Water Resources and Surveying Engineering

Estimation of Surface Runoff to Bahr AL-Najaf

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ABSTRACT

The estimation of the amounts of Surface runoff resulting from rainfall in the water basins is of great importance in water resources management. The study area (Bahr Al-Najaf) is located on the western edge of the plateau and the southwestern part of the city center of Najaf, with an area of 2729.4 (km^2). The soil and water assessment tool (SWAT) with ArcGIS software was used to simulate the runoff coming from the three main valleys (Kharr (A and B)), Shoaib Al-Rahimawi, and Maleh), that contribute the flow to the study area. The results of the model showed that the SWAT software was successfully simulating the flow conditions based on the coefficient of determination (R^2), the Nash coefficient (NSE), P-factor, and R-factor for calibration (validation) ranged between 0.59-0.62 (0.51-0.59), 0.59-0.66 (0,.60-0.62), 0.57-0.76 (0.62-0.76), and 0.58-0.74 (0.55-0.70) respectively for these valleys. Moreover, the sensitivity results revealed that the most sensitive parameters in (SWAT-CUP) SWAT calibration and uncertainty programs are the curve number (CN2) for the runoff, soil available water capacity (SOL_AWC), and Saturated hydraulic conductivity (Soil_k), according to the calibration results for the main three valleys related the study area. Three hypothesis scenarios were implemented according to the assumed amount of precipitation that would submit a water level of 16,18, and 22 (m.a.m.s.l.) which would result in filling with the bounded lake, the whole study area, and exceeding the boundaries to flood part of the ancient Najaf City.

Keywords: Bahr AL-Najaf Watershed, runoff, sensitivity analysis, SWAT-CUP, SWAT model, water balance.

تقدير الجريان السطحي الوارد لبحر النجف

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الخلاصة

ان تقدير كميـات الجريــان السـطحي النـاتج عـن سـقوط الأمطـار فـي الأحـواض المائيـة لـه أهميـة كبيـرة فـي مجـال إدارة الموارد المائيـة. تقـع منطقـة الدراسـة (بحـر النجـف) علـى الحافـة الغربيـة للهضبـة والجـزء الجنـوبي الغربـي مـن مركـز مدينــة النجــف بمســاحة 2729.4 كيلــومتر مربـع. تــم اســتخدام أداة تقيــيم التربــة والميـاه (SWAT) مــع برنـامج ArcGIS لمحاكـاة الجريــان السـطحي القـادم مـن الأوديـة الثلاثـة الرئيسـية (الخـر (أ و ب) وشـعيب الرحيمـاوي والمـالح) ، والتـي تسـاهم فـي التـدفق لمنطقـة الدراسـة. أظهـرت نتـائج النمـوذج أن برنـامج SWAT نجـح فـي محاكـاة ظـروف التـدفق بنـاءً علـى معامـل التحديـد (R²) ومعامـل نـاش (NSE) وعامـل P وعامـل R للمعـايرة (التحقـق) تراوحــــت بــــين 0.62 -0.59 (0.59-0.51) ، (0.66-0.59 (60.-0.62) ، 0.76-0.57 (0.76-0.62) ، 0.58- 0.74 (0.70-0.55) لهـذه الوديـان علـى التـوالي. عـلاوة علـى ذلـك ، كشـفت نتـائج الحساسـية أن أكثـر المعلمـات حساسـية فـي بـرامج معـايرة SWAT وعـدم اليقـين (SWAT-CUP) هـي رقـم المنحنـى (CN2) للجريـان السـطحي ، وسـعة الميـاه المتاحـة للتربـة (SOL_AWC) ، والتوصـيل الهيـدروليكي المشـبع (Soil_k) ، وفقًـا لنتـائج المعـايرة للوديـان الثلاثـة الرئيسـية المتعلقـة بمنطقـة الدراسـة. تـم تنفيـذ ثـلاث سـيناريوهات فرضـية وفقًـا لكميـة السـقيط المفترضـة التـي مـن شـأنها أن تقـدم مسـتوى مـائي 16 و 18 و 22 (ملـم) ممـا ينـتج عنـه امـتلاء البحيـرة المحصـورة ومنطقـة الدراســة بأكملهـــا وتجــــاوز الحــــدود لفيضــان جــزء مــن مدينــة النجــف الاثريـــة.
الكلمــات الرئيســية: مسـتجمعات ميـاه بحـر النجـف ، الجريــان السـطحي ، تحليـل الحساسـية ، SWAT-CUP ، نمـوذج SWAT ، توازن المياه.

