Application of SWAT Model for Sediment Loads from Valleys Transmitted to Haditha Reservoir

Ayad Sleibi Mustafa
Assistant Professor
Engineering College-Anbar University
email:ayad_eng2001@yahoo.com

Sadeq Oleiwi Sulaiman
Assistant Professor
Engineering College-Anbar University
email:dr.sadiq1969@yahoo.com

Omar Manfi Hussein
Master Student
Engineering College-Anbar University
email:omar_manfy@yahoo.com

ABSTRACT

This study included the extraction properties of spatial and morphological basins studied using the Soil and Water Assessment Tool (SWAT) model linked to (GIS) to find the amount of sediment and rates of flow that flows into the Haditha reservoir . The aim of this study is determine the amount of sediment coming from the valleys and flowing into the Haditha Dam reservoir for 25 years ago for the period (1985-2010) and its impact on design lifetime of the Haditha Dam reservoir and to determine the best ways to reduce the sediment transport. The result indicated that total amount of sediment coming from all valleys about ($2.56 * 10^6$ ton). The maximum annual total sediment load was about ($488.22 * 10^3$ ton) in year 1988 due to the surface runoff about $167.79 * 10^6$ m^3, while the minimum annual total sediment load was about ($8.62 * 10^3$ ton) in year 2007. This due to the total runoff volume that was $5.67×10^6$ m^3. Model calibration and verification were carry out using flow rate and sediment yield data observed at the study area and the results were satisfactory.

Key words: SWAT model, sediment load, runoff, Haditha Dam Reservoir

تطبيق نموذج SWAT لحساب الحمل الرسوبي المنقول من الوديان الى خزان سد حديثة

اياد صليبي مصطفى
استاذ مساعد
جامعة الانبار-كلية الهندسة

صادق عليوي سليمان
استاذ مساعد
جامعة الانبار-كلية الهندسة

عمر منفي حسين
طالب ماجستير
جامعة الانبار -كلية الهندسة

الخلاصة

تهدف الدراسة الى تحديد كمية الرسوبيات القادمة من الوديان وتصريفها الى خزان سد حديثه ل 25 سنة للفترة من 1985 لغاية 2010 وتأثيرها على العمر التصميمي لخزان سد حديثة وتحديد أفضل الطرق لتقليل الرسوبيات الواصلة إليه. شملت الدراسة استخراج الخواص المساحية والمورفولوجية للأحواض المائية المدروسة وتم تطبيق اداة النمذجة المعروف باسم Soil and Water Assessment Tool (SWAT) مرتبطة بنظم المعلومات الجغرافية Geographic Information System (GIS)لأيجاد كمية الرسوبيات ومعدلات الجريان التي تصب في خزان حديثة. اشارت النتائج الى ان الكمية الكلية للرسوبيات القادمة من جميع الادوية بلغت حولي ($2.56 * 10^6$ ton). وكانت أعظم كمية رسوبيات خلال الفترة 1985-2010في سنة 1988 وبلغت ($488.22 * 10^3$ ton) وكان حجم الجريان السطحي في هذه السنة ($167.79 * 10^6$ m^3)، بينما اقل كمية رسوبيات خلال هذه الفترة كانت سنة 2007 وبلغت ($8.62 * 10^3$ ton) وكان حجم الجريان السطحي في هذه السنة ($5.67×10^6$ m^3). خلصت الدراسة بمعايرة النموذج واختياره بالاعتماد على بيانات التصاريف والرسوبيات المقاسة حقليا في منطقة الدراسة وكذلك اشارت النتائج الى قدرة النموذج على تمثيل منطقة الدراسة.

الكلمات المفتاحية: نموذج سوات، الحمل الرسوبي، الجريان السطحي، خزان سد حديثة

1. INTRODUCTION

Many reservoirs can no longer perform their design functions because much of their original active storage volume has been fill by sediment. For hydropower projects and water supply schemes, any loss of storage increases the risk of failure to meet the design objectives in extreme dry periods **Ijam** and **Al-Mahamid, 2012**.

Several factors are effects on reservoir sedimentation, such as sediment transportation rate, mode of sediment deposition, sediment production, sediment type, reservoir operation, reservoir geometry, and stream flow variability. Sediment is transport as suspended and bed- loads by streams and rivers coming into the reservoir. Due to flow deceleration when rivers approach a reservoir, the sediment transport capacity decreases, and some of the incoming sediment was trapped and deposit in the reservoir. In addition, the deposited sediment may consolidate by their weight and the weight of overlying water through time. Predicting the sediment coming into a reservoir, its deposition and its accumulation throughout the years after construction of dam have been consider as important problems in hydraulic engineering.

There are several model types that can be used in prediction of sediment load ,**Arnold**, and **Fohrer**, **2005**; **Gassman, et al., 2007**; **Lin, et al., 2010**; **Neitsch, et al., 2005**.; **Sadeghi, et al., 2007**.; **Winchell, et al., 2010**.; **Wischmeir**, and **Smith**, **1978**.; **Zhu, et al., 2013**.

SWAT is a river basin scale model developed to quantify the impact of land management practices on water and sediment yields in large complex watersheds with varying soils, land use and management conditions over long periods. The main components of SWAT include weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond & reservoir storage, crop growth & irrigation, groundwater flow, reach routing, and water transfer.

