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Stream flow modeling using SWAT model and performance evaluation in Adhaim watershed

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Abstract

Understanding the hydrological cycle and finding data crucial for water management require a foundational understanding of basin-scale simulation. To create the most accurate stream flow modeling possible, data from the weather stations was combined with input from other maps of the research area, such as soil, land cover, land use (LCLU), and digital elevation model (DEM). Regarding Adhaim Watershed, period 2000 to 2013 SWAT model calibration was done using the Sequential Uncertainty Fitting (SUFI–2) technique and the Nash–Sutcliffe simulation efficiency (NSE) and coefficient of determination (R^2). This included an initial calibration from 2000/1/1 to 31/9/2009 which was then validated for 1/10/2010 to 31/12/2013 using daily streamflow values. Adhaim Watershed's whole area was determined to be 11816.82 km^2. Grasslands make up 41.01% of the total area. Additionally, 28% of LCLU came from croplands and desolate regions in equal measure. A hydrological type D clay soil was discovered, along with the watershed's primary slope (0–5). The mean streamflow of Adhaim was determined to be 21.3.m^3/sec, and upon calibration, it was found to be 22 m^3/sec.

Keywords: SWAT model, Adhaim watershed, SUFI–2, SWAT-CUP.

الخلاصة:

يتطلب فهم الدورة الهيدرولوجية وإيجاد البيانات الحاسمة لإدارة المياه فهمًا أساسيًا لمحاكاة مستوى الحوض. لإنشاء نموذج تدفق التدفق الأكثر دقة، تم دمج البيانات من محطات الأرصاد الجوية مع مدخلات من خرائط أخرى لمنطقة البحث، مثل نموذج الارتفاع الرقمي DEM، وغطاء الأرض، واستخدام الأراضي LCLUوالتربة. بالنسبة لمستجمعات المياه في العظيم، في الفترة من 2000 إلى 2013، تم استخدام كفاءة محاكاة Nash-Sutcliffe (NSE) ومعامل التحديد R^2 لتقييم معايرة نموذج SWAT باستخدام خوارزمية تركيب عدم اليقين المتسلسل SUFI–2 وشمل ذلك معايرة أولية من1 /2000/1 إلى 31/9/2009 والتي تم التحقق من صحتها بعد ذلك للفترة من 1/10/2010 إلى 31/12/2013 باستخدام قيم تدفق التدفق اليومي. تم تحديد مساحة مستجمع مياه العظيم بـ 11816.82 كيلومتر مربع. تشكل المراعي 41.01% من إجمالي المساحة. بالإضافة إلى ذلك، جاء 28% من LCLU من الأراضي الزراعية والمناطق المقفرة بنفس القدر. تم اكتشاف تربة طينية هيدرولوجية من النوع D، بالإضافة إلى المنحدر الأساسي لمستجمع المياه (0-5). تم تحديد متوسط جريان نهر العظيم على أنه 21.3 م^3 /ثا ، وبعد المعايرة وجد أنه 22 م^3/ثا.

1. INTRODUCTION

All river basins are impacted by a number of factors, such as precipitation, soil, , land cover, land use (LCLU) and human activities and natural disasters like bushfires and storms. Globally, the equilibrium between the availability and requirement of water resources is greatly influenced by climate change [1, 2]. The study of surface water hydrology focuses on the flow of water caused by snowmelt and precipitation across the surface of the planet [3]. When modeling and managing runoff in watersheds using hydrological models, To fully understand the effects of changing land cover and climate on runoff behavior in these watersheds, it is usually best to simulate runoff over longer time periods. [4, 5]. The best method for examining and assessing Adhaim's water resources is to use remote sensing and hydrologic modeling due to the dearth of knowledge regarding management of land and hydrology, particularly in the more rural areas [6]. There are significant impacts of the digital elevation model (DEM) on the stream flow simulation [7, 8] . A watershed's hydrologic regime changes as a result of changes LCLU. Several studies have found a significant correlation among LCLU, water amount, and quality [9, 10]. In addition to human activity, the lack of precipitation resulting due to climate change impacts could be the primary cause of the changes in Iraq's land cover. Several effective SWAT model application for modeling streamflow have been recorded throughout the literature by authors [11-13]. Among others however, due to how local hydrologic processes are impacted by climate change, fewer studies have concentrated in the long run assessment showing a simulation of watershed stream flow but this might be the most advantageous. Adhaim watershed was selected for this study because, given its size, it is regarded as one of the most significant catchments that feeds the Tigris River in Iraq. As a result, the Tigris River's water quality is significantly impacted [14]. The main objective of this study is to determine the stream flow for Adhaim watershed using the SWAT hydrological model . The rapid increase of water demand in Iraq, as well as the predicted water storage problems due to various factors (climate change), can be assessed by hydrological modeling, which can help decision-makers to take preemptive actions such as storing water in the dams, depending on stream flow predictions. Furthermore, the calibrated parameters of this model can be used for hydrological studies in this and adjacent catchments.

