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Performance of SWAT Model for Long-Term Runoff Simulation within Al- Adhaim Watershed, Iraq

Mahmoud Saleh Al- Khafaji and Mustafa Al-Mukhtar and Ahmed Mohena

Abstract-- Runoff estimation is a very important aspect in many water resources issues e.g. Watershed management and flood controlling etc. To this end, the hydrological modelling has been identified as a valuable tool. The Soil and Water Assessment Tool (SWAT) model was used in this study to model the runoff flow in Al-Adhaim River northeast of Iraq. The model was calibrated against daily-measured flow for the period from 1Jan. 1983 to 31Sep. 1984 and validated for the period from 1Jan. 1985 to 31Sep. 1985. Coefficient of determination (R2), Nash- Sutcliffe efficiency (NS) and standardization root mean square error (RSR) were used to perform the statistical assessment of the model performance. The statistical values for calibration of runoff results show satisfactory agreement between measured and modeled daily values. R2, NS and RSR during calibration (validation) were 0.76, 0.75 and 0.5 (0.71, 0.69 and 0.55), respectively. Consequently, the calibrated model was run for a long-term period (1986-2013) to assess the causation between runoff and land cover/land use (LC/LU) changes. Therefore, the model was run once with one LC/LU of 1992 (Case 1); and once with two LC/LU i.e. of 1992 and 2001 (Case2). The two cases were compared by computed statistical value to evaluate SWAT model performance for long-term period. The result showed that there is no effects of LC/LU change on runoff simulation in this area. R2, NS and RSR were 0.99, 0.98 and 0.02, respectively between runoff of case 1 and case2. Therefore, SWAT model can be used for detecting LC/LU changes over a long-term simulation in Al-Adhaim watershed.

KEYWORDS: SWAT; Al-Adhaim ; CFSR; runoff; land cover change.

1 Introduction

Surface water hydrology deal with the movement of water along the earth's surface because of precipitation and snow melt. Detailed analysis of surface water flow is highly important to such fields as municipal and industrial water supply, flood control, stream flow forecasting, reservoir design, navigation, irrigation, drainage, water quality control, water- based recreation and wildlife management [3].

Water resources development and management require an understanding of basic hydrologic processes and simulation capabilities at the river basin scale. Current concerns that are motivating the development of large area hydrologic modelling include climate change, management of water supplies in arid regions, large-scale flooding and offsite impacts of land management. Recent advances in computer software, including increased speed and storage, advanced software-debugging tools and GIS/spatial analysis software, have allowed large-area simulation to become feasible [5]. In most of watershed runoff modeling and management by using hydrological model, it is preferred to simulate the runoff for long-term period to understanding the impact of climate change and land cover change on runoff behavior for these watersheds.

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Sometime there is lack in GIS spatial data like land cover land use. It is not available for long period of simulation, therefore it necessary to test the ability of hydrological model for simulating runoff with long-term period.

Hydrological models can be classified into distributed model, lumped model and semi-distributed model. Deterministic models, divided the sub-watershed into smaller grid cells and flows routed one grid to another. These models based upon the numerical solution to an almost complete set of the coupled partial differential equations [19]. Lumped models describe the hydrologic processing of watershed as a single system that meaning the input data spatially averaged for entire a watershed with model equation and parameter perform the response entire watershed as a single unit [17]. It is worth mentioning that there is a middle point between the distributed and lumped models what is called a semi-distributed models that is dependent on the distributed concept in a catchment discretization into units, and lumped concept in the hydrological representation per unit [2].

The Soil and Water Assessment Tool (SWAT) as a physically based semi-distributed model has been widely used in assessing the impact of climate change, developed to predict the impact of land management practices and simulating runoff for ungagged catchment. SWAT model is being; integration between semi and fully-distributed approach, free source, and user friendliness in handling input data [4]. For these reasons, SWAT model was selected in this study.

Many successful application of SWAT model in modelling runoff have been reported in the literature "[10], [14]"and [16]" and others. However, fewer publications have focused on the long-term evaluation of a watershed runoff simulation due to climate change impacts on regional hydrologic processes. Yet this may be the most beneficial application of hydro climatology to support long-term water resources management and planning [1].