Several studies were used SWAT model on sediment measurements that have been conducted to estimate the deposit of sedimentation in reservoirs. **Hao et al.,2003,** simulate the runoff and sediment yield in the upper basin of the Luohe River, a tributary of the Yellow River by using a GIS-based distributed Soil and Water Assessment Tool (SWAT) model, the simulated results demonstrate that the GIS-based SWAT model could be successfully used to simulate long-term runoff and sediment yield in large river basins . **Licciardello, et al., 2005,** have reported the results of a SWAT model for an experimental semi-arid watershed in Sicily, Italy. The watershed was discretized into 31 subbasins and 63 hydrologic response units to simulate different soil types and landuses. **Oeurng, et al., 2011**, used SWAT to simulate discharge and sediment transport at daily time steps within the intensively farmed. **Al-Madhhachi, A. T., 2014** was used Universal Soil Loss Equation (USLE) erosion model in order to quantify soil erosion risk in Little Washita River Watershed, Oklahoma. The objectives of his study were to quantify the average annual soil loss in Little Washita River Watershed using Geographic Information System (GIS) technique integrated with USLE model and compare the erosion risk in 2006 with those in 1992 for Little Washita River Watershed. Average annual soil losses were performed by USLE model show that the highest soil erosion risk values were 35.4 and 17.7 tons/ha/yr with mean value equal to 0.03 and 0.017 tons/ha/yr for 2006 and 1992, respectively.

The main objectives of this study are to estimate the runoff volume and the sediment load entering Haditha Dam reservoir from the main valleys using Soil and Water Assessment Tool (SWAT) model with GIS technique.

2. DESCRIPTION OF THE STUDY AREA

The study area **Fig. 1** was located in the desert of Anbar province between the longitudes (42°28'12") - (41°25'48") in the east, and the Latitudes (34°24'54") - (34°11'6") to the north. This desert contains many valleys, such as Al Akhdher, Al Fuhaimy, Al Qasir, Al Rihana, Al Skarh and Gedah, discharging to the Hadithah Dam reservoir. Some of them have broad and deep underway capacity that flows with the main stream that trends from south- west towards the north-east, producing a network of valleys with various configurations .The climate of study area is a dry weather when streams occurs in valleys at the winter season after heavy rainfall. The climate is hot and dry in summer with high diurnal changes in temperature and classified as a hyper arid.

3. THEORETICAL BACKGROUND OF SWAT MODEL

3.1 Estimation of Runoff

Precipitation-runoff relation affected by various storm and basin characteristics; therefore, accurate computation of runoff amount is difficult. Based on field experience and observations, the most commonly adopted methods to estimate runoff components, which are the runoff volume and the peak runoff rate, are the Curve Number (CN) method of the Soil Conservation Services of the USA (USSCS) for estimation of runoff volume, and the Rational method for the peak flow rate, along with several empirical relationships for estimation of flow rates (Das, 2000).

3.1.1 Curve number method

The US Soil Conservation Service (USSCS, 1972) developed the curve number method to transform daily rainfall to surface runoff using the following equation.

$$Q = \frac{(P_d - 0.2\,S)^2}{0.8S + P_d} \tag{1}$$

Where

Q : runoff (mm),

P_d: is the daily rainfall (mm), and

S : the potential maximum retention of rainfall at any time.

It can be predicted using the curve number (CN) by the following equation:

$$Q = \frac{25400}{254+S} \tag{2}$$

The CN depends upon basin characteristics, type of the cover, soil group and antecedent moisture conditions at the time of rainfall occurrence. It varies from zero for most permeable surface to 100 for impervious surface.

3.1.2 Rational method

The rational method is the most common procedure to predict the peak runoff rate, which considered as an indicator of the erosive power of storms and used to predict sediment loss (Chow et al, 1988).

$$Q_p = \frac{1}{3.6}\, C\, I\, A$$
(3)

Where,

Q_P : the peak runoff rate (m^3/sec),

A : the watershed area (km^2),

I : rainfall intensity (mm/hr) for storm duration ≥ the time of concentration (Tc),

C : the runoff coefficient, it ranges from 0 to 1.

The time of concentration is the time required for the effective rain falling on the furthest point of the basin to reach the outlet. There are several empirical relations to determine (Tc) in hour is:

$$T_c = \frac{1}{18}\left[\frac{L_s\, n_{ov}}{\sqrt{S_s}}\right] + 0.62\, L\, \left[\frac{n_{ch}}{\sqrt[4]{A_s}\quad \sqrt{S_{ch}}}\right]^{0.75}$$
(4)

Where,
L_s : basin slope length (m),
n_{ov} : Manning's roughness coefficient for overland flow,
n_{ch} : Manning's roughness coefficient for channel flow,
S_s : the average slope in the basin (m/m),
A_s : basin area (km^2) and
S_{ch}: channel slope (m/m).

3.2 Soil Erosion Model

Many socio-economic and ecological factors caused and influenced in Soil erosion and sedimentation. The effects of some major factors on both soil erosion and sediment yield on catchment scale are Climate and rainfall, Soil type, Land use/cover, Catchment extent, and Geologic formation. There is a variety of predictive equations and models have been developed by several investigators in order to understand erosion occurrence and predict soil loss, the USLE has formulated the essence of many soil loss and sedimentation prediction models. It has achieved high degree of popularity and applicability for different regions of the whole world. **Williams, 1995** have introduced the updated formula for the (USLE) as:

$$E = 1.292\, .EI\, .K\, .LS\, .C\, .P\, .F_{cfrg} \quad (5)$$

Where,
E : the soil erosion on a given day (ton/ha),
EI : the rainfall erosion index (m.ton.cm/ (m^2 hr)),
K : the USLE soil erodibility factor (ton.m^2 hr/ (m^3- ton.cm)),
LS : the USLE topographic factor,
C : the USLE cover and management factor,
P : the USLE support practice factor and
F_{cfrg}: the coarse fragment factor.