2. MATERIALS AND METHODS

2.1 STUDY AREA

2.1.1 LOCATION

Adhaim watershed is located in Iraq with total area of 12482.8 km^2. The tributary of Adhaim lies between the latitudes longitudes are 34°00'–35°45'N and 43°30'–45°30'E. Adhaim watershed spans the region between the Lesser Zap and Diyala watersheds. The Tigris River borders the watershed to the west, the Hamrin mountain range to the southwest, and the Taslouja, Shawan, and Dagarma highlands to the northeast [15].

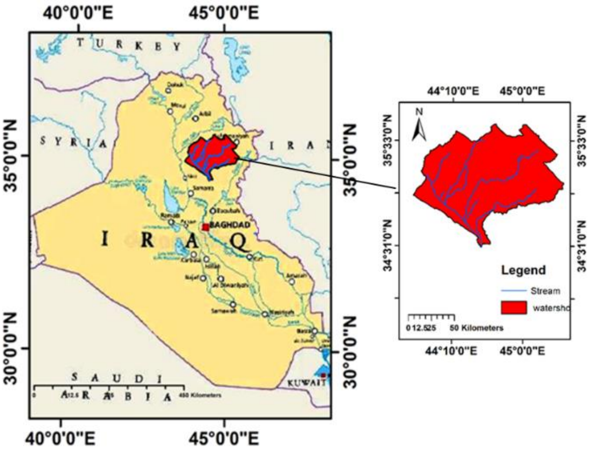

Fig. 1 Adhaim watershed study area's location

2.1.2 TOPOGRAPHY

Adhaim River originates from a height of 1864 meters above sea level in the Sulaymaniyah Province's highlands and flows through Kirkuk City before emptying into the downstream simple . The primary mountain range that makes up the Zagros dictates the rivers' alignments, which come together to form the Adhaim River near the Hemmrin Mountain. The two largest tributaries that flow upstream from Adhaim into the Lesser Zab are the Qelaa Chulane and the Beneh River [16] .

2.1.3 GEOLOGY

This hilly portion is of Adhaim Watershed are made up of gritty, sandy soil that is frequently produced from the same rocks as the mountainous areas, with some organic components present. The mountainous portions of the watershed are composed of boulders and lime stones. Most Adhaim Watershed is covered in loamy surface soil [17].

2.1.3 CLIMATE

The Adhaim region is characterized as being desert, with very little rainfall and almost no snowfall. Runoff that is useful only happens during the wet seasons. October to May sees heavy downpours; the remaining months of the year are dry. The region receives approximately 610 mm of rainfall annually, with big rainfall storms occurring from October to May. In winter, lows are as low as -4 °C, while in summer, highs can reach 49 °C [18].

2.2 Description of SWAT Model

The United States Department of Agriculture (USDA) created the Soil and Water Assessment Tool. The goal behind the creation of SWAT is to forecast how land management practices will affect throughout an extended simulation period, Agriculture chemical yields, sediment flow, and management scenarios in sizable, intricate watersheds with a variety of soil types, LC/LU, and management scenarios [19, 20]. Using the provided DEM data, a physical (deterministic) SWAT model discretizes the watershed into many subbasins. Slope, LC/LU, and soil maps are overplayed within each subbasin to provide a number of consistent hydrological response units (HRUs). Surface and subsurface water flow are processed by SWAT, which also takes into consideration a number of other processes such as evapotranspiration, plant uptake, both percolation into the aquifers and lateral flow [21].