1. INTRODUCTION

At present, different hydrological models are developed in the valleys to check the climate change impact and soil characteristics on the hydrological cycle. The relation between runoff and rainfall is important in managing the available water resources through hydraulically design and flood control structures. The field research in the Bahr Al- Najaf area was performed to find out the capacity of bearing for the bored bile model established in gypseous soil. Several criteria have been used to calculate the bearing capacity of the model bored pile through the results of the pile load tests **(Al-Busoda and Al-Rubaye, 2015).** While the other field study has considered two sites were chosen to determine the rate of water leakage in the depth of pits filled with water in these two sites in the study area with an area (2 m x 1.5 m and 0.5 m). Two sites were used, the first site to investigate the characteristics of infiltration and the second to verify the results, and they classified the type of infiltration rates as moderate to high **(Al-Saoudi, et al., 2014).** A field study was conducted in the study area Bahr Al- Najaf showed a correlation between the hydraulic and geoelectrical parameters and dictated that most of the selected wells and boreholes located in the studied area have depths of more than (100) m. They were classified into two types of self-flowing of artesian wells, but few are artesian only (non-flowing) **(Thabit, et al., 2014).** An analysis of a hydrological study directed that the spatial distribution of average runoff depth from sub-basins indicated that the intermediate sub-basins are the highest in contributing to the watershed runoff **(Omran, et al., 2014).** A relied study was conducted on the Bouregreg Basin located in north-central Morocco for water resources to evaluate and simulate the watershed's hydrology using SWAT and to analyze and define the hydrological processes of the watershed with different conditions. The model showed a good correlation between the observed and simulated monthly average river discharge with R² and Nash coefficient of about 0.8. These results revealed that the SWAT model could be used efficiently in semi-arid regions to support water management policies

(Fadil, et al., 2011). SWAT model was used in the Upper Zab river basin to forecast and simulate the flow in the Upper Zab river watershed efficiently. The obtained results helped study and expect future amounts of resource discharges on the Tigris river's effects. Also, results show a redaction on the precipitation and flow on the river basin in the future, which will cause an impact on the Tigris river resources and a major impact on hydrological regimes **(AL-Heetimi, et al., 2016).** This study aimed to model surface runoff using (SWAT) model in the Ketar watershed and the importance of development and suitable strategies of runoff modeling for the designers for watershed management. Where, the results show that there was an excellent relation between monthly observed and simulated streamflow during both calibration and validation **(Sime, et al., 2020).** Another study evaluated performance for modeling the precipitations and rainfall in the Watershed of Laou; they showed the feasibility of implementing the SWAT model was enabled to simplify the representation of the flows on the watershed **(Aqnouy, et al., 2019).** Other Studies involved the variation in surface parameters (e.g., Topography, soil, and land cover) that affected the linkage between rainfall and surface water in watersheds **(Shivhare, et al., 2014).** Conducted a study to estimate the groundwater vulnerability in the Bahr Al-Najaf area, the middle of Iraq. The researcher's used data in this study were of two types: spatial data and non-spatial data, and the scope of pollution was analyzed by developing the seven map layers and generating the drastic technique **(Al-Aboodi and Hashim, 2018**).

(**Singh and Saravanan, 2020**) conducted a study to simulate streamflow and predict water balance components by using the (SWAT) model for the Ib River watershed in India's Mahanadi geographical area. The results showed that the calibration better response than verification as the parameter setting, Nash-Sutcliffe efficiency, and percentage bias was 0.77. 0.75 and 19.1, respectively. (**Khayyun, et al., 2019**) conducted a study on the hydrological processes in The Watershed area of the Hamrin Dam, located in Iraq, at the middle river Diyala reach. The study aims to estimate the surface runoff of the middle River Diyala by using Arc SWAT and the model's calibration by using monthly observed discharges. Used the Arc SWAT Software to estimate the amount of runoff that comes from the valleys in the Western Desert of Iraq that flow into the Haditha dam reservoir. The study results demonstrated that the SWAT software could be useful in modeling the valleys **(Hussein, et al., 2016).** Researchers have been building a hydrological model for the Mecis watershed in Morocco using Arc SWAT software. This research aims to correct water resources in the study area using the SWAT model, which needs a set of computer files, including rainfall, soil characteristics, land use, temperature, and a digital elevation model (DEM). When calibration, the SWAT-CUP Software was used with the sequential uncertainty fitting version 2(SUFI-2) procedure to find out the efficiency ratio of the model, where the results were good and the statistical indicators with suitable results $R^2 = 0.74$, NSE = 0.67 **(Khalid, 2017).** Conducted a study using the (SWAT) model in an ungauged catchment to test SWAT performance in simulating the discharge in daily and monthly time-step for both calibration and validation in one of the sub-catchments of Tonle Sap Basin in Cambodia called Stung Pursat River catchment. The study results showed that the SWAT model is quite good at simulating discharges with the changes in time series daily and monthly for both calibration and verification periods **(Ang and Oeurng, 2018). (Mustafa, et al., 2016)** conducted a study using the (SWAT) model Haditha reservoir catchment to test SWAT performance to find the amount of sediment and rates of flow that flows. Model calibration and verification were carried out using flow rate and sediment yield data observed at the study area, and the results were satisfactory.