Change in land cover /land use (LC/LU) leads to a change in the hydrologic regime of a watershed. A strong relationship has been noted by many researchers between LC/LU, water quality and water quantity "[7] and [13]" and others.

The changes in land cover in Iraq could be attributed mainly to the lack of precipitation stemming from effects of climate change besides the anthropogenic activities. Because of the limitations in LC/LU data along the period of simulation SWAT model must be test for long-term period.

In this research Al-Adhaim watershed was selected, it is considered one of the most important catchment that feeding Tigris river in Iraq due to its size. Therefore, it effects remarkably on water quality of Tigris River. The watershed boundaries totally located inside Iraq in the northeast zone. In other words, the watershed is entirely managed by the Iraqi water resources ministry.

The aims of this study were firstly to modeling the runoff in Al-Adhaim watershed along long-term period (1986-2013). Secondly, to assess the SWAT model performance with long-term period simulation and land cover change.

1.1 Descriptions of the Study Site

Al-Adhaim watershed was selected in this research as a case study. The area located in the northeastern part of Iraq nearby the Iranian border. The coordinates of the study area are between 35° 42' 24"to 34° 33' 8" N and 43° 41' 9" to 45° 27' 31" E. The total area is estimated about 11217 Km^2 (Figure 1). This area is the second watershed located along Diyala River (which is one of the Tigris River tributaries) behind Derbendi-Khan dam. Due to scarcity of rainfall, the climate in this area is characterized as an arid. The majority of rainfall occurs during October to May with annual amount of 610mm. Therefore, the river is essentially seasonal. The temperatures fluctuated between -4 °C in winter to 49 °C in summer E [3].

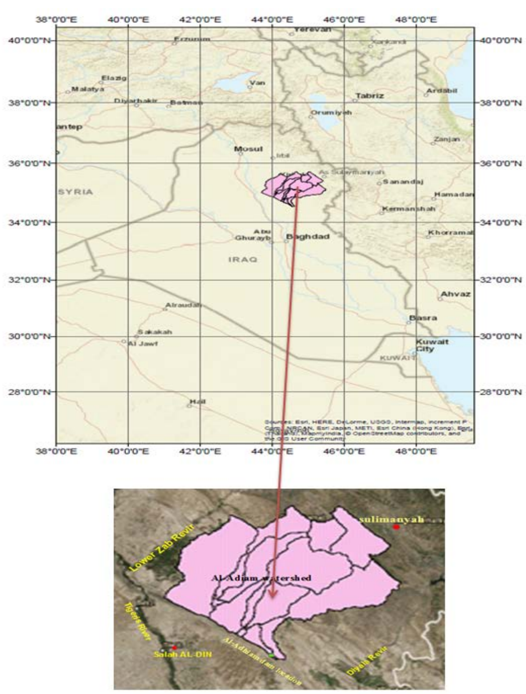

Figure (1): A location map for Al-Adhiam watershed.

2 Martials and Methods

2.1 Data Used

In this research, river discharges, climate data, topography, land use, and soil data were used as inputs data to SWAT model to modeling the streamflow discharge in Al-Adhaim watershed.

2.1.1Hydrological Data

Considering the purpose of this study, SWAT model needs for calibration and validation measured discharge value. Daily flow record was obtained from the Ministry of Water Resources/ The national center for water resources management in Iraq for the period from 1983-1985 measured in m^3/sec [11]. The data were recorded at Enjana gauge station which located at coordinates 34° 32' 9"N and 44° 30'44" E at the current outlet for the watershed.

2.1.1.1Satellite Data

i. Digital Elevation Model (DEM)

Topography is a necessary input in the SWAT model and is used in the delineation of the watershed and analysis of the land surface characteristics and drainage patterns. It influences the rate of movement and direction of flow over the land surface. The digital elevation model (DEM) with 90 m by 90 m horizontal resolution from the SRTM of NASA was used in this analysis. DEM 90 m was selected, because it represents an optimum resolution for Al-Adhiam watershed [17]. DEM 90 m available for download on the site (http://glcf.umd.edu/data/srtm/) with geographic WGS84 datum. Figure (2) shows the elevation for Al-Adhiam watershed that used in SWAT model.