SWAT depends on Equation 1, or the water balance.

$$SWt = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw) \qquad (1)$$

where,

SWt is the final soil water content (mm)

SWo is the initial soil water content on day (mm)

t is the time (days)

$Rday$ is the precipitation on day (mm)

$Qsurf$ is the surface runoff on day (mm)

Ea is the evapotranspiration on day (mm)

$Wseep$ is the amount of water entering the vadose zone from the soil profile on day (Soil interflow) (mm)

Qgw is the amount of return flow on day (mm)

The direct runoff volume was estimated using the Soil Conservation Service Curve Number (SCS-CN) approach, one of SWAT's options. Furthermore, The Muskingum routing technique, an optional flow routing feature, and a variable storage mechanism that discretizes daily time are all provided by SWAT. For this investigation, the variable storage method was chosen. Channels lost water not only from transmission but also from evapotranspiration, which is caused by the surface area of the water.

2.3 Model input

Divided the basin up into 188 hydrological response units and 19 sub-basins. The SWAT model requires a input data in order to perform the tasks envisioned in this study. They are the soil map, the digital elevation model (DEM), weather data and the discharge data.

1. The DEM was download freely from USGS Earthexplorer in (.tif) format from https://earthexplorer.usgs.gov/
2. After processing the initial Digital Elevation Model (DEM), ArcMAP (ESRI, 2015) software has been used to splice, crop, and project the data . River formation, slope reclassification, and sub-watershed divides were all produced using the pre-treated DEM Fig 2 .
3. The LCLU for the year 2009 was downloaded from USGS Earthexplorer in order to complete this task. The MODIS instrument is installed on NASA EOS-PM and Terra EOS-AM programs' Aqua satellite. The International Geosphere-Biosphere Programmer (IG-BP) supervised method of classification is used to construct the MODIS Land Cover class item, as shown in Fig 3. The method makes use of top-notch LCLU training databases to anticipate the data. The data was downloaded from https://earthexplorer.usgs.gov /in the (.tif) format.
4. The database was integrated into the SWAT database, and the soil classification in the SWAT hydrologic model was done using lookup tables provided by FAO from FAO/UNESCO Soil Map of the World as show in Fig 4 .
5. In order to simulate runoff in SWAT, meteorological data from the Climate Forecast System Reanalysis (CFSR) is a source of weather information. The wind speed, relative humidity, sun radiation, precipitation, and highest and lowest temperatures are among the information provided.

