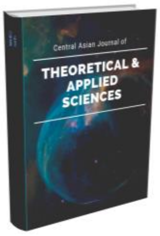

CENTRAL ASIAN JOURNAL OF THEORETICAL AND APPLIED SCIENCE

https://cajotas.centralasianstudies.org/index.php/CAJOTAS
Volume: 05 Issue: 05 | September 2024 ISSN: 2660-5317

Article

Assessment of Groundwater Recharge Under Changing Climatic Conditions in Alguwair Area, Northern Iraq

Mohammed Abdilfattah Ali[1*]

1. Department of Sciences, College of Basic Education, Shirqat, University of Tikrit, Tikrit, Iraq
* Correspondence: mohamedgeo@tu.edu.iq

Abstract: Water resources in the Alguwair region of Northern Iraq are largely dependent on groundwater, making effective management critical, especially under changing climate conditions. This study applied the SWAT model to estimate groundwater recharge and assess its sensitivity to climate variability. The model was calibrated and validated using hydrological data, and sensitivity analysis identified key recharge parameters. Results showed that shallow unconfined aquifers receive an average annual recharge of 350 mm, while deep confined aquifers receive 500 mm, influenced by hydrogeological characteristics and aquifer connections. Recharge contributed 34.4%-37.9% of total rainfall from 2016-2023, suggesting watershed characteristics, rather than rainfall variability, drive recharge patterns. These findings highlight the SWAT model's utility in predicting sustainable groundwater management and could inform water resource policies for the region.

Keywords: Groundwater recharge, Alguwair area, Northern Iraq, Soil and Water Assessment Tool (SWAT) model, Climate change impacts, Hydrogeological properties.

Citation: Mohammed Abdilfattah Ali. Assessment of Groundwater Recharge Under Changing Climatic Conditions in Alguwair Area, Northern Iraq. Central Asian Journal of Theoretical and Applied Science 2024, 5(5), 518-532.

Received: 18th August 2024
Revised: 18th Sept 2024
Accepted: 25th Sept 2024
Published: 2th Oct 2024

1. Introduction

The Middle East's freshwater deficit poses a significant danger to economic progress and political stability. Freshwater consumption is no longer confined to present and future supply but is also determined by competitive consumption demands on a regional and global scale. Previous study suggests that the Middle East area may face greater drought as temperatures rise and rainfall decreases [1]. Climate change will impact water resources by directly affecting the quantity, schedule, and intensity of rainfall. Global warming changes the hydrological cycle by affecting evapotranspiration, soil moisture, and precipitation as temperatures rise [2].

Overall, global precipitation patterns will become more erratic. Various parts of the world could experience significant decreases in rain or alterations in the duration of wet and dry periods [3]. Several research studies have determined that the main cause of the decline in groundwater quality and availability is climate change, due to the decrease in natural recharge and the growing need for groundwater at both regional and local levels [4]. Therefore, it is essential to research the effects of global warming and climate change on various water resources and hydrological factors [5].

Water and groundwater play critical roles in food security and economic development across the world. Unfortunately, in recent decades, the ever-increasing demand for water owing to urbanization, economic development, population increase, and climate change has resulted in water shortages and limited economic development in many nations. When surface water is scarce, groundwater serves as an alternate supply of water. Arid and semiarid regions rely heavily on groundwater for irrigation. In several Middle Eastern nations, the home water supply is entirely dependent on groundwater. Effective management of groundwater resources is crucial to fulfil rising water demand [6].

Climate change and global warming have a wide range of direct and indirect effects on groundwater supplies. Increasing temperatures and shifting precipitation patterns will have a direct influence on groundwater recharge, discharge, water levels, and yearly storage. Furthermore, increasing sea levels, increased demand for agricultural water, and changes in plant cover all have an indirect impact on the quality of groundwater supplies. Global warming will cause changes in plant transpiration and evaporation rates, indicating soil dryness, resulting in increased soil moisture losses and less natural groundwater recharge. Overexploitation of groundwater has resulted in a significant fall in groundwater levels across Iraq.

Groundwater recharge is the process of adding water to the groundwater storage below the land surface, resulting in a change in the water table level. Quantifying groundwater recharge is critical for sustainable groundwater use. In order to prevent the depletion of groundwater, people should only utilize groundwater that can be replenished annually [7]. Natural groundwater recharge is determined by climatic conditions, ground levels, aquifer lithology, and land use in the research area. These characteristics have a direct relationship to precipitation and soil conditions.

While climate change affects precipitation through warmth and evaporation, the natural recharging of groundwater may vary. Drought is expected in southern and central Iraq due to differences in how rainfall is distributed and water policies in countries upstream from the Tigris and Euphrates rivers [8]. Based on two decades of past data, predictions suggest that temperatures in the Middle East will rise by 2 °C by 2040 and by 4 °C by the end of the twenty-first century. This will occur simultaneously with a 20% reduction in precipitation levels (IPCC, 2014). However, the extent of regional alterations caused by climate change is currently unknown, with differences attributable to the grid's poor resolution and local topography variances.

More sophisticated methods are being used by a new generation of models, like ParFlow [9], GSFLOW [10], SWAT-MODFLOW [11], HydroGeoSphere [12], CATHY, and FEFLOW [13], to connect the hydrologic processes that take place beneath and on top of the ground. Importantly, modeling is a crucial tool for understanding both the past and present conditions of geophysical and earth systems, such as land use, climate patterns, soil profiles, and processes. It also helps with forecasting and, eventually, controlling the future results of these systems. The Soil and Water Assessment Tool (SWAT), selected from 73 models because it is currently the most applied model for watershed management, soil, and water also corroborates this [14].