This study aims to develop a numerical model to simulate the Surface Runoff by using SWAT software in the study area (Bahr Al-Najaf) and checkup the possibility of floods occurs due to high water levels.

2. Materials and methods

2.1 Soil and Water Assessment Tool (SWAT)

Soil and Water Assessment Tool (SWAT) is applied to model the hydrology of the Bahr AL-Najaf watershed in Iraq. In this study, the data set used in the simulation is considered a description of the study area and the hydrological model. SWAT is a physically-based model that requires specific input details about the weather, soil properties, topography, vegetation, and land cover changes in the watersheds. In the model processes, a watershed can be partitioned into several sub-basins, which are divided into Hydrologic Response Units (HRUs). The land phase of the hydrologic cycle is based on the water balance equation **(Neitsch, et al., 2011):**

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad (1)$$

where t is time measured by days, SW_t and SW_0 are the water content of the soil at the final and initial time measured by mm, R_{day} is the daily precipitation depth mm, Q_{surf} is the daily surface runoff mm, E_a is the evapotranspiration in mm, W_{seep} is the percolated water in mm, and Q_{gw} is the return flow in mm, all the parameter is for the day i.

2.2 Description of The Study Area

The study area (Bahr Al-Najaf) is one of the ancient low wetlands in Iraq. It was considered a natural lake, located in the southwestern part of Najaf City Centre. The location of an area can be specified by 44º 11′ 34″ to 44º 22′ 37″, and 31º 47′ 11″ to 32º 04′ 08″ longitudes and latitudes respectively, with a total surface area of 251 km². It involves a lake with an approximate area of 49 km². That area was increased and decreased due to inflow and precipitation and weather conditions in summer and winter periods. The region is characterized as a desert area in which water levels rise in the winter season due to increased rainfall. In the summer season the depths of evaporation increase. The study area represents an extension of the alluvial natural plain in the western plateau that forms a tongue shape that extends across from the south towards the north side of Al-Manathira city **(Omran, et al., 2014)**. The slope of the study area is decreasing gradually from the west and from the south-west to the north and north-east. Many valleys deliver water to the study area (Bahr Al-Najaf), three main valleys have a large area, are Kharr, Shoaib Al-Rahimawi, and Maleh, as well as these valleys, contribute to the recharge of groundwater in the study area **Fig.1.**

2.3 Input Data

In this research, Digital Elevation Model (DEM), the land use, the soil map, and the weather information were used to provide the inputs for the SWAT model for conducting the calibration and verification process with the use of water level observations in the Bahr AL-Najaf watershed.

2.3.1 Digital Elevation Model (DEM)

The ground topography is considered an essential input of the SWAT model. It is a useful tool in analyzing the watershed and analysis of the characteristics of the land surface and the patterns of the drainage. Moreover, it usually affects the flow rate and direction over the ground surface **(Al-Khafaji and Saeed, 2018).** The digital elevation models (DEM) with 30m resolution were adopted for elevation ranges and spatial data of the study area provided by the global Shuttle Radar Terrain Mission (SRTM) from USGS. These DEMs were merged and reprojected to the UTM zone to be

ready for the Arc SWAT processes to delineate the watersheds and flow directions. **Fig. 2** shows the DEM of each basin.

2.3.2 Land use Map

The global land cover map was used from the European Space Agency Glob Cover Portal with a resolution of 300m for the period of December 2004 - June 2006. The study area contains two land-use classes, including Bare areas, Rainfed croplands, **Fig. 3.**

2.3.3 Soil Map

The soil Map used in the study was from the Food and Agriculture Organization at a scale of 1: 5000 000. The map is divided into many polygons. Each polygon contains different properties of study area soils such as hydrological soil group, hydraulic conductivity, soil texture, and other physical and chemical properties matched with the FAO soil database. These polygons were clipped to identify with the watershed area and then reclassified for the definition of Hydrological Response Units (HRUs). Soil data are merged using ArcGIS processes with DEM, Land-use, and slope classes into SWAT to define the HRU level, **Fig. 4.**