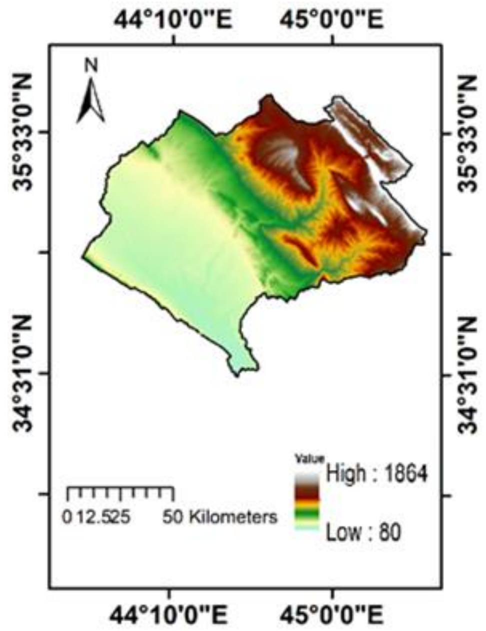

Fig. 2 Model for Adhaim watershed using SRTM DEM (30 m spatial resolution

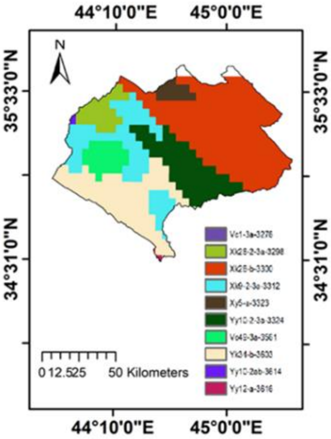

Fig. 3 LCLU data for the watershed of Adhaim

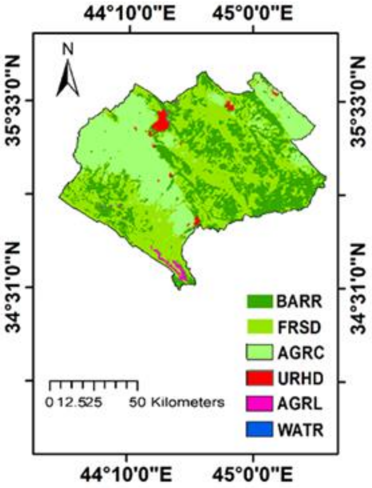

Fig .4 FAO soil data for the watershed of Adhaim

2.4 SWAT-CUP Model

The SWAT-CUP program performs automatic calibration and uncertainty analysis. The SUFI-2 for Calibration of Models (SWAT-CUP) program was used to calibrate and validate the model [22]. The SUFI-2 method repeatedly iterates using an inverted modeling technique that defines a large number of parameters [23]. The range results for each parameter are assessed as part of the uncertainty analysis procedure. The best range of parameters for the model is found through a comparison of every iteration's outcomes [24]. The iterative SUFI-2 procedure accounts for uncertainty in parameters arising from multiple sources, including model structure, parameters, and meteorological circumstances. It provides a comprehensive grasp of uncertainty and optimization by utilizing the global search technique [25]. The findings of the modeled simulation need to be calibrated and validated in order to determine the watershed's features in a satisfactory manner. Many of the variables inside SWAT-CUP impact hydrological cycle simulation. Selecting the right parameters can have a significant impact on how well the calibration works.

2.5 Methodology

SWAT simulates runoff using DEM and LCLU data. The model uses the DEM and the geographical input data that has been transformed into HRUs with uniform slope, LCLU, and soil to discretize the watershed into smaller sections known as subbasins. SWAT model indicated that the main variables to be considered were LCLU, soil characteristics, topography, and climatic data. Initially, raster maps were loaded into the ArcSWAT 2012 interface, including topography, land use, and soil. Subsequently, parameters related to land use and soil were superimposed for every sub-catchment. Furthermore, the meteorological data were defined. In the end, a 14-year period from 2000 to 2013 was simulated and run. We conducted four years of validation, from 2010 to 2013, and ten years of calibration, from 2000 to 2009.

2.6 Model setup, calibration, and evaluation

The watershed is divided into sub-basins using DEM. Sub-basins are then further defined using HRUs, referring to land parcels inside sub-basin boundaries that have distinct slope, soil, and land use. NSE was designated as the objective function and R^2 was utilized as a minor indicator to evaluate the model's performance. To evaluate the performance of the model, NSE and R2 have been estimated between observed and simulated streamflow. Since all two indices have met the necessary streamflow requirements (NSE > 0.50 and $R^2 > 0.70$). Model results are applicable for the watershed [26].

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{t}(Oi - Si)^2}{\sum_{i=1}^{t}(Oi - Mo)^2} \tag{2}$$

$$R^2 = \frac{[\sum_{i=1}^{t}(Oi - Mo)(Si - Ms)]^2}{[\sum_{i=1}^{t}(Oi - Mo)^2][\sum_{i=1}^{t}(Si - Ms)^2]} \tag{3}$$

where

Oi is the observed stream flow

Si is the simulated stream flow

Mo is the mean observed stream flow during the evaluation period

Ms is the mean simulated stream flow for the same period

t is the number of observations.