Since SWAT cannot provide comprehensive geographical conclusions and can only assess groundwater fluctuations, it has traditionally focused on surface functions. Therefore, this study expanded the specific soil profile of the root zone and unsaturated zone. The surface water model uses DEM to divide the watershed into sub-basins, each of which is divided into hydrological response units (HRUs), which can capture changes in soil type, land use, and slope. In addition, by integrating MODFLOW-NWT (Newton-Raphson formulation of MODFLOW-2005) into the framework of the SWAT model, the practicality of both models can be significantly improved. MODFLOW is known for its detailed modeling of subsurface flow, while SWAT is known for its ability to mimic total rainfall runoff and water volume [15].

Iraq is a Middle Eastern nation where extreme weather events are occurring more frequently and with greater intensity due to climate change and global warming. Therefore, shows how regional climatic change impacts on rainfall, water requirement, and temperature. According to the current ND-Gain Index, Iraq is placed in the 101 of 182 countries while in terms of the emission it is in 33 out of the total 220 states in the globe as classified by Salman et al. (2017). Changes in the level of rainfall have led to shrinkage of the major rivers and the reservoirs of dams hence affecting the replenishment of the groundwater especially where water is scarce. While there are some studies on various areas of the Iraq that have investigated groundwater recharge [16,17], the impact of climate change on the formation of ‘‘naturally’’ recharged groundwater has not been factored in. This research employs the hydrological and climatic assessment tools to determine the levels of water recharging the aquifers under the climatic variability in Alguwair region of northern Iraq.

2. Materials and Methods

2.1. Study Area

The study area is located in northern Iraq (southeast of Nineveh Governorate) between longitudes (″07 ′30 ˚43), (″00 ′48 ˚43) E, and latitudes (″15 ′47 ˚35) (″00 ′06 ˚36) N. It is bounded to the northwest by the Al-Guwair Anticline and to the southwest by the Qara Chauq Mountain, which serves as a natural barrier. To the northeast, it is bordered by the Avanah Dome, also acting as a natural barrier. The area of the study region is approximately 740 km². Figure (1) shows a part of the map of Iraq, highlighting the location of the study area.

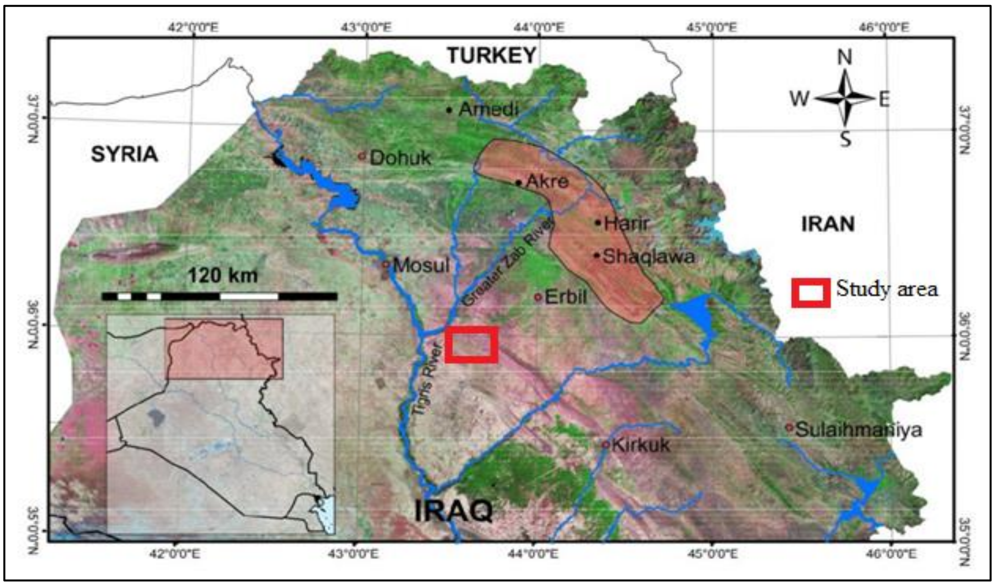

Figure 1. Location of studied area

2.1.1 Climate and hydrology

The temperature in the study area is characterized by a large variation between the summer and winter seasons. We find that the monthly average temperature begins to rise gradually at the end of the spring season and during the month of May, reaching (34) until it reaches a peak in the month of July (43.5 C) and then begins to decrease from the middle of the fall season or the beginning of the winter season during the month of October, which is (22.5 AD). These rates are considered appropriate for humans to carry out their various activities, including agriculture and building human settlements and service facilities.

The rain falling in the study area is subject to the influence of air depressions coming from the Mediterranean Sea and associated with the blowing northern and northeasterly winds and the Mediterranean depressions that recur throughout the region, as well as the thunderstorms that fall on the region in the spring and fall seasons. The study area is under the influence of the Mediterranean climate, which is characterized by fluctuations in the amount of rainfall falling from year to year, which is considered insufficient to carry out agricultural operations, especially winter ones. This deficiency is filled by projects built on the Great Zarab River and artesian wells.

2.2. Methods

2.2.1 Description of SWAT Model

Soil Water Assessment Tool or SWAT is a medium complex, process-based continuous time model supported by the USDA and ARS for water flow and quality simulation for river basins. It is initiated within a Geographic Information System tactical panel interface namely ArcGIS, which compiles several spatial environment al data. The SWAT model has two major divisions: namely Three individual phases: the land phase and the routing phase. The land phase includes identification of the surface runoff, evapotranspiration, ground water contribution, lateral flow and ponds. The routing phase has to do with flow of water through the channels of the basin and movement of sediment, nutrients and organic chemicals. The basic components of the model involve computation of the surface runoff with the help of the SCS curve number procedure and Infiltration by the Green and Ampt method. It also estimates lateral flow in each layer of the soil when the water rates surpass the field capacity after percolation [18].