4. MODEL SETUP AND INPUT DATA

4.1. Watershed Delineation

Watershed delineation is the first step in establishing a watershed simulation; it involves partitioning the watershed into smaller units (subbasins) and defining the spatial relationship of objects within these units, depending on the degree of complexity in topography and stream network. The watershed delineator is subdivide into four parts as follows:

A. Digital Elevation Model (DEM)

To delineate the watershed and subbasins and to determine drainage networks SWAT uses the digital representation of the topographic surface. The digital Elevation Model (DEM) of the study area watershed, **Fig. 2** take from the U.S. space agency (NASSA) with accurately 30 m resolution, where the data resides in the NASSA office site files format (HGT) where it has been converted to a formula (DEMs) through the program (Global Mapper).

B. Stream definition

SWAT starts to formulate the flow accumulation grid, based on the DEM, by counting the number of cells contributing to each cell in the grid. The stream branches were controlled by specifying a threshold on contributing a number of grid cells making up each branch (Di Luzio *et al*, 2002). The major streams are define and the downstream edge of each one is marked as its outlet; **Fig. 3** displays the stream definition for study area.

C. Main watershed outlet selection and definition

This is the last step in the delineation by which study area location is selected as the main outlet of the study area, hence, the upstream area which is the catchment is clipped and discretized into subbasins in a manner that a mainstream is associated with each subbasin; this forms the first level of subdivision. Study area catchment has been delineated into 188 subbasins as shown in **Fig. 4**. **Table 1** summarizes the calculated parameters for the study area streams and basins; respectively. The total area of all basins was (1725.181 km^2).

4.2 Land Use Map

Land use/cover data is assigned to SWAT in the form of separate GIS-layer (either vector or raster) reclassified using crops and landuse types that are defined within the model databases. The map has been loaded to the model interface, and clipped to the delineated 188 subbasins to produce **Fig. 5** shows study area basins with their respective land use cover, and the percentage of each category with respect to the catchment area.

4.3 Soil Map and Data

The upper layer soil characteristics in study area (about 25 cm depth) are estimate as follows:

1- During the field study of nine soil samples have been collected, at a depth 25 cm representing the study areas. **Fig. 6** shows the location of soil samples.
2- Soil texture: classified according to the USDA classification system.

4.4 Weather Data Definition

SWAT requires daily or sub-daily meteorological data. The meteorological data used was daily precipitation, daily maximum and minimum air temperature, daily solar radiation, wind speed, and relative humidity on a daily basis. **Table 2** shows Location of Weather stations.

4.5. Running the SWAT Model

After finalizing the set up of input, the SWAT model run by selecting the “Run SWAT” option in the SWAT Simulation menu. The simulation period used was from 1 December 1985 to 31 December 2010.

5. FIELD MEASUREMENTS

The rainfall depth for two daily rain storms were obtained from Ana hydrological weather station for data 25/11/2012 and 28/1/2013 which was 30.3 mm and 28 mm respectively. At the same data throughout the runoff flow time, the flow velocity was measured by a current meter at a cross-section on the outlet of valley perpendicular to the flow of water for the six catchments of the study area as shown in **Fig. 7.**

The flow velocity measurement was taken at 0.6 of the flow depth and the reading of depth at each point of measurement. The velocity – area method was used to estimate the discharge at each of six valleys at the specified time and the measurement of flow velocity and depth were repeated wherever there is significant variation in flow depth.

6. MODEL CALIBRATION AND VERIFICATION

Calibration is the process of adjusting model input parameters until the outputs satisfactorily match with field-observed values. The typical procedure for SWAT models calibration is to calibrate stream flow and sediment in succession. The current model calibrated by use the surface flow and sediment data at the outlet of study area. An initial simulation made for the period (1/11/2012 through 30/11/2012) because the data is only available for this period for the study area model setup and calibration.

Calibration of stream flow performed depending on observed flow measurements. Outflows from the whole catchment calculated by use SWAT Model and compared with the flow-measured from the study area valleys. The initial annual simulation has shown a general overestimation of flow values, thus the CN has been selected as a calibration parameter for its significant effect on flow computation, and the subbasins' CN values have been varied (mostly decreased) iteratively within a reasonable range during several calibration runs until satisfactory agreement has been reached between simulated and observed flow values.

The flow calibration results show that SWAT has simulated the hydrological processes of the study area watershed realistically, so calibration has proceeded to involve sedimentation results as well. Because of the shortage of direct measurements of sedimentation in the study area watershed, the required observed sediment loads acquired from the field measurement that was taken during November 2012. The USLE cover factor (C) and practice factor (P) have been adjusted to match observed and simulated sediment loads through several iterations, for which the previous model performance indicators and the context of relative errors have been applied, and accordingly, the best simulation has been selected by optimization. **Fig. 8** shows the procedure of calibration for SWAT model.

A good correspondence obtained between observed and calibrated monthly flow and sediment load for the period of calibration. Calibration for flow and sediment is acceptable and indicates that SWAT is able to simulate the study area and predict flows and sediment loads well.

Model verification is the approach by which parameters developed in calibration are tested and verified against independent observed data for the area of concern. Based on calibration results, the study area SWAT model verified using the calibrated parameters to check its capability of reproducing measured flows and the corresponding sediment loads at Valleys in the study area. The period of verification was selected on the basis of quality of the available observations, the record and of surface runoff and sediment concentration of storm rainfall at (28/1/2013) was selected to verify the study area model because it is the only available data records for the model verification in the study area. A good indication obtained between measured and calculated flow and sediment load for the period of verification, giving more support toward utilizing SWAT to model the six valleys watersheds in the study area and achieve the intended modeling objectives.