2.3.4 Weather Data

Arc SWAT Software requires information on weather like precipitation, solar radiation, temperature, relative humidity, and wind speed. Previous daily rainfall was obtained from the Iraqi Metrological Organization and Seismology (IMOS) for the Al-Najaf station for the period (2009-2019). It is stated that these data are invalid for use in the SWAT simulations. Weather data that is needed to run SWAT should be a continuous daily time-step. However, the weather data from IMOS is losing years and some months of weather data. Therefore, another weather data source was used in the study called the Climate Forecast System Reanalysis (CFSR). CFSR can provide weather data for regions that are missing weather stations. CFSR climate data are available for the period (1979-2014). A study by **(Fuka, et al., 2014)** showed that the weather data produced by CFSR to use for the purpose of watershed simulations are good or better than weather data used in simulations produced by traditional weather stations. These data were compared and calibrated with data from The Iraqi Meteorological Organization and Seismology (IMOS) for station Al-Najaf for the period (2009-2014). The R^2, NSE, and RMSE were 0.85, 0.77, and 6.88 for the calibration, respectively **Fig. 5.**
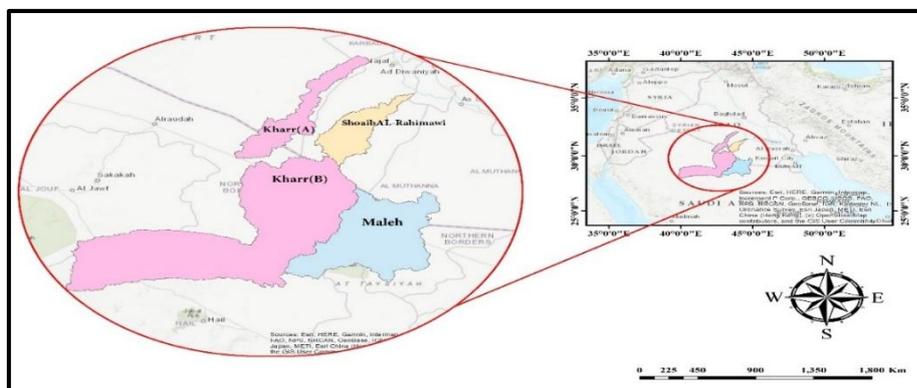
Figure1. The location of the study area, Bahr Al-Najaf, and the three feeding watersheds (valleys).
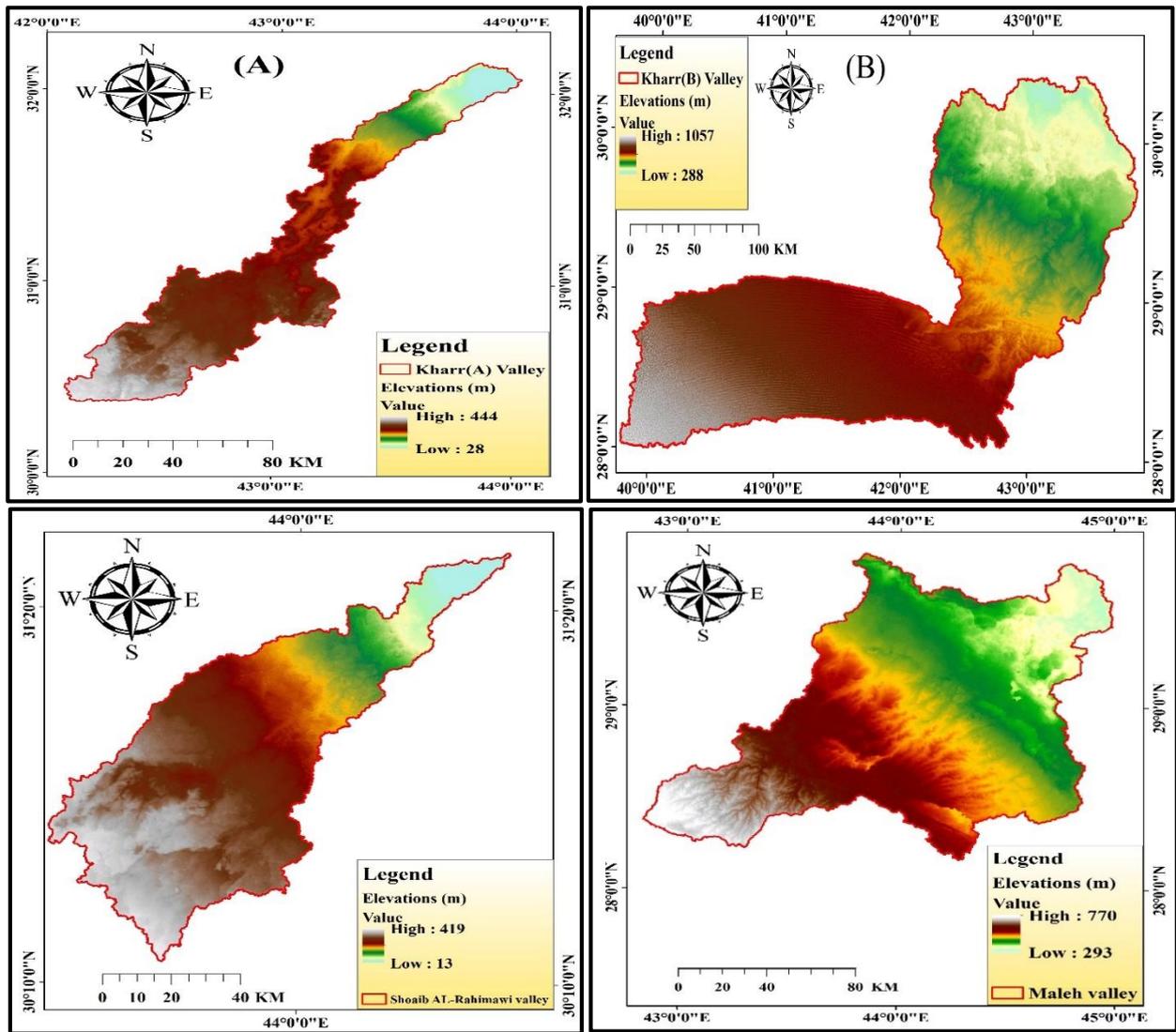
Figure 2. Kharr(A)Valley, Kharr(B)Valley, Shoaib AL_Rahimawi Valley, and Maleh valley
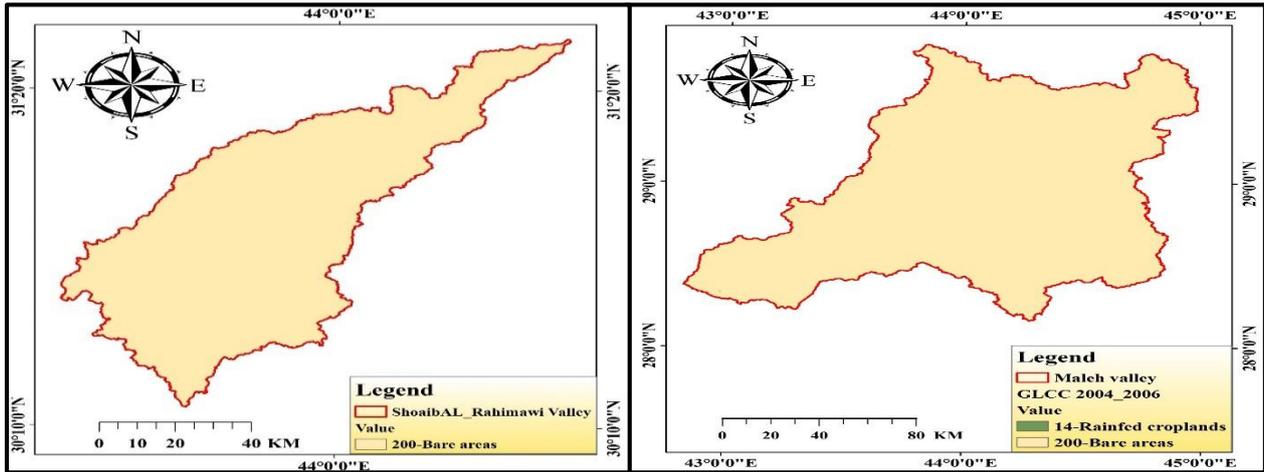
Figure 3. Kharr(A)Valley, Kharr(B)Valley, Shoaib AL_Rahimawi Valley and Maleh valley for Land use map.
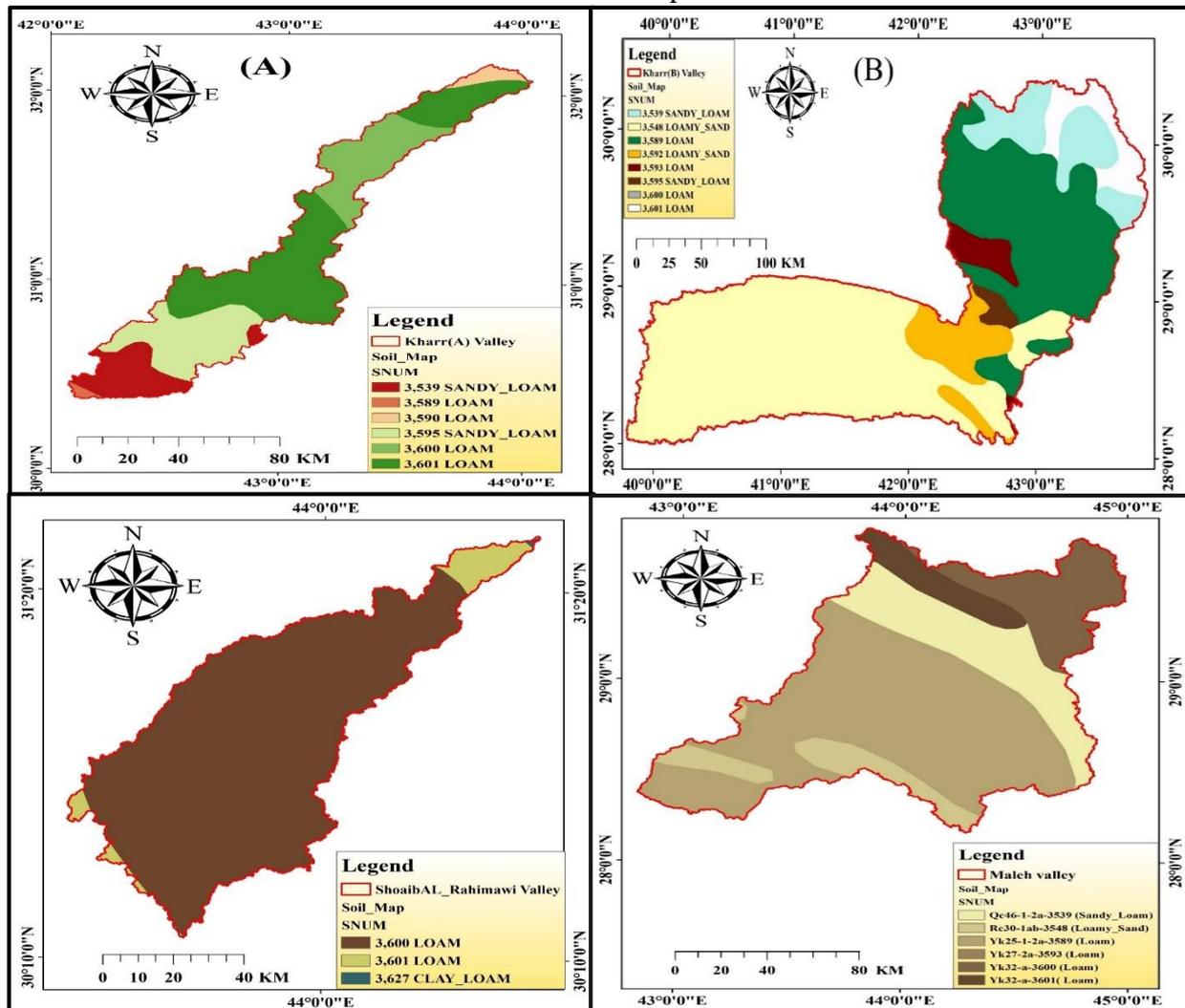
Figure 4. Kharr(A)Valley, Kharr(B)Valley, Shoaib AL-Rahimawi Valley, and Maleh valley for Soil map.