2.2.1.1 Model Input

The enormous volume of input data needed for the SWAT model's functions forms its basis. These include digital elevation models, soil maps, land use maps, discharge data, and meteorological data. The DEM was created using information from many sources, including the Food and Agriculture Organization's soil map, the European Environment Agency's land cover map, the ASTER Global Digital Elevation Model, and the Iraqi Bureau of Meteorology's weather data. As shown in the fig2.

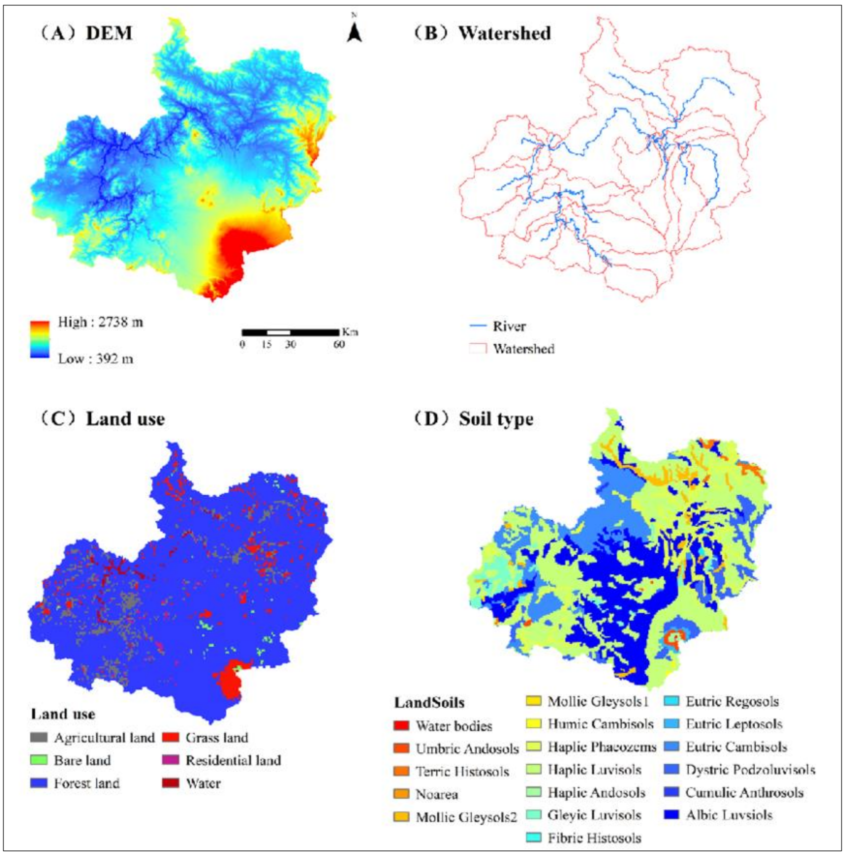

Figure 2. SWAT model setup: (A) DEM, (B) watershed, (C) land use, (D) soil type.

2.2.1.2 SWAT Model Setup

The SWAT model uses the digital elevation model (DEM) to split the watershed's area into sub-basins. Consequently, the slope, soil, and land use maps were combined with the SWAT datasets. Then, the divisions that follow comprise Sub-basins are mentioned, followed by Hydrologic Response Units (HRUs). HRUs are defined as sections of land with certain topographical slope, specific soil type, and specific land use area that are anticipated in the sub division of the basin. HRUs assist the user in distinguishing between various hydrologic circumstances, such as the evapotranspiration of different soil kinds and land usages. From the HRUs' area entities to the sub-basin level and then via the river system to the watersheds outflow, contaminants and water are projected to be transferred Fig3.

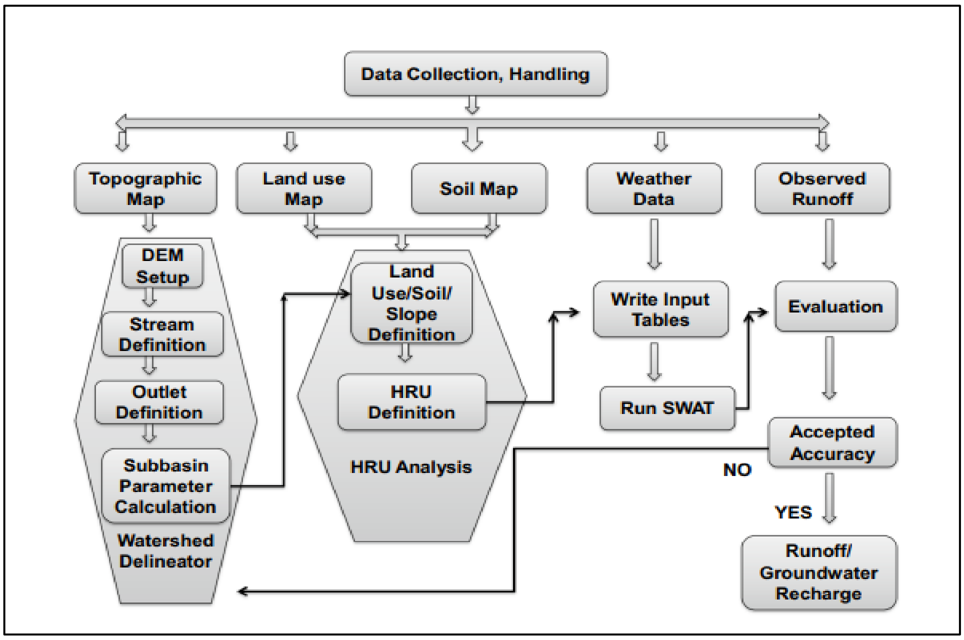

Figure 3. Methodology of SWAT model

2.2.2 Groundwater Recharge Modeling

While using the SWAT model to assess the groundwater recharge in the Alguwair area of Northern Iraq, an important consideration was made regarding the simulation of the recharge processes. This modeling entailed the replication of important hydrological parameters that have a direct impact on the occurrence of groundwater recharge. It included different hydro logic processes like the runoff, evapotranspiration, and lateral flow. These components were useful in determining the water balances of the watershed and consequently, the status of the groundwater recharge rates. Additionally, the aquifer system within the study area was calibrated to assess the level of the shallow and deep confined aquifers in terms of recharging of the water table.