7. RESULTS ANALYSIS

The daily rainfall data, maximum and minimum temperature, sunshine, humidity, and wind speed of Haditha station was considered in this study. The data is use to estimate the annual runoff volume and sediment load that were delivered from the main valleys of the left bank on Haditha Dam reservoir for the period December/1985 - December/2010. The SWAT (soil and water assessment tool) was considered for monthly simulation for both runoff and sediment of the considered valleys. The total annual precipitation and surface runoff from period 1985 to

2010 where shown in **Fig. 9**. The maximum annual total runoff volume for the considered valleys was about 167.79 * 10^6 m^3 (97.26 mm) in 1988 , which was due the maximum total annual rainfall depth in that year (286.47 mm). The minimum total runoff volume was 5.67×10^6 m^3 (3.29 mm) for the year 2007, which had a minimum average annual rainfall depth of 51.86 mm.
The total sediment load for all years for period from 1985 to 2010 was about 1484 ton/km^2 (2.56 * 10^6 ton) .This was due to the total annual surface runoff volume about 1.0688*10^9 m^3 (619.55mm) , where the amount of sediment varies from year to year depending on the amount of precipitation and surface runoff. From **Fig. 10**, we can see the amount of the sediment load for 25 year ago. The maximum annual total sediment load in year 1988 is about 283 ton/km^2 (488.22 * 10^3 ton). This was due to the effect of high surface runoff in year 1988 that was 167.79 * 10^6 m^3 (97.26 mm) , which are due to the maximum total annual rainfall depth in that year (286.47 mm). The minimum total sediment load was in year 2007 about 5 ton/km^2 (8.62 * 10^3 ton), this is due to the total runoff volume which was 5.67×10^6 m^3(3.29 mm) for the year 2007 that had an average annual rainfall depth of 51.86 mm. it showed that the higher the amount of precipitation caused an increase of high surface runoff leading to erosion of large amount of soil and therefore this causes an increase of the amount of sediment yield from valleys. From Figures, SWAT shows a good performance in simulating the seasonal variation in flow as expected according to the climate of Iraq, where most precipitation occurs during the months (October to April).

8. CONCLUSION

Based on the results obtained from this study, the following conclusions can be drawn:

1- The SWAT model working under GIS (Geographical Information System) was applied to estimate the yearly runoff and sediment load carrying from the main valleys at the left bank of Haditha Dam reservoir .
2- The total sediment load for period from 1985 to 2010 was (2.56 * 106 ton); this was due to the total annual surface runoff volume about 1.0688*109 m^3.
3- The maximum annual total sediment load was in year 1988 about (488.22 * 10^3 ton), this was due to the effect of high surface runoff in year 1988 that was 167.79 * 10^6 m^3, while the minimum annual total sediment load was in year 2007 about 8.62 * 10^3 ton. This due to the total runoff volume is 5.67×10^6 m^3.

REFERENCES

- Al-Madhhachi, A. T., 2014. “*Quantifying Erosion Risk for Little Washita River Watershed Using GIS Technique Integrated with USLE Model*”. IJERT, Vol. 3(11) , ISSN: 2277-9655

- Arnold, J. and Fohrer, N., 2005. "*SWAT2000: Current Capabilities and Research Opportunities in Applied Watershed Modeling*". Hydrological Processes, No. 19: 563-572

- Di Luzio, M., R. Srinivasan, and J. G. Arnold. 2002. "*Integration of Watershed Tools and SWAT Model into BASINS*". J. American Water Resour. Assoc. 38(4): 1127-1141.

- Engel, B., D. Storm, M. White, J. Arnold, and M. Arabi. 2007. "*A Hydrologic/water Quality Model Application Protocol*". J. American Water Resour. Assoc. 43(5): 1223-1236.

- Gassman, P.W., M. R. Reyes, C. H. Green and J. G. Arnold, 2007. "*The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions*", Soil & Water Di-vision of ASABE 50(4), 1211-1250.

- Hao, F., Zhang, X., Cheng, H., Liu, C., and Yang, Z., 2003." *Runoff and Sediment Yield Simulation in a Large Basin Using GIS and a Distributed Hydrological Model*". GIS and Remote Sensing in Hydrology, Water Resources and Environment, IAHS Publ. 289.

- Ijam, A., and Al-Mahamid, M., 2012." *Predicting Sedimentation at Mujib Dam Reservoir in Jordan*". Jordan Journal of Civil Engineering, Volume 6, No. 4.

- Licciardello, F., Srinivasan, R. and Zimbone, S. M., 2005. "*Evaluation of the SWAT Model in a Small Experimental Mediterranean Basin*". Proceedings of 3rd International SWAT Conference, Zurich, Switzerland, No.27: 261-269.

- Lin, S., Jing, C., Chaplot, V., Yu, X., Zhang, Z., Moore, N. and Wu, J., 2010." *Effect of DEM Resolution on SWAT Outputs of Runoff, Sediment and Nutrients*". Hydrology and Earth System Sciences Discussions, 7, 4411–4435.

- Neitsch, S., Arnold, J., Kiniry, J. and Williams, J., 2005. "*Soil and Water Assessment Tool Theoretical Documentation*", Texas Water Resources Institute, USA.

- Oeurng, C., Sauvage, S., and Pérez, J., 2011." *Assessment of Hydrology, Sediment and Particulate Organic Carbon Yield in a Large Agricultural Catchment Using the SWAT Model*". Journal of Hydrology, vol. 401 (n°3-4). pp. 145-153. ISSN 0022-1694.

- Sadeghi, S., Mizuyam, T. and Vangah, B., 2007. "*Conformity of MUSLE Estimates and Erosion Plot Data for Storm-Wise Sediment Yield Estimation*". Terr. Atmos. Ocean. Sci., Vol. 18, No. 1, 117-128.