Table .1 General performance for recommended statistics value R^2 and NS

Performance Rating	**R^2**	**NS**
Very good	No limit	$0.75 < Ns \leq 1$
Good	No limit	$0.65 < Ns \leq 0.75$
Satisfactory	> 0.6	$0.5 < Ns \leq 0.65$
unsatisfactory	< 0.6	$Ns < 0.5$

3 Results and Discussion

3.1 Model Calibration and Validation

The results of the calibration (validation) procedures analysis indicated that Adhaim's NSE and R^2 values were, respectively, 0.67 and 0.76 (0.61 and 0.64). According to [21], these values are regarded as falling within an acceptable range. Furthermore, for the Adhaim model, the first model (uncelebrated model) showed two key discrepancies between the simulated and observed streamflow: first, the simulated streamflow was bigger than the observed, and second, the estimated peak flow occurred later on the time scale than the observed. The adjusted simulated to observed streamflow involved the overcoming steps. Additionally, because some rainfall water cannot reach the stream as it enters groundwater recharge, peak timing and values also control the groundwater parameters (GW_DELAY, ALPHA_BF, GWQMN, and REVAPMN). Additionally, groundwater might assist by acting as the stream's baseflow. Twelve parameters were used for the daily simulation (Tables 2 and 3).

Table.2 The sensitive parameters for watershed of Adhaim

Rank	**Parameter Name**	**t- Stat**	**P -Value**
1	R__CN2.mgt	-26.44	0.88
2	V__GW_DELAY.gw	0.26	0.79
3	V__ALPHA_BF.gw	0.65	0.52
4	V__GWQMN.gw	-2.29	0.02
5	R__REVAPMN.gw	-0.15	0.88
6	R__SOL_AWC.sol	- 1.05	0.29
7	R__ESCO.htu	0.04	0.97
8	R__OV_N.hru	-105.33	0.2
9	R__USLE_K(..).sol	-0.67	0.7
10	R__CH_N2.rte	8.62	0.0
11	R__USLE_P.mgt	-0.99	0.95
12	R__SPCON.bsn	-0.80	0.43

Table .3 The fitted and optimally calibrated parameters of SWAT

Rank	Parameter Name	Fitted_ Value	Min_ value	Max_ value
1	R__CN2.mgt	0.01	0.01	0.02
2	V__GW_DELAY.gw	490	480	501
3	V__ALPHA_BF.gw	0.63	0.63	0.64
4	V__GWQMN.gw	0.56	0.55	0.56
5	R__REVAPMN.gw	124.71	48.45	145.35
6	R__SOL_AWC.sol	0.82	0.82	0.82
7	R__ESCO.htu	0.89	0.88	0.89
8	R__OV_N.hru	1.06	1.00	4.00
9	R__USLE_K(..).sol	0.91	0.88	0.96
10	R__CH_N2.rte	0.10	0.07	0.10
11	R__USLE_P.mgt	0.57	0.51	0.60
12	R__SPCON.bsn	0.01	0.01	0.02

3.2 Streamflow analysis

The SUFI-2 technique was used to compare the monthly streamflow that were observed and those that were simulated for the model. We conducted four years of validation, from 2010 to 2013, and ten years of calibration, from 2000 to 2009. The calibrated model both overestimates and underestimates peak runoff, according to hydrograph analysis Fig 5. which attests to the extreme degree of uncertainty. Appropriate parameter ranges were established following the determination of the initial values for each of the 12 parameters. It's possible to narrow the range of uncertainty. The observed stream flow rate is 21.3 m^3/sec on average, peaking at 159.57 m^3/s in February 2006. While the simulated flow rate was 10.159 m^3/s while the largest simulated stream flow value was 153 m^3/s in 1/1/2013, the simulated daily water flow was recorded at 144.76 m^3/s in December 2002,than the observed flow during that period was 109.22 m^3/s. During this calibration period NSE 0.46 and R^2 0.51

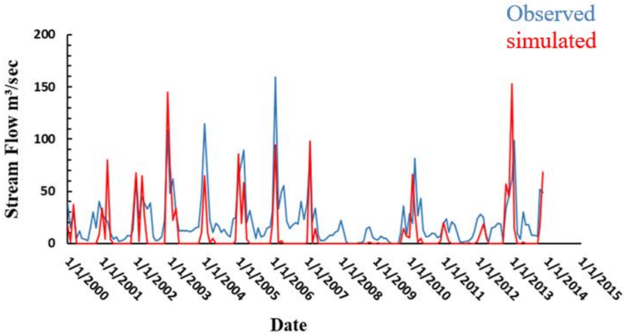

Fig .5 Observed and simulated streamflow before calibration.