2.2.3 Climate Change Scenarios

In the evaluation of the impact of climate change on the re charge of groundwater in Alguwair area of Northern Iraq using hydrological modeling with SWAT, climate change was an important component as shown in the fig4. Since to predict the future climate conditions there is use of GCMs and for different climatic conditions and simulation different climate conditions there is use of GCMs. These models enabled the logical deduction of how climate factors; namely temperature and precipitation, could change in the study region in the future. With regard to GCM selection, other choices of emission scenarios were considered to investigate the possible effects of climate change on the rate of groundwater recharge. Other emission scenarios such as A2, A1B and B1 were used in order to estimate the contribution of Green House Gases and their impact on the future climate.

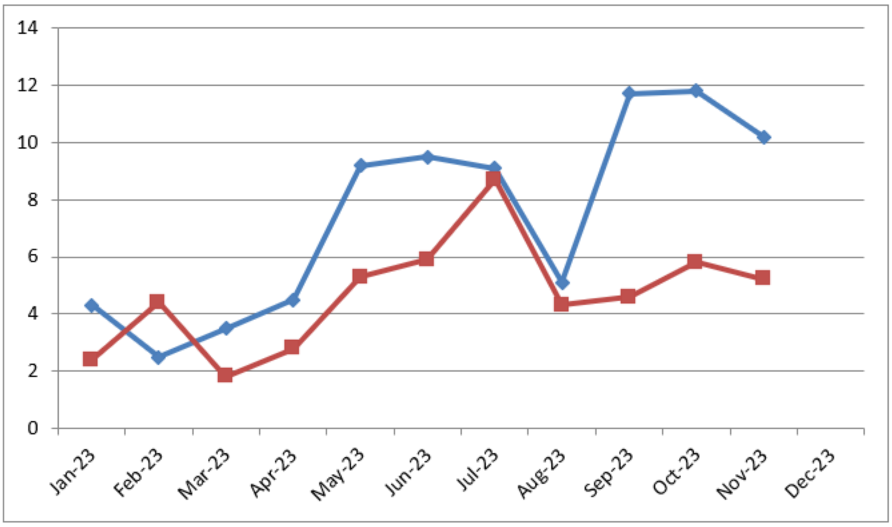

Figure 4. Comparison of the future climate with the baseline for (a) average monthly minimum and maximum temperature and (b) average monthly rainfall.

2.2.4 Parameters Sensitive Analysis of SWAT

Using the Sequential Uncertainty Fitting Version 2 (SUFI2) technique, which was run using the SWAT Calibration and Uncertainty Programs (SWAT-CUP) program, the sensitivity of the SWAT parameters was determined. The SWAT-estimated flows and the observed flows must be included since this procedure is done in tandem with the calibration procedure as shown in the fig5.

This is required since the objective function that assesses the efficacy of the model calibration uses variations to determine sensitivity. The following equation, which shows the values of the parameters produced by the Latin hypercube sampling vs the values of the objective function, is used to calculate the sensitivity of the parameters using multiple regression systems.

$$g = \alpha + \sum_{i=1}^{m} \beta_i b_i$$

Where g is the objective function value; b is the parameter; α is the regression constant; β corresponds to the technical coefficient attached to the variable b; and m is equal to the number of parameters.

The mean fluctuations in the objective function, which are ascertained by contrasting the t-stat and p-value values, indicate a parameter's sensitivity. Greater sensitivity is indicated by a smaller p-value and a higher t-statistic, whilst a smaller p-value denotes a 95% chance that a change in the parameter would have an impact on the dependent variable.