- U.S. Department of Interior, Bureau of Reclamation, 2006, "*Erosion and Sedimentation Manual"*, US Department of Interior, Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulic Group, Denver, Colorado, pp. 508.

- Winchell, M., R. Srinivasan, M. Di Luzio, J. Arnold, 2010. "*ArcSWAT Interface for SWAT 2009*", User's Guide.

- Wischmeir, W.H. and Smith, D.D., 1978. "*Predicting Rainfall Erosion Losses-A Guide to Conservation Planning*". USDA Handbook No.537, Washington.

- Zhu, A.X., Wang, P., Zhu, T., Chen, L., Cai, Q. and Liu, H., 2013." *Modeling runoff and soil erosion in the Three-Gorge Reservoir drainage area of China using limited plot data*". Journal of Hydrology 492, 163–175.

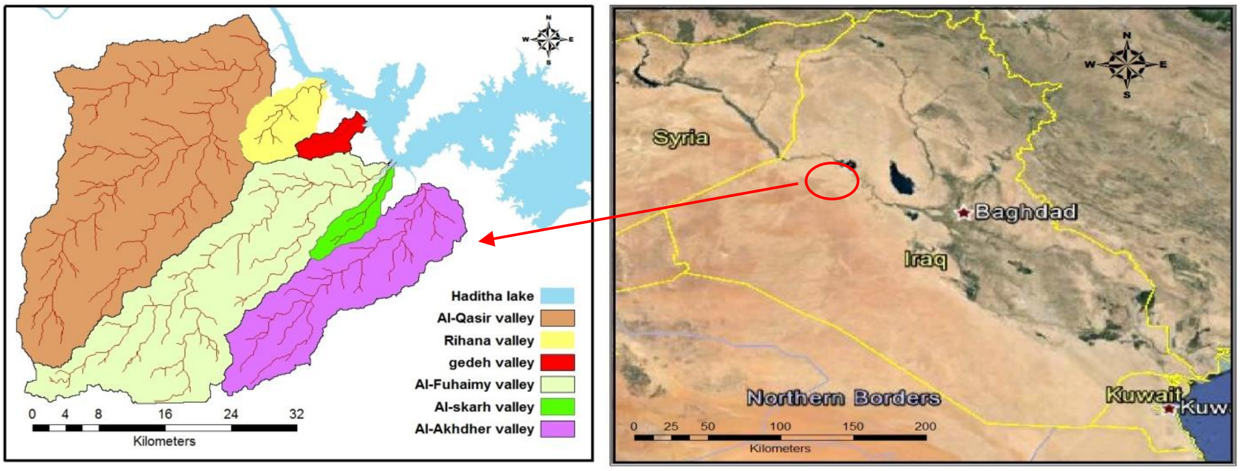

Figure 1. Location of the Haditha Dam Reservoir, and study area

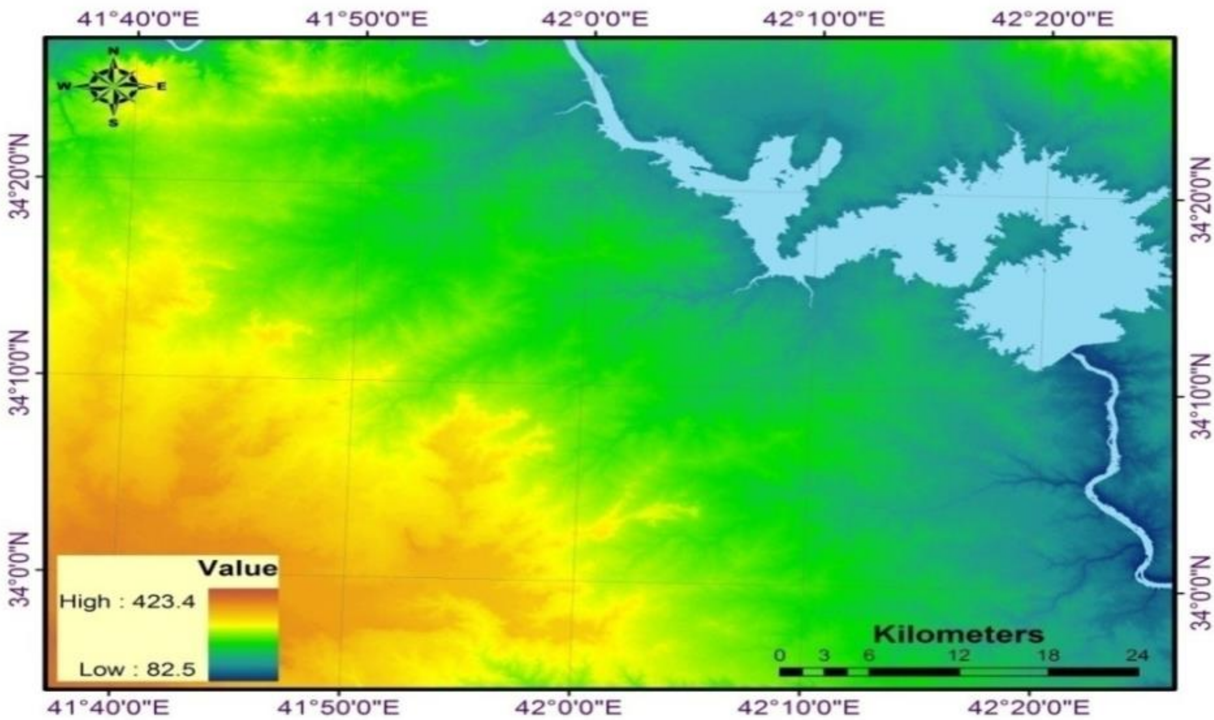

Figure 2. The digital elevation model of study area.