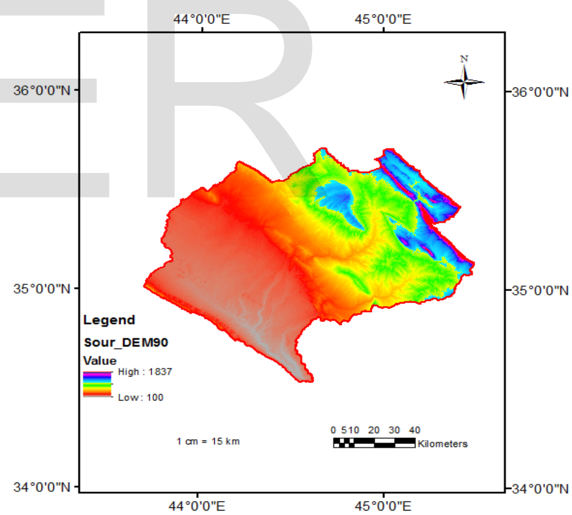

Figure (2): SRTM DEM (90 m spatial resolution) of Al-Adhiam watershed (SRTM, 2015).

ii. Land Use Map

Two maps were employed to assess the impact of LU/LC change on runoff i.e. maps of 1992 and 2001. The 1992 LU/LC map was downloaded from earth explorer website (http://earthexplore.usgs.gove/) and the 2001 LU/LC map from (https://landcover.usgs.gov/global). Figures 3 and 4 show the LU/LC maps of 1992 and 2001, respectively. It can be noticed from the figures that the land cover witnessed some changes in this area along the two aforementioned periods. For example, the barren area increased between the two periods by 12.6%, the winter pasture increased by 24%, while the agriculture decreased by 35% as well as urban areas increased by 0.4%.

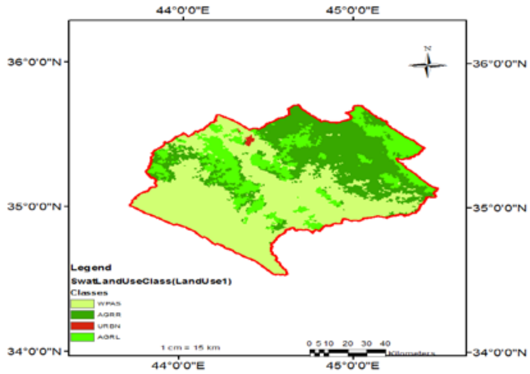

Figure (3): LC/LU of Al-Adhiam watershed in 1992 (Earthexploral USGS modified in 2013).

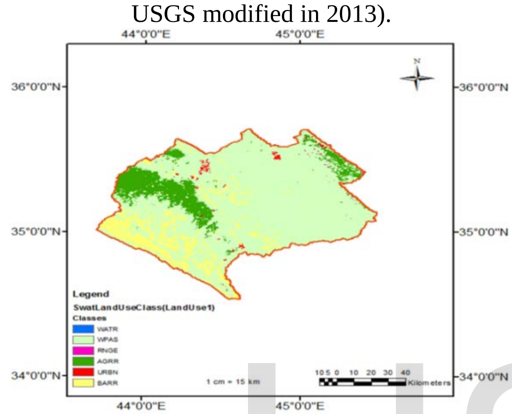

Figure (4): LC/LU of Al-Adhiam watershed in 2001(MODIS, modified in 2014).

iii. Soil map

The response of a river basin to a rainfall event depends on the nature and conditions of underlying soils. The SWAT model requires soil property data such as the texture, chemical composition, physical properties, available moisture content, hydraulic conductivity, bulk density and organic carbon content for the different layers. Soil data were obtained from the 1:1000 Soil Terrain Database were deriving from the digital soil map of the world from Food and Agriculture organization of the Unit nation (FAO) [8]. The data was downloaded on 15October 2016 from the FAO soil database (www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/en) in (shp) file . Figure (5) shows the soil map that used in SWAT model for Al-Adhiam watershed. Among the eight types of soil with different texture, the predominant soil of the watershed is clay-loam with 42% followed by loam with 33%.

