-2019	17
22-1-2020	17.5
25-1-2020	18.2

By using the water balance formula to estimate the recharging, evaporation was assumed to be constant at a rate of 3000 mm/day, and the surface runoff and infiltration were calculated by Muneer [6]. After calculating the amount of water needed to saturate the soil, the depth and quantity of groundwater recharge were estimated for the study area for each rainfall. The results showed that 455,306,884 m^3, representing 52.45% of the precipitation for the three years, went as underground water storage. As shown in Table 5.

Table 5. Division of rain water for years (2018, 2019, 2020) according to water balance

No.	Rainfall (mm)	Date	Area (km^2)	Volume (m^3)	Runoff Volume (m^3)	Evaporation Volume (m^3)	Infiltration Volume (m^3)	Soil Moisture Volume (m^3)	Recharge Volume (m^3)
1	18.6	04/11/2018	5,579	103,769,400	3,504,648	16,737,000	83,527,752	28,065,325	55,462,427
2	29.6	06/11/2018	5,579	165,138,400	18,618,443	16,737,000	129,782,957	43,607,074	86,175,883
3	24.4	24/01/2019	5,579	136,127,600	12,149,447	16,737,000	107,241,153	36,033,027	71,208,126
4	30.3	25/03/2019	5,579	169,043,700	17,990,527	16,737,000	134,316,173	45,130,234	89,185,939
5	17	20/04/2019	5,579	94,843,000	3,971,934	16,737,000	74,134,066	24,909,046	49,225,020
6	17.5	22/01/2020	5,579	97,632,500	4,088,756	16,737,000	76,806,744	25,807,066	50,999,678
7	18.2	25/01/2020	5,579	101,537,800	4,906,507	16,737,000	79,894,293	26,844,482	53,049,811
Sum				868,092,400	65,230,262	117,159,000	685,703,138	230,396,254	455,306,884
Percentage from total rainfall%					7.51	13.50	78.99	26.54	52.45
Average				124,013,200	9,318,609	16,737,000	97,957,591	32,913,751	65,043,841

Groundwater recharge rates were highest in sandy loam soils, moderately recharged in loam soils and low recharged in silty loam soils.

Contributing sandy loam soils were the most rate groundwater recharge rate in the study area by 17% of the total recharge amount because they represented only 14% of the area of the study area. While the loam soil was a moderate rate in recharging, as it contributed 50% of the total recharge because it represented 56% of the area of the study area, and silty loam soils were the least contributing to the recharge rates, as they contributed 33% of the amount of recharge because they represented 30% of the area of the study area.

Through the rainwater division table (Table 5), the increase in the amount of rain falling on the study area, the process of recharging groundwater gets an excellent recovery, as it is directly related to the amount of rain and the type of soil.

7. CONCLUSIONS

Soil, geology and rainfall quantities are the main influencing factors on infiltration and groundwater recharge. The infiltration rate is roughly 79% of the amount of rain that fell on the study area during the years during which the tests were carried out, according to practical experiments that were done to examine the humidity of the samples taken from the study area and the actual observed surface runoff rates in the area. The rate of groundwater recharging was equivalent to around 52.45% of the total quantity of rainfall. 26.54% of the rainfall was estimated to have been absorbed by the soil as soil moisture.

Groundwater recharge rates were highest in sandy loam soils, moderately recharged in loam soils and low in silty loam soils. Contributing sandy loam and silty loam soils by a little less than half of the total recharge amount because they represented 44% of the area of the study area together. At the same time, the loam soil contributed more than half of the total recharge because it represented 56% of the study area.

The region's pumping amounts and recharge rates exhibited significant convergence when compared to the groundwater wells in the area. Additionally, the water testing revealed that several wells had water of a very high grade. It is evident because the salinity rates in wells 1 and 3 were 965 and 473 ppm, respectively. using the local groundwater for diverse human needs, such as grazing and cultivation.

In order to obtain a thorough understanding of the quality of groundwater for the entire Western Sahara region, we advise conducting additional experiments and studies on groundwater levels in the area to examine how its rates fluctuate and how much it is impacted by the succession of rainfalls and climatic changes. We also advise testing additional water samples.

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NOMENCLATURE

P	The amount of rainfall (mm/day)
R_o	Runoff (mm/day)
G_{off}	Ground Moisture(mm/day)
E	Evapotranspiration (mm/day)
ΔS	Groundwater Recharge (mm/day)

Greek symbols

S_y	Specific yield
ϕ	The rock's ability to retain water as a percentage of its volume
S_r	Specific retention

Subscripts

ANN	Artificial Neural Networks
GIS	Geographic Information Systems
RS	Remote Sensing
USGS	United States Geological Survey