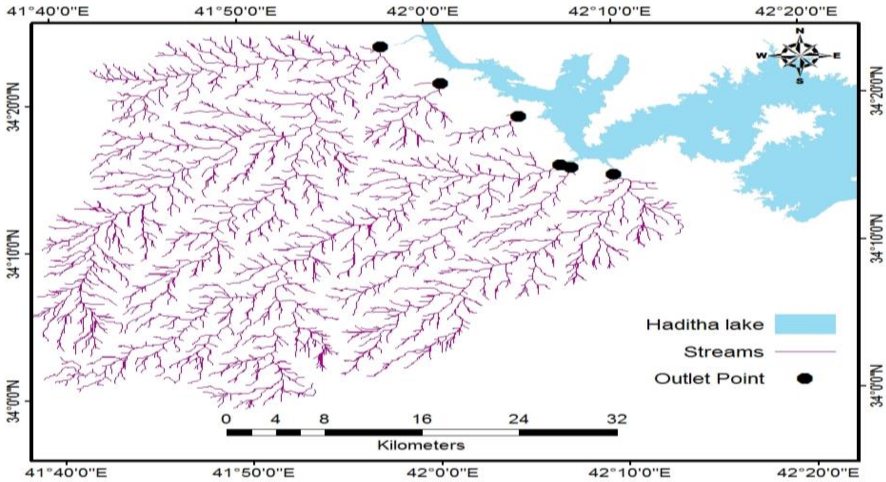

Figure 3. Study area watershed major streams and outlets.

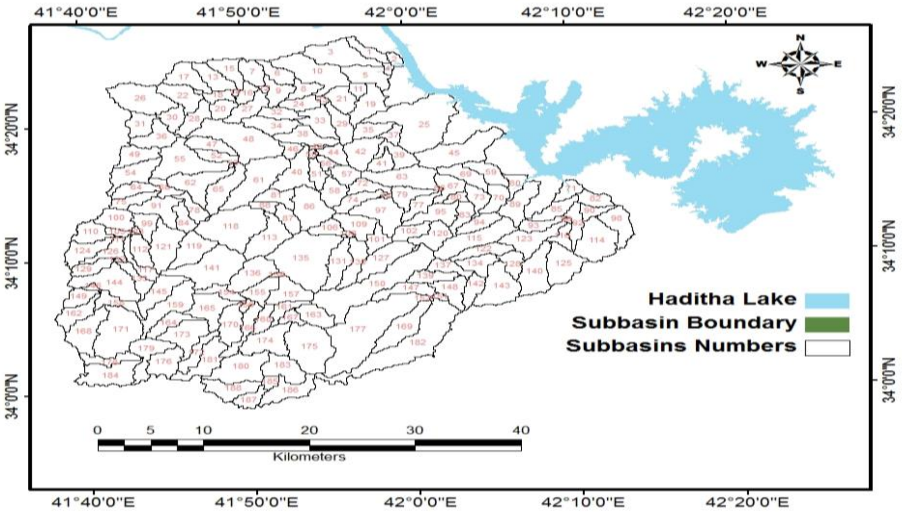

Figure 4. Catchment subbasins in study area as configured by SWAT.

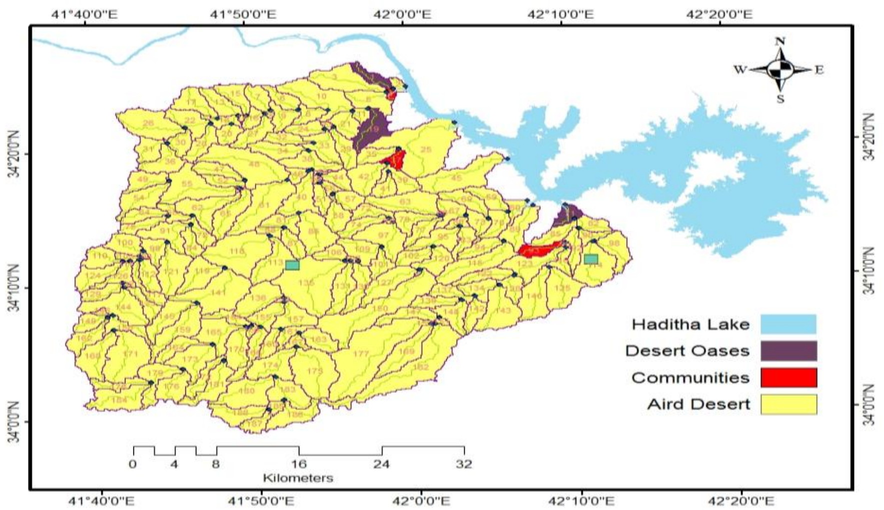

Figure 5. Landuse/cover map of study area catchment as defined by SWAT.