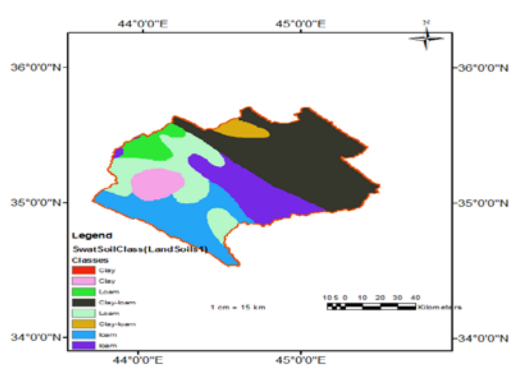

Figure (5): Soil map of Al-Adhiam watershed (FAO, 2015).

2.1.2 Meteorological Data

Precipitation, temperatures, solar radiation, wind speed and relative humidity are required in SWAT to represent the hydrological behavior of the watershed. These data was obtained from the Climate Forecast System Reanalysis (CFSR) based on daily time step. Before using in SWAT, these data were validated with some monthly observed climate data available for the period 1985-1989 and collected from Iraqi meteorological organization and seismology. So that, the data were averaged across the available CFSR stations of Al-Adhaim watershed and compared with those from the observed. Figure (6) show the CFSR weather station distribution that applied in SWAT for Al-Adhiam watershed. The data were downloaded on 23March 2017 from Global weather data for SWAT (http://globelweather.tamu.edu/) of Al_Adhaim watershed. 12 CFSR weather stations were applied in SWAT model for this study. Figure (6) show the weather station distribution that applied in SWAT for Al-Adhiam watershed.

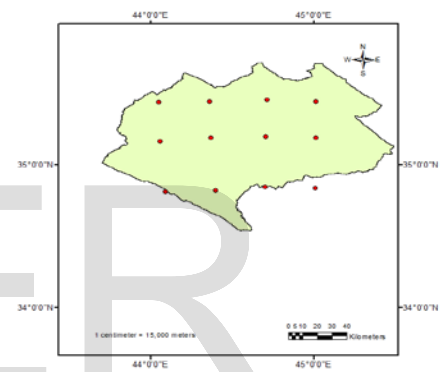

Figure (6): Distribution of Al-Adhiam watershed weather stations according to CFSR.

2.2 Methods

2.2.1 Model Setup

Three different layers were used to set up the hydrological model of Al-Adhaim watershed i.e. 90 SRTM digital elevation model, soil, and land use layers. Accordingly, the study area were discretized into twenty five sub-catchments with the default threshold area of 6.25 km^2 (Figure 7). A multiple HRU definition was employed for better representation of heterogeneities in soil, land use and topography in the study area. Ultimately, 313 HRU's for the whole watershed were created. In the simulation procedure, Penman-Monteith method was used to calculate evapotranspiration and the variable storage method for stream flow routing.

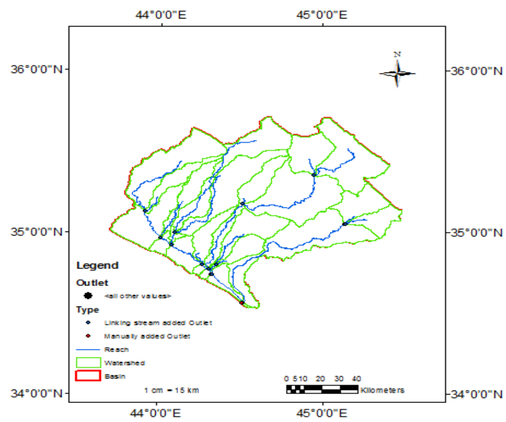

Figure (7): Al-Adhiam watershed delination and stream network.

2.2.2 Calibrations Procedure and Uncertainty Analysis

In this research, automatic calibration approach was applied. The simulated stream flow was calibrated against measured runoff. The Sequential Uncertainty Fitting Version 2 (SUFI-2) calibration tool is part of the stand-alone, public domain SWAT Calibration and Uncertainty Program software (SWAT-CUP), which has its own interface and is used for sensitivity analysis. SUFI-2 is commonly used mostly due to the relatively less required number of runs to get satisfactory calibration results. SUFI-2 requires 2–3 times less runs than the other software of the SWAT-CUP [20].

Uncertainties of driving variables (e.g., rainfall), model, parameters, and measured data (e.g., flow) are all accounted for in parameter uncertainty during a SUFI-2 calibration/uncertainty analysis. The measure of the degree to which these uncertainties are accounted for is defined as the *P-factor* (the percentage of measure of data bracketed by the 95 % prediction uncertainty, 95PPU) and the *R-factor* (the ratio of average thickness of the 95PPU band to the standard deviation of the measured data). These two measures work together to bracket most of the measured data with the smallest possible uncertainty band. Calibration was done to obtain the optimum parameters for runoff.