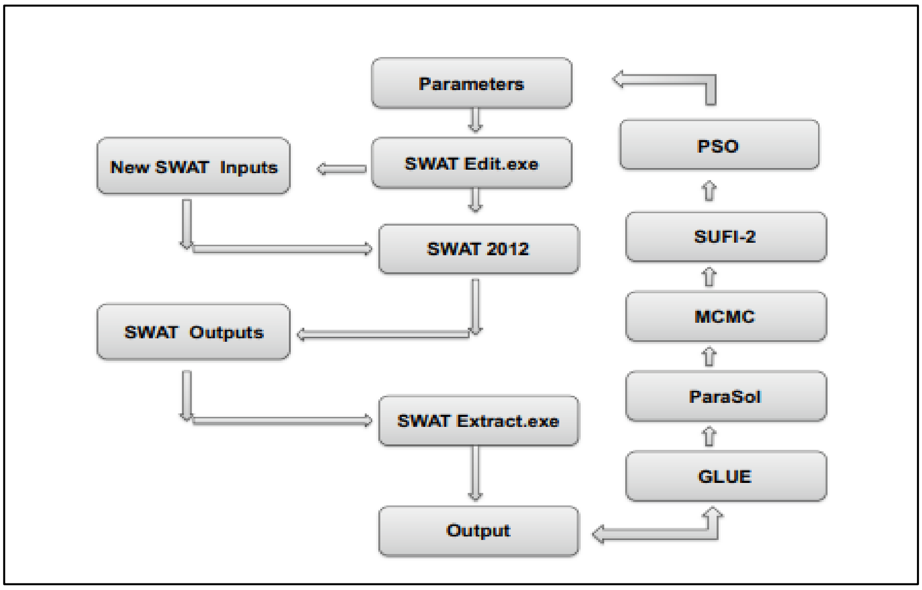

Figure 5. Complete program structure of SWAT-CUP

2.2.5 Model Calibration and Evaluation

The SWAT-CUP package of Abbaspour et al (2007) utilized the sequential unpredictability fitting technique application SUFI-2 to measure the dependability of the calibrating SWAT model. As a result, the SUFI-2 has the advantages of combining optimization with unpredictability analysis, being simple to use, and being able to handle a wide range of inputs with the use of LHS. SUFI-2 allows the user to perform the global sensitivity analysis as incorporated among the Latin Hypercube and the multiple regression analysis. The multiple regression equation is defined as below (Keenan& Cleugh, 2011):

$$g = \alpha + \sum_{i=1}^{m} \beta_i * b_i$$

Where: g is the value of the evaluation index for the model simulations, α is a constant in multiple linear regression equation, β is a coefficient of the regression equation, b is a parameter generated by the Latin hypercube method and m is the number of parameters.

The equation's t-statistic, which measures parameter sensitivity, is used to calculate each parameter's relative importance; the more sensitive the parameter, the higher the t-statistic absolute value. When p-value is utilized, it serves as a measure of the sensitivity's relevance; p-values near 0 are more significant.

3. Results

3.1. SWAT Model Performance Evaluation

Table 1. SWAT Model Performance Evaluation

Metric	Value
P-factor	0.87
R-factor	0.74
Coefficient of Determination (R^2)	0.91
Nash-Sutcliffe Efficiency (ENC)	0.80

The SWAT model performance for the Alguwair area was evaluated using the following metrics: The P-factor is the part of the measured data enveloped by the 95% prediction uncertainty (95PPU). The reported P-factor of 0.87 implies that 87% of the results that were observed were within the model's 95% prediction interval. This implies that the model was able to capture the observed hydrological processes in the study area. The R-factor is the quantity formed as the ratio of the average width of the 95PPU band to the standard deviation of the measured variable [19].

The R-factor value of 0.74 means that the range of 95PPU is approximately 74% of the standard deviation of the measured data. The smaller the R-factor value, the better the performance of the model and the narrower the uncertainty range. The coefficient of determination (R^2) is the degree of fit of the data to the linear regression equation between the observed and the simulated values.

The reported value of $R^2$of the model was 0.91 simply means that the model has the highest correlation that is, 0.91, which means the model was able to explain 91% of the observed data. Last, the Nash Sutcliffe Efficiency NSE indicates the relative measure of the residual variance to the measured data variance. The NSE value was 0.80 indicates that the ability of the model in the estimation of the hydrological processes is incredibly good, meaning that any value more than 0.75 are mostly acceptable [20].

In general, confirmed by a rather high P-factor, a rather low R-factor, and a very high coefficient of determination R^2 and Nash Sutcliffe efficiency NSE, it can be concluded that the SWAT model successfully approximated the hydrologic processes in Alguwair area including recharge. These performance metrics give confidence in the ability of the model to evaluate the effects of changing climatic conditions on the water resource in the study region [21].

3.2 Parameters Sensitive Analysis of SWAT

Table 2. Parameters Sensitive Analysis of SWAT

Parameters	Description	Rank	Calibrated values	
			Initial values	Fitted values
CN2.mgt	Number on the initial SCS runoff curve for condition II moisture	1	-0.3 to 0.3	0.04
Alpha_BF.gw	Baseflow alpha factor (days) in the shallow aquifer	2	0 to 1	0.22
ESCO.bsn	Soil evaporation compensation factor	3	-0.1 to 0.5	0.41
EPCO.bsn	Plant uptake compensation factor		50 to 500	248.9
SOL_AWC.sol	Available water capacity of the soil layer (mm H2OAvailable water capacity of the soil layer (mm H2O/mm soil−1/mm soil−1)	4	0.1 to 25	19.8
SOL_BD.sol	Moist bulk density (gcm−3)	5	0 to 0.3	0.14
GW_DELAY.gw	Groundwater delay (days)	6	0 to 0.3	0.25
SURLAG.bsn	Surface runoff lag coefficient (days)	7	-4 to 4	3.75
GW_REVAP.gw	Groundwater "revap" coefficient	8	-0.3 to 0.3	0.04

Using 25 parameters, the SWAT model represents stream flow. These parameters need to undergo sensitivity analysis before being prioritized in order to avoid ineffective parameters from the model. There appear to be eight most sensitive parameters, according to the data displayed in table (1). Therefore, CN2 was identified as the dominant SWAT calibration parameter for the Alguwair area basins. In most SWAT applications in different watersheds CN2 was the most sensitive parameter that was identified. CN2 has large influence on the degree of runoff produced by the HRUs; therefore, a higher sensitivity index can be expected for the majority of the basins.

Among all the parameters, the most affected was the curve number (CN2. mgt) that deals with the runoff originating from the watershed. The calibrated value that has been arrived at is 0. 04 shows that the model needed the first CN values to be adjusted a little higher than measured streamflow data. The second most sensitive parameter was the base flow alpha factor, Alpha_BF.gw that was calibrated to 0. 22. This parameter adjusts the recession constant of the baseflow component, and their calibrated values indicate that the baseflow of the watershed responds quickly.