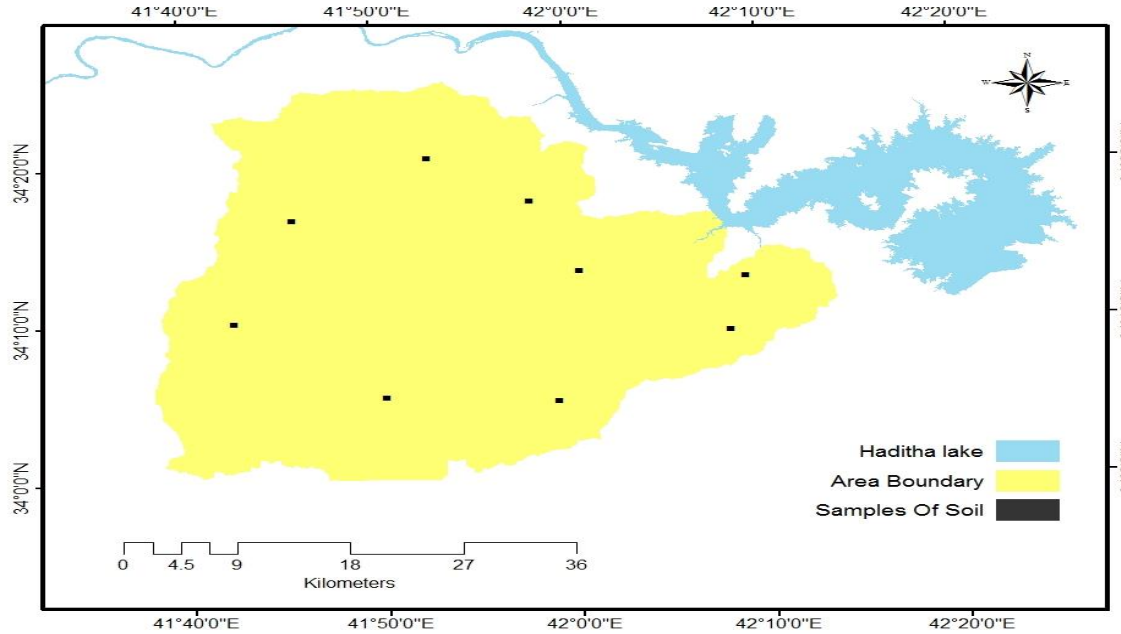

Figure 6. Location of soil samples.

Figure 7. Measurement velocity of valleys by current meter.

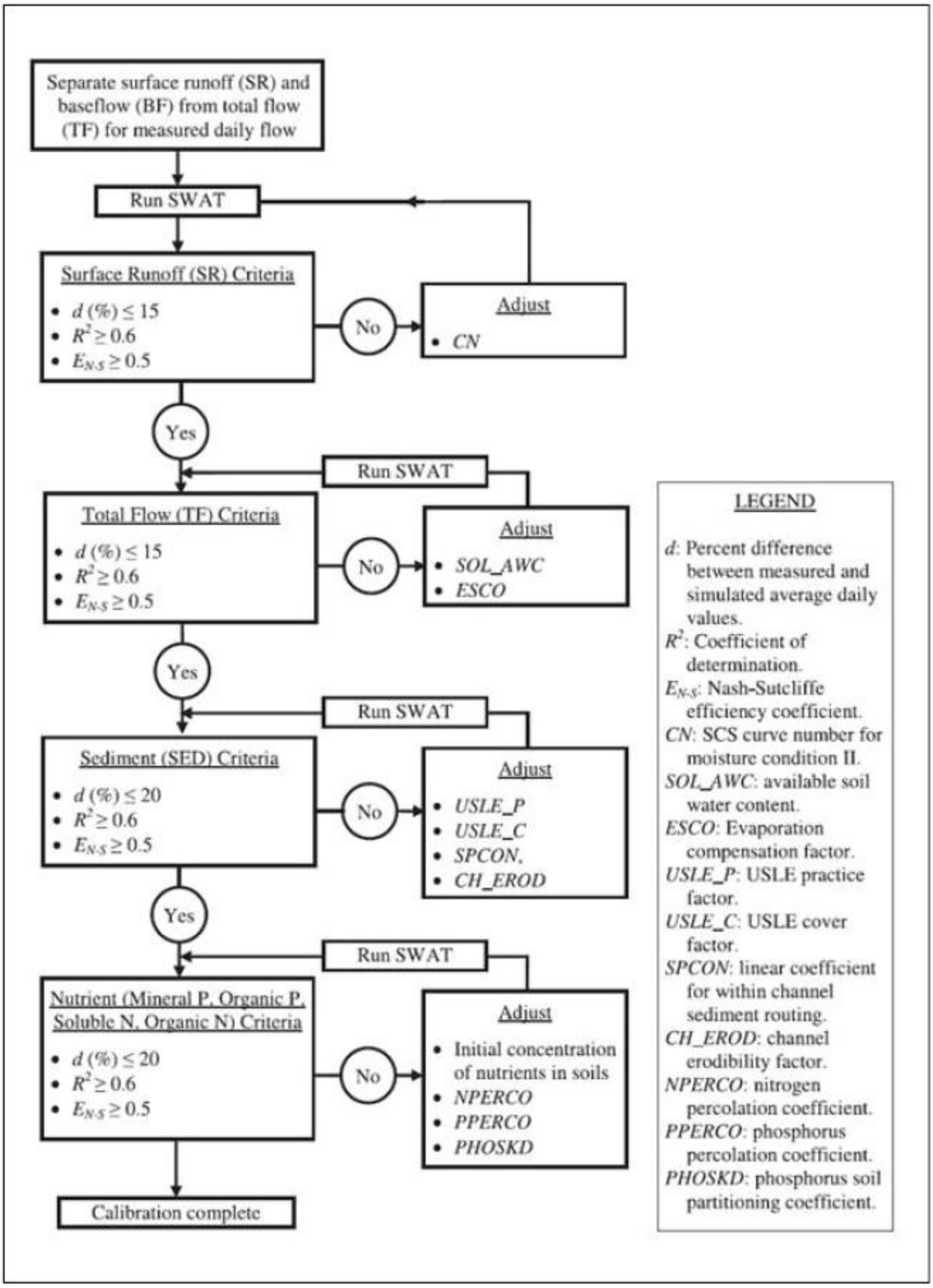

Figure 8. The procedure of calibration for SWAT model **(After Engel et al., 2007**).