2.2.3 Evaluation of Model Performance

Three statistical criteria were used to assess the performance of the SWAT model. i.e.

1. Coefficient of determination (R^2)

$$R^2 = \frac{[\sum_{i=1}^{n}(q_{o,i}-\overline{q_o})(q_{o,i}-\overline{q_s})]^2}{[\sum_{i=1}^{n}(q_{o,i}-\overline{q_o})^2\sum_{i=1}^{n}(q_{o,i}-\overline{q_s})^2} \qquad (1)$$

R^2 is the measure of the variability of the explanatory variable explained by the response variable. Where the closer R^2 value to 1, the better model performance

2. Nash-Sutcliffe simulation efficiency (NS) [15].

$$NS = 1 - \frac{\sum_{i=1}^{n}(q_o - q_s)_i^2}{\sum_{i=1}^{n}(q_{o,i}-\overline{q_o})_i^2} \qquad 2$$

Where:

q_o : the observed value variable (suspension sediment or flow) .

$\overline{q_o}$: mean of the observed variable (suspension sediment or flow).

q_S : the simulated value variable(suspension sediment or flow).

$\overline{q_s}$: mean of the simulated values variable (suspension sediment or flow).

n:number of data points considered.

NS is a measure of how well the observed versus simulated value fits the 1:1 line. NS is 1 when the observed values match perfectly the modelled, While, when the Ns less than 1, it gives an indication of deviations between measured and predicted values. The value of NS less than zero indicates that the predictions are very poor, and the average value of output is a better estimate than the model prediction.

3. The (RSR). standardizes of root mean square error

$$RSR = \sqrt[2]{\frac{[\sum_{i=1}^{n}[q_{o,i}-q_{s,i}]^2}{[\sum_{i=1}^{n}[q_{o,i}-\overline{q_o}]^2}} \qquad (3)$$

RSR standardizes of root mean square error RMSE. using the observations standard deviation, and it combines both an error index and the additional information recommended by Moriasi et al., (2007) [12]. RSR is calculated as the ratio of the RMSE and standard deviation of measured data Equation (3). RSR incorporates the benefits of error index statistics and includes a scaling normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR
varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. The lower RSR mean the better model simulation performance.

2.2.4 Model Runs

In this study, the simulation period was from 1981to 2013 using 2 years of initialization (1981 to 1982) as warm up period. SWAT model was run according to the following periods.

Calibration and validation periods

i- From 1/1/1983 to 31/12/1984, SWAT model run with daily time step for calibration.

ii- From 1/1/1985 to 31/12/1985, SWAT model run with daily time step for validation.

Simulating and assessment SWAT periods

The calibrated SWAT model was run with two cases in order to simulating and assessing the model performance with long-term period.

Case1

i-From 1/1/1986 to 31/12 /2013, SWAT model run with monthly time step with LC/LU 1992 for simulating runoff with long-term period.

Case2

i- From1/1/1986 to 31/12 /2001, SWAT model run with monthly time step with LC/LU 1992 for simulating runoff for this period.

ii- From 1/1/2002 to 31/12 /2013, SWAT model run with monthly time step with LC/LU 2001 for simulating runoff for this period.

3 Results and Discussion

3.1 Global sensitivity analysis

Twelve hydrological parameters were tested for identifying sensitive parameters for the simulation of stream flow using the automated global sensitivity analysis procedure. (Table 1) were the higher value of *p* and lower of *t* means the more sensitive parameter. The five most sensitive parameters from the global sensitivity analysis were; curve number (II) value (CN2), manning's "n" value for overland (OV_N), threshold water depth in the shallow aquifer for flow (GWQMN), manning's "n" value for the main channel (CH_N2) Soil evaporation compensation factor (ESCO.hru) , respectively.

Table (1): The sensitive parameters for Al-Adhiam watershed.