Furthermore, Fig 6. displays the optimal calibration following. The stream flow for the Adhaim Watershed was modelled with the best possible range of parameters that came from the calibration and validation procedures. time series of the simulated stream flow for Adhaim watershed following calibration, the average stream flow was found to be about 22 m^3/sec, peaking at 182 m^3/sec in February 2006.

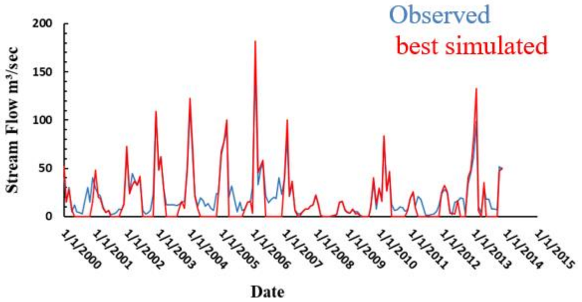

Fig .6 Observed and simulated streamflow after calibration.

Figure (7) a) shows the weak relationship seen in the hydrograph evaluation prior to calibration. Following calibration, the hydrograph demonstrated a strong agreement with the model during the calibration phase shows in b). This suggests that the simulated and observed values have a strong correlation.

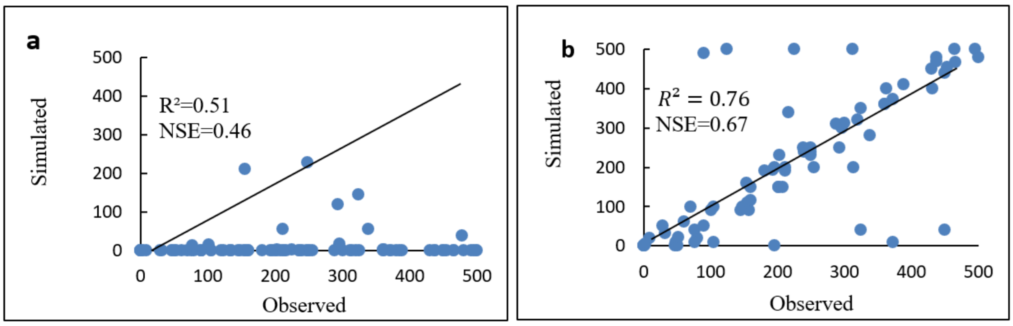

Fig.7. Scatter plot of river streamflow : (a) Before calibration and (b) After calibration

4. Conclusion

The model can forecast the streamflow in Adhaim based on the outcomes of the sensitivity and uncertainty analyses carried out using SUFI-2 and SWAT. The primary conclusions demonstrate the value of the SWAT-CUP approach in predicting water resources and evaluating related presumptions and underlying uncertainty. The model exhibits a good match to the observed streamflow, according to the final calibration and validation results. For hydrological projections, like discharge, a thorough model calibration is necessary to provide meaningful results. In addition to the results for superior modeling procedures, uncertainty must be indicated during the model's forecast. In order to simulate streamflow over the years 2000–2013, this study used the SWAT model, which underwent a thorough calibration and validation process utilizing the SUFI–2 technique. SUFI-2 is a well-known technique for determining the uncertainty and sensitivity of a hydrological model. Consequently, it aids in producing compelling model predictions and communicating largely accurate results to end users. The conservation of soil and water, agricultural water management, and the mitigation of natural disasters such as droughts and floods can all benefit from the study's conclusions. Future analyses of how land use and cover and climate change affect water resources can make use of this calibrated model.

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