The soil evaporation compensation factor (ESCO. bsn) was the third most sensitive parameter, with the calibrated value of 0. 41. This parameter modifies the depth distribution for evaporation from the soil profile and confirmed that the model needed a better compensation factor to simulate the real physical processes of soil evaporation. The fourth most sensitive parameter, in terms of calibrated value, was the available water capacity of the soil layer (SOL_AWC.sol) with its calibrated value of 19. 8 mm H2O/mm soil. This parameter determines the extent to which water can be held in the soil profile and that is available to plants; the calibrated value indicates that the soil in the watershed has a relatively high capacity for holding water.

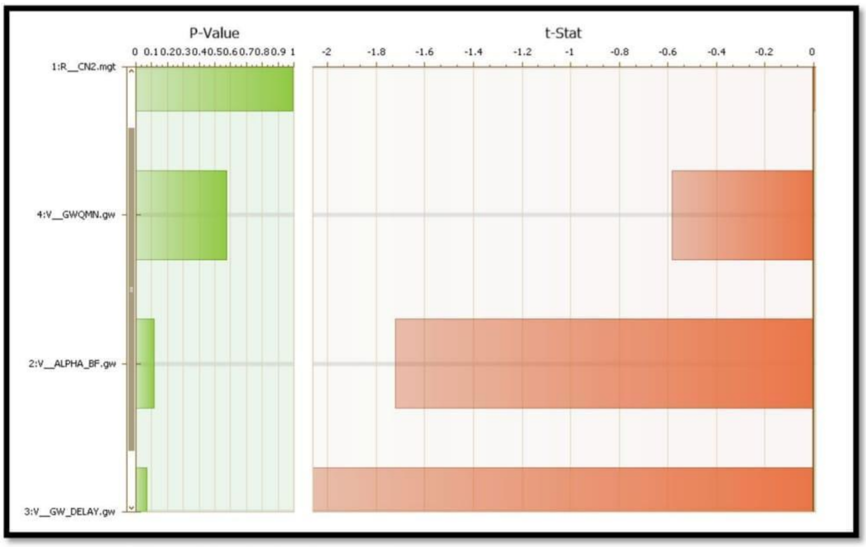

Figure 6. Sensitivity analysis using t-Stat and P-Value

3.3 Calibration and Validation

Table 3. Calibration and Validation

Metrics	Calibration	Validation
P-factor	0.85	0.87
R-factor	0.72	0.74
Coefficient of Determination (R^2)	0.89	0.91
Nash-Sutcliffe Efficiency (ENC)	0.78	0.8

The SWAT model was proven to have a good fit and yield a good predictive ability for both the calibration and the validation. The P-factor of 0.85 means, 85% of variations actually observed are accounted for by the model and the R-factor of 0.72 means a better fitment. The coefficient of determination or R^2 of 0.89 suggests that 89% of the tendencies of the dependent variable are explained by the independent variable.

The Nash-Sutcliffe Efficiency (ENC) was 0.78 reveals the capacity of the model in emulating the central tendencies of the observed data. For the overall workout, the P-factor is 0.87 signifies a slight better fitness of the model by explaining 87 percent of the actual variation. The R-factor of 0.74 suggests that there is a fair level of accuracy between the actual and the modeled data.

The Nash-Sutcliffe Efficiency, in this case, is 0.80 is desirable in terms of how effectively the model recreates observed data after calibration. The SWAT model was calibrated and validated using the SUFI2 program in the SWAT-CUP computer based tool. Runoff was the parameter of sensitivity used to calibrate the model. The simulation was performed after completing the SWAT model calibration and included calibrated parameters. It is also noted that simulation of the storm peak was overestimated; the observed storm peak in January 2016 and April 2019 was higher than the required one. The validity of the assessments used in the model depended on the quality of the information obtained on soil, land use, and the cover. The general prediction of the model was satisfactory as seen from the overall trend, but the observed and simulated runoff spread was too compact.

3.4 Use of SWAT to calculate groundwater recharge

Table 4. Groundwater Recharge Estimates

Aquifer Type	Average Recharge (mm/year)	Maximum Recharge (mm/year)	Minimum Recharge (mm/year)
Shallow Aquifer	350	420	280
Deep Confined Aquifer	500	580	450

In the research region, groundwater recharge was estimated at the watershed scale using the SWAT model. The SWAT model is essentially a detailed, semi-distributed surface and subsurface flow model that may simulate agricultural chemicals and sediment. In the study site for the shallow aquifer, the total annual recharge potential was found out to be 350 mm/year with the maximum of 420 mm/year and the minimum of 280 mm/year.

Such values imply that the shallower aquifer in the study area undergoes significant recharge via infiltration, besides lateral contribution from nearby water bodies. The deep confined aquifer was estimated to have higher average groundwater recharge of 500mm/year with the maximum of 580 mm/year and the minimum of 450mm/year as shown in table 3. The higher recharge rates in the deeper aquifer may imply that it is hydraulically connected to the shallow aquifer or other sources of recharge through vertical leakage or preferred flow paths.

Due to the variations in the re-charge estimates for the shallow and the deep aquifers, it was deemed necessary to explain some factors that will influence the two aquifer systems Deep aquifers are different from the shallow aquifers in depth, geology, and hydraulic properties. Depending upon the depth a ground water is more susceptible to surface water as well as climate variations a shallow aquifer can borrow water from shallow wells a deep aquifer may get recharge from more broader or longer period source.