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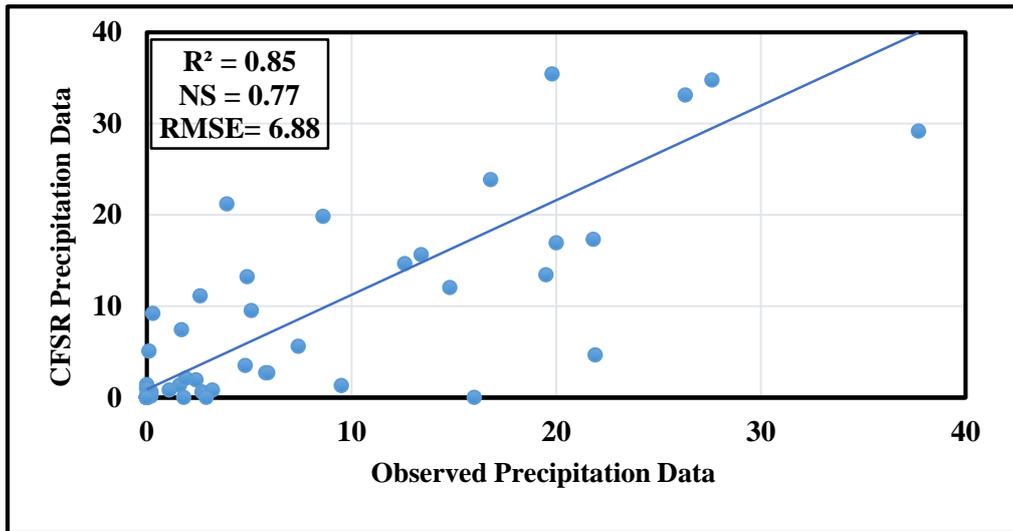
Figure 5. Result of Correlation between the Climate Forecast System Reanalysis Weather Data With AL-Najaf Gauge Station Weather Data.