Parameter Name	t-Stat	P-Value
7:V__ALPHA_BF.gw	0.15	0.88
11:R__SLSUBBSN.hru	0.18	0.86
8:V__GW_DELAY.gw	-0.91	0.36
5:R__REVAPMN.gw	-1.01	0.31
1:R__SURLAG.bsn	1.37	0.17
10:R__ESPO.hru	-1.50	0.14
3:R__SOL_AWC(..).sol	1.61	0.11
2:R__ESCO.hru	-1.94	0.05
12:V__CH_N2.rte	1.95	0.05
9:R__GWQMN.gw	-2.00	0.05
4:V__OV_N.hru	-3.44	0.00
6:R__CN2.mgt	-72.37	0.00

Soil evaporation compensation factor (**ESCO.hru**), Plant evaporation compensation factor (**ESpO.hru**) .Baseflow alpha factor (**ALPHA_BF.gwc**), Groundwater delay time, (**GW_DELAY.gw**), Treshold depth of water in the shallow aquifer required return flow to occur (mm) (**GWQMN.gw**). Threshold depth of water in the shallow aquifer for "revap" to occur (mm) (**REVAPMN.gw**), Manning's "n" value for overland flow (**OV_N.hru**), Curve number, (**CN2.mgt**), Manning's n value for the main channel (**CH_N2.rte**), Soil available water storage capacity,(**SOL_AWC.sol**), Average slope length(**SLSUBBSN.hru**) Surface runoff lag time (SURLAGE.bsn)

- The qualifier (V__) refers to the substitution of a parameter by a value from the given range, while (R__) refers to a relative change in the parameter were the current values is multiplied by 1 plus a factor in the given range.

3.2 Model Calibration and Validation

Calibration of the SWAT model for runoff was done by using the daily-measured runoff data at the outlet of Al-Adhaim watershed. The simulated and measured daily discharge at the outlet of the watershed were plotted for visual comparison as shown in Figures (8). The model was calibrated by adjusting the values of parameters that were identified as highly sensitive to runoff and sediment as it was described in the preceding section.

At the initial run of the model using the default values of parameters, there were two major problems in water balance; the first was that the simulated runoff was higher than observed runoff and the second was the peak of simulated flow was latish of observed flow. Thus, it was necessary to adjust the parameter that has a direct influence on flow modeling. To this end, the value of curve number (CN2) was gradually decreased and the value of manning's "n" value for overland (OV_N). On the other hand the manning's "n" value for the main channel (CH_N2) must be decreased, The lower value of (CH_N2), help to increase the velocity in the mean channel is. Thus, make the peak simulated flow matches with measured flow.

Figure (8) and (9) show the measured against modelled flow during the calibration and validation periods respectively. As it can be seen, the peak flow of measured was matched with the modelled during the both periods. Moreover, the values of during the R2, NS and RSR during calibration were equal to 0.76, 0.75, and 0.5 respectively. While, during the validation period were 0.71, 0.69 and 0.55 respectively, all these value were within the acceptable rang according to recommended of Moriasi et al (2007). The range of calibrated parameters and their fitted values as obtained from SWAT model given in Table (2).

Table (3): SWAT's parameters that were fitted and their best-calibrated values

Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__ESCO.hru	0.89	0.88	0.89
2:R__SOL_AWC(..).sol	0.88	0.88	0.86
3:V__OV_N.hru	0.82	0.22	2.7
4:R__REVAPMN.gw	164	93.6	184
5:R__CN2.mgt	0.0037	0.0037	0.0145
6:V__ALPHA_BF.gw	0.634	0.63	0.64
7:V__GW_DELAY.gw	490	480	500
8:R__ESPO.hru	0.39	0.39	0.4
9:R__ GWQMN.gw	0.56	0.55	0.56
10:R__SLSUBBSN.hru	7.80	7.50	15.00
11:R__ SURLAG.bsn	10.6	8.6	12.8
12:V__CH_N2.rte	0.10	0.07	0.10

3.3 Runoff Prediction and Assessing of Model

The best parameters range that obtained from calibration and validation processing was used to predict monthly runoff for Al-Adhiam watershed pre and post dam construction. In this research, two cases were applied with SWAT model (Case1 and Case2).

In Case1, the calibrated model was run on the basis of monthly time step with LC/LU 1992 along the period of simulation from 1986 to 2013. While in Case2, the calibrated model was run with two different LC/LU for two different periods so that the model run on the basis of monthly time step from 1986 to 2001 with LC/LU 1992 and from 2002 to 2013 with LC/LU 2001.