Table 5. Estimation of groundwater recharge using SWAT model (2016–2023)

Year	Rainfall in mm	Recharge in mm	Recharge in %
2016	850	320	37.6
2017	900	310	34.4
2018	950	340	35.8
2019	870	330	37.9
2020	920	345	37.5
2021	880	325	36.9
2022	850	320	37.6
2023	900	310	34.4

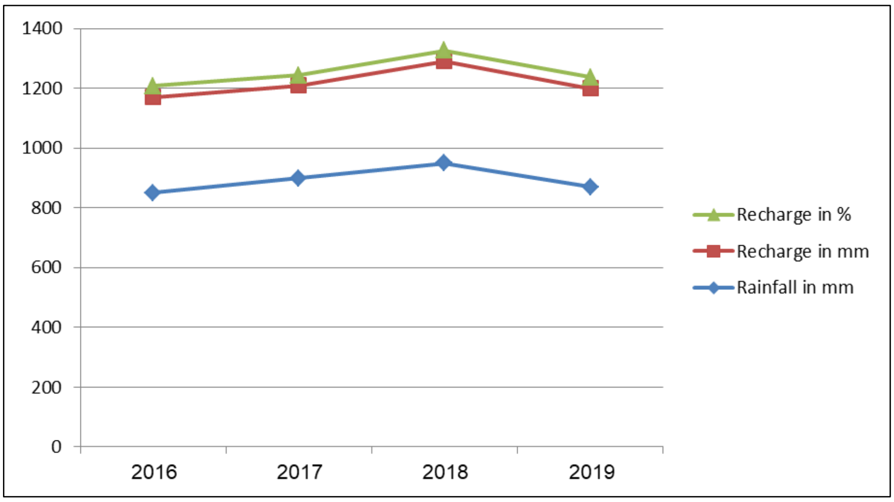

Figure 7. Estimation of groundwater recharge using SWAT model (2017–2022)

The two most prevalent land use types in the river basin are agriculture and forest land. The input data for the SWAT model was analyzed using computerized soil and land use maps, daily rainfall data from two rain gauges, and meteorological observations made inside the watershed for daily relative humidity (RH), wind speed (WS), solar radiation (SLR), and temperature (TMP). The SWAT model was fine-tuned for seven years utilizing daily stream flow data and the global optimization method.

Annual recharge estimated in the present study with the help of SWAT model varied shown in table4 and Fig7, between 850mm and 950 mm during this period. The estimates of the rates of groundwater recharge obtained with the SWAT model present a notable response to rainfall at the same site. The rainfall received in the year 2016 was found to be 850mm and accordingly, the estimated ground water recharge was 320mm which is equivalent to 37.6% in the total rainfall. Similarly, in 2017, while the rainfall was at 900 mm, the recharge was estimated at 310 mm, or 34.4% of the rainfall.

The recharge percentage has been fluctuated over the years and has averaged at a low of 34.4% in 2017 to a high of 37.9% in 2019. This might imply that some of the physical properties of the watershed including the soils, land use, and the relief played the most important role in determining the nature of the recharge-rainfall equation rather than the yearly fluctuations. The fair fluctuating of the recharge percentage for different years offers enable a confident conclusion that the SWAT model can better simulate the Alguwair area groundwater recharge.

4. Discussion

The study aimed to evaluate the recharge of the groundwater through the SWAT model and understanding of the hydrological processes and an allusion of the climate change in the Alguwair area, Northern Iraq. Data retrieved from the SWAT model showed that of all the parameters used, CN2. mgt, Alpha_BF. gw, ESCO. bsn, SOL_AWC.sol, and SOL_BD. sol were the most critical in predicting the hydrology of the watershed. Consequently, the findings of this study indicate that the primary processes controlling the recharge of the groundwater reservoir in the research area depend on the characteristics of the watershed, the soil that overlies the aquifer, and the land cover as well as surface water and ground water interaction.

The simulation of the SWAT model proved that the shallow aquifer gets the level of recharge of 350mm per year on average, with lower limit of 280 mm/year and upper limit of 420 mm /year. In the other hand the deep confined aquifer has slightly higher average recharge of 500mm/year, maximum of 580mm/year and minimum of 450mm/year. Such differences could be as a result of the differences in recharge rates occasioned by the controlling hydrogeological factors as well as the level of interconnection between the shallow and deep aquifer systems.

For the assessment on the recharge of groundwater under varying climatic conditions, the results indicated that according to the recorded data of the 2016-2023 years, the annual rainfall in the Alguwair area varied from 850 mm to 950 mm, and, therefore, the corresponding recharge estimations made up 34.4% to 37. The proportion contributed for the total rainfall by this source is only 9 percent. The year-to-year stability in the recharging-rainfall curve an indication that other than the year to year fluctuations in rainfall, the other hydro-geological characteristics of the Watershed are the main determinates of the extent of probable groundwater recharge. Nonetheless, the research found out that climate change effects such as changes in precipitation, temperature, and evapotranspiration might affect the nature of the Alguwair area’s groundwater recharge in the long run. This paper has also shown that as climate is continues to change then the SWAT model would be useful for relating the changing climate to groundwater resources and for guiding the creation of effective water management practices.

5. Conclusion

The Soil and Water Assessment Tool (SWAT) model was employed in evaluating the Recharge in the Alguwair area of Northern Iraq with emphasis to climatic variability. The model has shown processes controlling recharge at a given area including the type of soil, land use and hydrological interface of the water table and surface water. The shallow aquifer was recharged at an average rate of 350mm/year and the deep confined aquifer at an average of 500mm/year. The study also revealed a strong correlation in recharge and precipitation whereby recharge was estimated to contribute 34.4% to 37.9% of total rainfall. Nonetheless, climate change effects like changes in rainfall frequency and intensity as well as evapotranspiration can affect the rate of groundwater recharge in the long-run. This paper has shown that the SWAT model can be used to fit proper water management strategies to support the sustainable use of groundwater resources. The results of this study would offer insights, which could be beneficial to water resource managers and policymakers in the Alguwair area, while formulating sustainable groundwater extraction and management strategies.