3. SWAT-CUP Outputs

(SWAT-CUP) SWAT Calibration and Uncertainty Programs is a statistical software used in this study for titration and Validate the three valleys with monitored discharges. This section clarifies results, including the most sensitive parameters and objective function calibration results (2013-2016) and the two validation periods (2017-2019).

3.1 Sensitivity Analysis

The selected SWAT flow parameters were used for calibration in sensitivity analysis on monthly time steps of the observed discharges for the three valleys in the study area using SWAT-CUP. Sensitivity analysis was performed using T-Statistics and P-value methods to statistically assess the effect of these parameters on the SWAT runoff discharge. The results for T-stat and P-value show that the runoff curve number (CN2), and available water capacity for soil (SOL_AWC), and soil saturated hydraulic conductivity (SOL_K) are the most sensitive parameters in the valleys. **Table1.** And **Fig. 6.** illustrates the sensitivity analysis results using these two methods to one of the valleys, Maleh Valley.

Table 1. Sensitivity analysis of the runoff parameters for Maleh valley.

NO.	Parameter Name (Parameter Description)	t-stat	p-value
1	r_CN2.mgt (Runoff curve number)	71.154	0.00
2	v_ALPHA_BF.gw (Baseflow alpha factor)	0.32536	0.745
3	v_GW_DELAY.gw (Groundwater delay time)	-1.7764	0.079
4	v_GWQMN.gw (Treshold depth of water in the shallow aquifer required for return flow to occur)	1.1527	0.252
5	v_ESCO.hru (Soil evaporation compensation coefficient)	0.42428	0.672
6	r_SOL_AWC().sol (Soil available water capacity)	2.2157	0.029
7	v_OV_N.hru (Manning's "n" value for overland flow)	0.92480	0.357
8	r_SOL_K ().sol (Saturated hydraulic conductivity)	1.26926	0.207

Figure 6. Sensitivity Analysis graph produced by SWAT-CUP for Maleh valley.

4. Results of Calibration and Validation

Calibration and validation were performed for the three main Valleys Kharr, Shoaib AL_Rahimawi, and Maleh, for the period from (2012/10/1) to (2013/9/1) for the Calibration, and (2013/10/1) to (2014/5/1) for the validation. Calibration and validation of measured estimation discharges were performed with simulation discharges of the SWAT Software. The results were acceptable, Where the results of sensitivity when calibration and verification indicate a decrease in the value of R^2. The reason is that the values relating to the discharges were predictive discharges assumed by the Ministry of Water Resources. **Fig. 7** shows the obtained graph of calibrated and validated period to one of the valleys is Maleh Valley and **Table 2** shows the simulated and observed discharges were compared on monthly time steps using several model evaluation criteria.
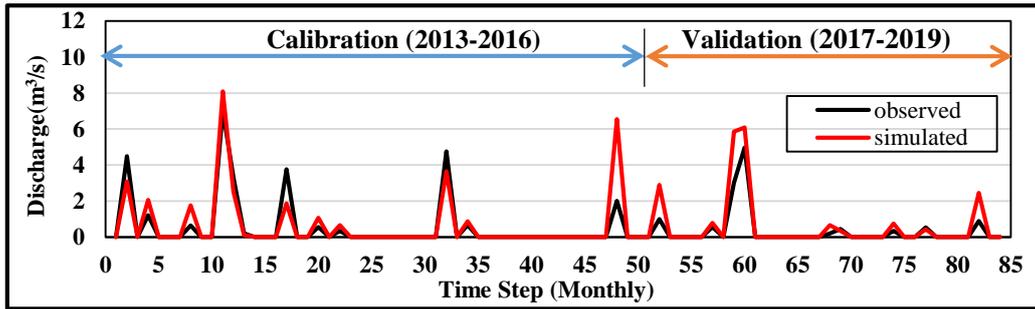
Figure 7. Comparison between the simulated and estimated discharges in the monthly time step for Maleh Valley's calibration and validation period.

Table 2. Criteria for testing the accuracy of the model calibration and validation for Maleh valley.

Model Evaluation	R^2	NS	P-factor	R-factor
CALIBRATION (2013 -2016)	0.61	0.62	0.38	0.11
VALIDATION (2017 – 2019)	0.58	0.59	0.62	0.44