The two cases were plotted in time series scale to comparing and assessing the performance of calibrated SWAT model for land cover changes with long-term period. From Figures (12) and (13), it can be noted that the perfect matching and correlation between monthly simulated runoff for the two cases. The result of statistical value of R^2 NS and RSR were 0.99, 0.98 and 0.02, respectively.

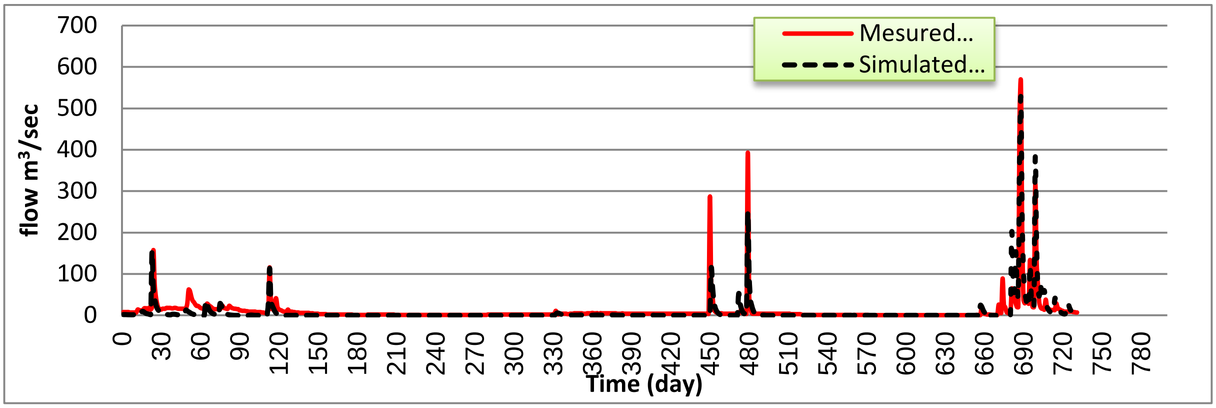

Figure (10): Measured and modelled flow during the calibration period (1 Jan. 1983 to 31 Dec. 1984).

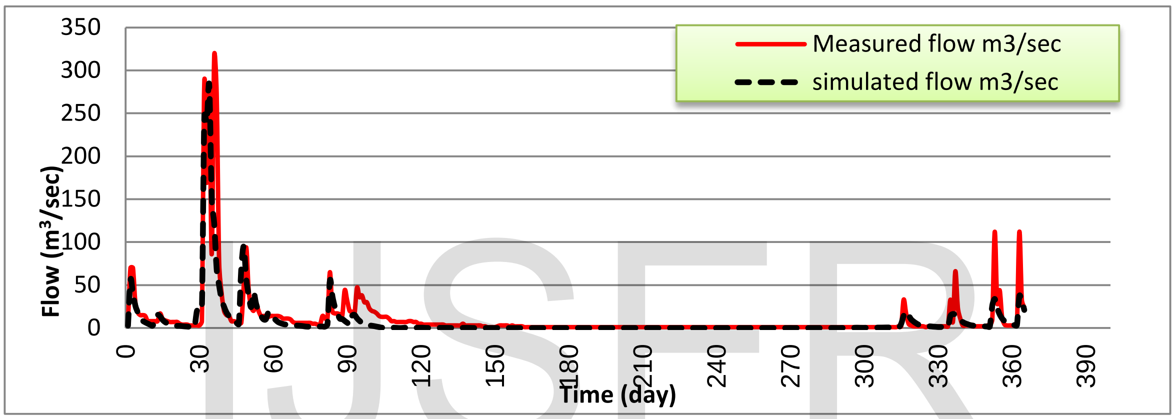

Figure (11): Measured and modelled flow during the validation period (1 Jan. 1985 to 31 Dec. 1985).