REFERENCES

[1] S. A. Abbas, Y. Xuan, and R. T. Bailey, "Assessing Climate Change Impact on Water Resources in Water Demand Scenarios Using SWAT-MODFLOW-WEAP," Hydrology, vol. 9, no. 10, p. 164, 2022.

[2] K. C. Abbaspour, J. Yang, I. Maximov, R. Siber, K. Bogner, J. Mieleitner, J. Zobrist, and R. Srinivasan, "Modelling Hydrology and Water Quality in the Pre-Alpine/Alpine Thur Watershed Using SWAT," Journal of Hydrology, vol. 333, pp. 413–430, 2007.

[3] S. Adhikari, L. Caron, B. Steinberger, J. T. Reager, K. K. Kjeldsen, B. Marzeion, and E. R. Ivins, "What Drives 20th Century Polar Motion?," Earth and Planetary Science Letters, vol. 502, pp. 126–132, 2018.

[4] M. A. Ali, S. A. Salih, and A. I. Hussain, "Groundwater Situation Before Production and After Production Stoppage in Al-Mishraq Sulfur Field-1, Northern Iraq," Iraqi Journal of Science, pp. 5095–5107, 2023.

[5] S. M. Awadh, H. Al-Mimar, and Z. M. Yaseen, "Groundwater Availability and Water Demand Sustainability Over the Upper Mega Aquifers of Arabian Peninsula and West Region of Iraq," Environment, Development and Sustainability, vol. 23, no. 1, pp. 1–21, 2021.

[6] A. Bauwe, P. Kahle, and B. Lennartz, "Evaluating the SWAT Model to Predict Streamflow, Nitrate Loadings and Crop Yields in a Small Agricultural Catchment," Advances in Geosciences, vol. 48, pp. 1–9, 2019.

[7] A. A. F. Beg and A. H. Al-Sulttani, "Spatial Assessment of Drought Conditions Over Iraq Using the Standardized Precipitation Index (SPI) and GIS Techniques," in Environmental Remote Sensing and GIS in Iraq, pp. 447–462, 2020.

[8] H. J. G. Diersch, FEFLOW: Finite Element Modeling of Flow, Mass and Heat Transport in Porous and Fractured Media. Berlin, Germany: Springer Science & Business Media, 2013.

[9] M. K. Goyal and R. Y. Surampalli, "Impact of Climate Change on Water Resources in India," Journal of Environmental Engineering, vol. 144, no. 7, p. 04018054, 2018.

[10] H. S. Hashim, Z. B. Hassan, and S. B. M. Drus, "Internet of Things: A Systematic Literature Review," Informatica, vol. 46, no. 8, 2022.

[11] W. H. Hassan and F. S. Hashim, "Studying the Impact of Climate Change on the Average Temperature Using CanESM2 and HadCM3 Modelling in Iraq," International Journal of Global Warming, vol. 24, no. 2, pp. 131–148, 2021.

[12] L. Hossard and P. Chopin, "Modelling Agricultural Changes and Impacts at Landscape Scale: A Bibliometric Review," Environmental Modelling & Software, vol. 122, p. 104513, 2019.

[13] Q. H. Jalut, N. L. Abbas, and A. T. Mohammad, "Management of Groundwater Resources in the Al-Mansourieh Zone in the Diyala River Basin in Eastern Iraq," Groundwater for Sustainable Development, vol. 6, pp. 79–86, 2018.

[14] T. Keenan and H. Cleugh, "Climate Science Update: A Report to the 2011 Garnaut Review," Centre for Australian Weather and Climate Research, Canberra, 2011.

[15] N. W. Kim, I. M. Chung, Y. S. Won, and J. G. Arnold, "Development and Application of the Integrated SWAT–MODFLOW Model," Journal of Hydrology, vol. 356, no. 1-2, pp. 1–16, 2008.

[16] S. J. Kollet and R. M. Maxwell, "Integrated Surface–Groundwater Flow Modeling: A Free-Surface Overland Flow Boundary Condition in a Parallel Groundwater Flow Model," Advances in Water Resources, vol. 29, no. 7, pp. 945–958, 2006.

[17] S. L. Markstrom, R. G. Niswonger, R. S. Regan, D. E. Prudic, and P. M. Barlow, "GSFLOW-Coupled Ground-Water and Surface-Water FLOW Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005)," US Geological Survey Techniques and Methods, vol. 6, p. 240, 2008.

[18] V. Nechifor and M. Winning, "Global Economic and Food Security Impacts of Demand-Driven Water Scarcity—Alternative Water Management Options for a Thirsty World," Water, vol. 10, no. 10, p. 1442, 2018.

[19] S. A. Salman, S. Shahid, T. Ismail, E. S. Chung, and A. M. Al-Abadi, "Long-Term Trends in Daily Temperature Extremes in Iraq," Atmospheric Research, vol. 198, pp. 97–107, 2017.

[20] R. Therrien, R. G. McLaren, E. A. Sudicky, and S. M. Panday, A Three-Dimensional Numerical Model Describing Fully-Integrated Subsurface and Surface Flow and Solute Transport: User Guide, 2010.

[21] Y. Wang, R. Jiang, J. Xie, Y. Zhao, D. Yan, and S. Yang, "Soil and Water Assessment Tool (SWAT) Model: A Systemic Review," Journal of Coastal Research, vol. 93, pp. 22–30, 2019.