5. Filling of Bahr AL-Najaf Scenarios

To study the water forecast for the Bahr AL-Najaf, three scenarios were proposed. The first Scenario is" Filling the bounded lake of 49 km^2". The results were obtained from the proposed scenarios for the Bahr Al-Najaf region. Firstly, if the precipitation depth is 90 mm, this amount of precipitation will lead to a rise in the water level in the region to (16 m.a.m.s.l) and lead to the lake filling with water for an area of (49 km^2). The second Scenario is "Filling of larger lake 251 km^2". If the rate of precipitation increased to 95 mm, it would lead to a rise in the water level in the lake to (18 m.a.m.s.l). The water would exceed the boundary of the lake that an area of (49 km^2) and the water would be delivered to the lake at an area of (251 km^2), this would lead to a rise in the water level to (18 m.a.m.s.l). The third Scenario is "The Possibility of Flood Occurrence". Finally, suppose the depth of precipitation reaches 100 mm. In that case, this will lead to a significant rise in the lake level, reaching (22 m.a.m.s.l), which will lead to the water exceeding the limits of the lake, which has an area of (251 km^2) and flooding the city with water and the delivery of water to the city. **Figure 8** shows the first proposed three scenarios when Filling the bounded lake of Bar Al-Najaf with water of 49 km^2 with a water level of (16 m.a.m.s.l), the second is the filling of a large lake of Bahr Al-Najaf with an area of 251 km^2 with a water level of (18 m.a.m.s.l), and the third is occurrence of the flood, and the city sinks with a water level of (16 m.a.m.s.l).
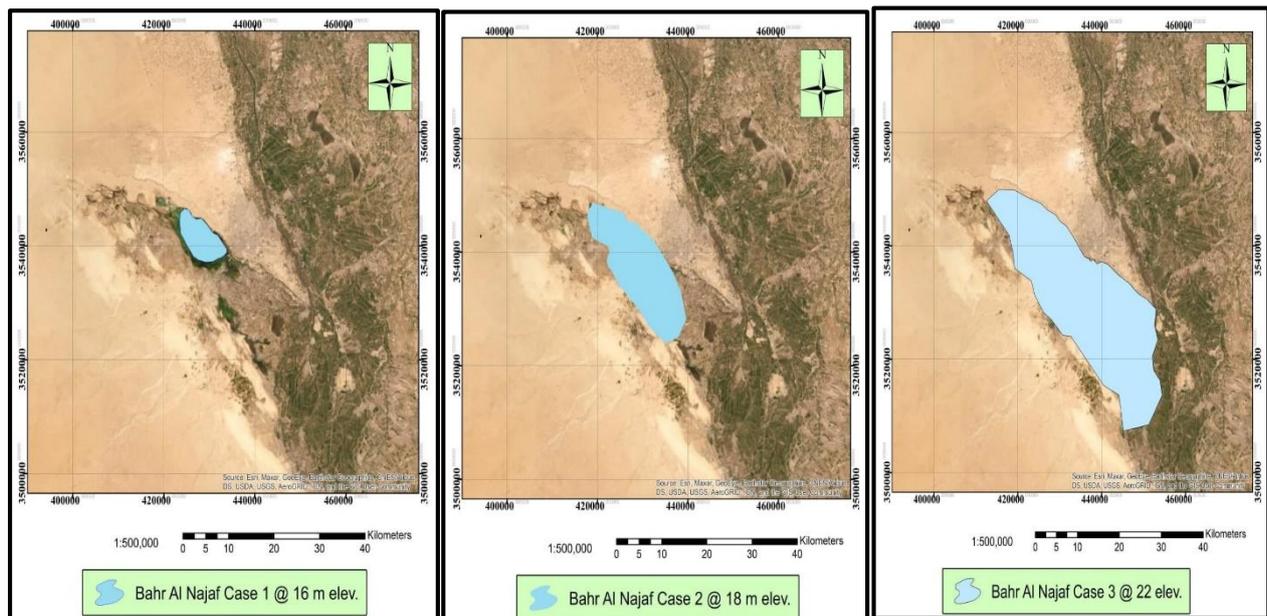
Figure 8. The three proposed scenarios in the study area.

6. CONCLUSIONS

1. The results of the model showed that the SWAT software was successfully simulating the flow conditions based on the coefficient of determination (R^2), the Nash coefficient (NSE), P-factor, and R-factor for calibration (validation), 0.61(0.58), 0.62(0.59), 0.38(0.62) and 0.11(0.44) respectively for the Maleh valley, one of the valleys in the study area.
2. The results showed that the Climate Forecast System Reanalysis (CFSR) weather data were used successfully in the modeling of Bahr AL-Najaf Watersheds. Where (CFSR) data were compared and calibrated with data from the Iraqi Meteorological Organization and Seismology (IMOS) for station Al-Najaf for the period (2009_2014). It can be concluded that the R², NSE, and root mean square error (RMSE) were 0.85, 0.77, and 6.88 for the calibration, respectively.
3. Three hypothesis scenarios were implemented according to the assumed amount of precipitation that would submit a water level of 16,18 and 22 (m.a.m.s.l.), resulting in filling with the bounded lake, the whole study area, and exceeding the boundaries to flood part of the ancient Najaf City.

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