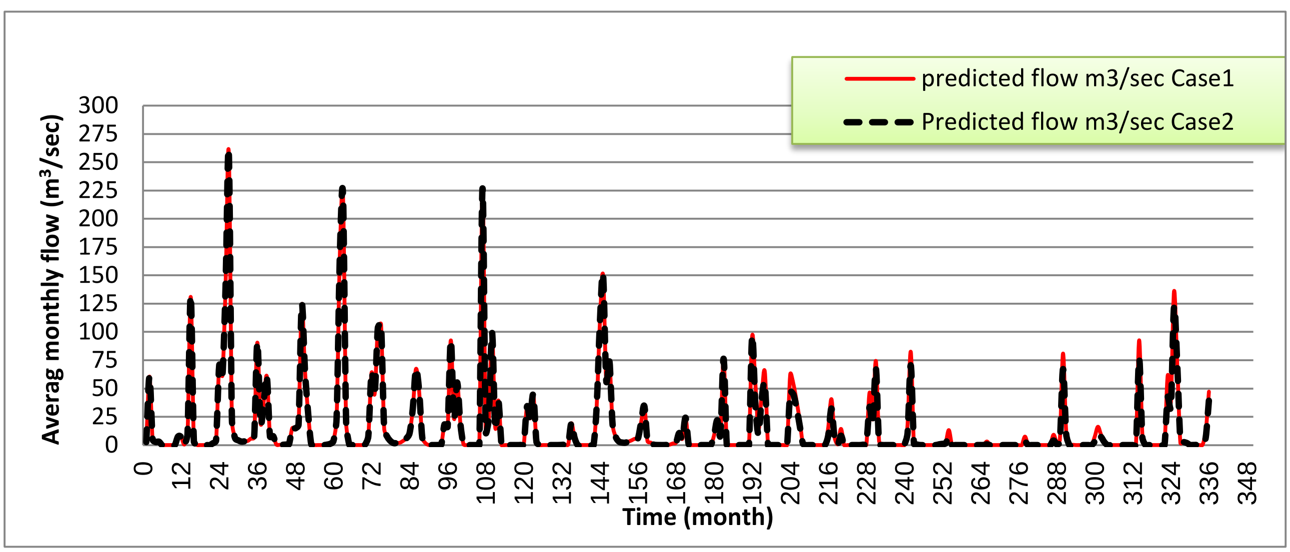

Figure (12): The simulated monthly flow (m^3/day) from 1986 to 2013 for CAS1 and CAS2 for Al-Adhiam watershed.

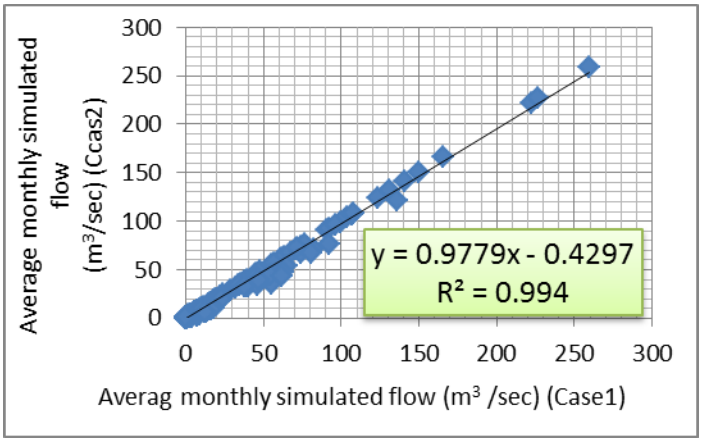

Figure (13): Correlation between the average monthly-simulated flow for Case1 and Case2.

4 Conclusion

In this research, SWAT was tested and applied for simulated runoff in Al-Adhaim watershed with different cases. From result of the calibration process and sensitivity analysis, it can be concluded that the most sensitive parameter for Al-Adhiam watershed were CN2.mgt followed OV_N.hru.

From the comparison between the simulated monthly runoff in Case1 and Case2; it can be concluded the calibrated SWAT model was capable to capture the changes in LC/LU due to climate with long-term period. In other words, the results of predicted simulating runoff for 29 years from 1986 to 2013 for the two cases proved the susceptibility of SWAT model to climate and land cover variability with time. Moreover, the calibrated model can be used for further analysis of different management scenarios on streamflow. The study results can help planners, decision makers, and other stakeholders to plan and implement appropriate soil and water conservation strategies. Also from this result, it can be proved that in the SWAT model there is no need to more than LC/LU for calibration, validation and simulation spatially if there were not significant variation in land use like expansion in urban area.

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