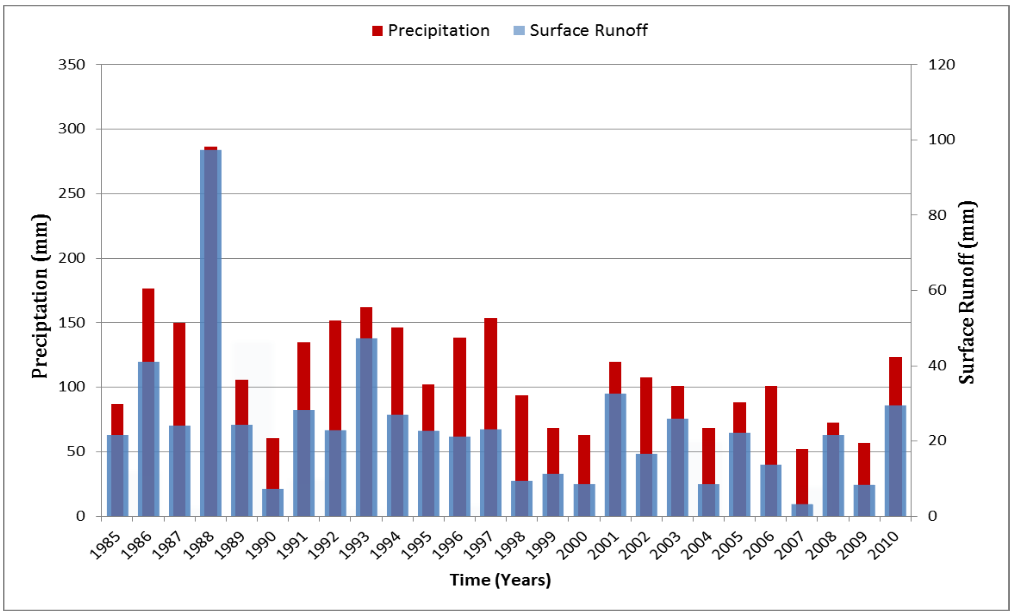

Figure 9. Annual precipitation and surface runoff simulated for the period (1985-2010).

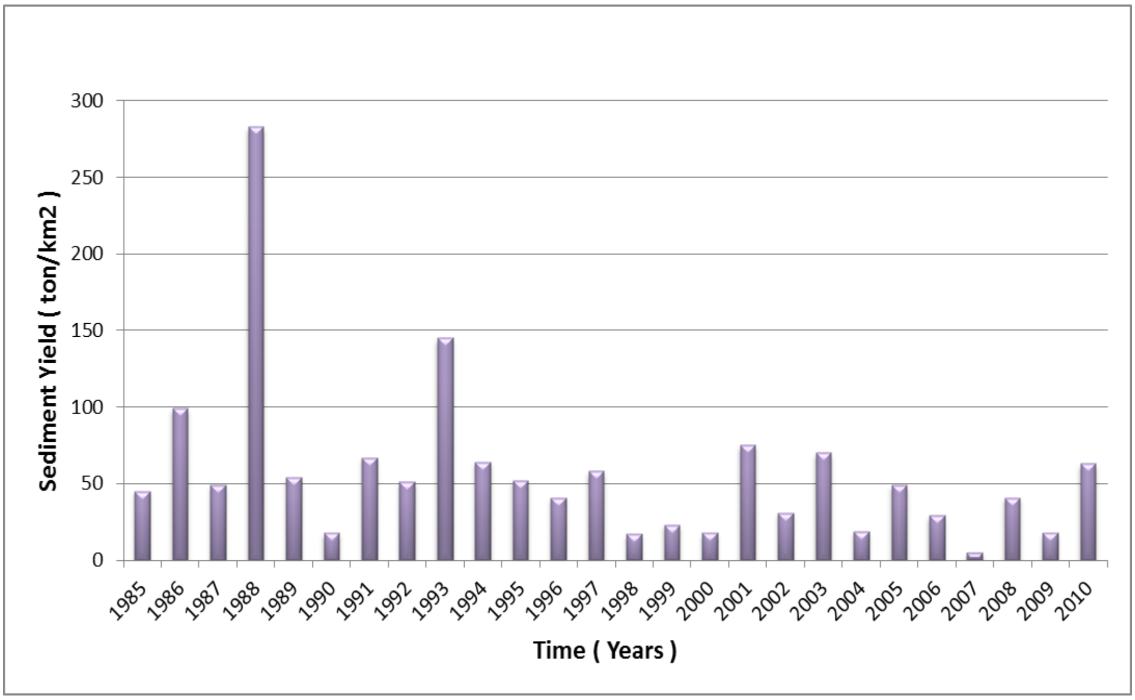

Figure 10. Annual total sediment yield simulated for the period (1985-2010).

Table 1. Study area basins parameters.

No.	Valley name	Area ($Km^{2)}$	Length of basin (m)	Slope %	Shape factor
1	Al-Qasir	769.55	48874.89	0.0120	3.10
2	Rihana	55.22	10777.24	0.0140	2.10
3	Gedeh	14.55	6209.32	0.0168	2.65
4	Al-Fuhaimy	531.21	50308.01	0.0129	4.76
5	Al-Skarh	33.36	12891.67	0.0135	4.98
6	Al-Akhdher	277.72	34560.19	0.0124	4.30

Table 2. Location of weather stations.

station	Latitude	Longitude	Elevatino
Haditha	34°08'41"	42°22'47"	120
Ana	34°22'14 "	41°50'07"	175