International Journal of Academic Research and Development
ISSN: 2455-4197; Impact Factor: RJIF 5.22
Received: 04-10-2020; Accepted: 20-10-2020; Published: 05-11-2020
www.academicjournal.in
Volume 5; Issue 6; 2020; Page No. 24-29

Runoff modeling of the upper Tarnak river basin, Afghanistan: Based on SWAT

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Abstract

Modern mathematical models have been developed for studying the complex hydrological processes of a watershed and its direct relation to climate, landscape, geology and land use. In the present study, 20-years runoff of the Upper Tarnak watershed located in the Arghandab River basin at the south of Afghanistan is modeled, using the Soil and Water Assessment Tool (SWAT). It is objected to simulate monthly stream flow of the Upper Tarnak river watershed in order to be assisted in the management of this important watershed, where water sacristy is already a big problem. The Arc SWAT software was used to delineate the study area and its sub-components, combine the associated data layers and edit the model database. To evaluate the efficiency of the model it has been calibrated from 1979 to 1980, based on three recommended statistical coefficients. The assessment indicates a good performance for calibration periods and satisfactory agreement between observed and simulated values of monthly base discharge. The value of R^2 and NSE are 0.769 and 0.81 respectively, while the value of PBIAS is about -9.31 that indicate only 9% overestimation. With proper calibration, SWAT model will be the best option to use in semi-arid regions for water management policies.

Keywords: hydrologic models, upper Tarnak river basin, SWAT model

1. Introduction

Water is one of nature's appreciated gifts that sustains life on the earth "Water is the prime requirement for the existence of life and thus it has been humankind's endeavour from time immemorial to utilize the available water resources. History has instances of civilization that flourished with the availability of dependable water supplies and then collapsed when the water supply failed" (K Subramanya [12]. It is a dynamic factor in economic development and augmenting the growth of agriculture and industry, especially in the perspective of rapidly increasing population and urbanization. Many zones face scarcity of freshwater or subject to pollution. Thus, the availability and the sustainable use of the water resources become the core of the local and national strategies and politics in these regions. Study surface runoff and the movement of water are dramatically increasing day-by-day from the need to estimate the available water at a specific location meet local demand as well as to assess the risk of flooding due to additional runoff. Hydrologist and water resource engineers always concerned with the discharge rates and runoff created by rainfall. Runoff is of the most important hydrologic variable use in most water resources applications. To deal with water management issues, one must analyse and quantify the different elements of hydrologic processes taking place within the area of interest. Obviously, this analysis must carry out on a watershed basis because all these processes are taking place within individual Micro watersheds. In this study, the GIS-based watershed model, Soil and Water Assessment Tool (SWAT) were applied. SWAT is a river basin, or watershed, scale model which has the culpableness to simulate both the spatial dissimilarity and the physical processes occurring within smaller modeling units, known as hydrologic response units (HRU) for the sustainable planning and management of surface water resources of rivers.

SWAT has been adjudged by researchers as computationally efficient in its prediction, Neitsch *et al.* [9]. It has a reliability, which confirmed in several areas around the world. SWAT model was applied in large scale to evaluate the hydrological processes in a mountain environment of the Upper Indus River Basin by Khan *et al.* [6]. Moreover, in other regions in Asia by Nasrin *et al.* [8]. It was tested and used in many regions of Africa by Fadil *et al.* [4], Ashagre [2].

2. Materials and methods

Soil and Water Assessment Tool (SWAT) is applied to runoff modeling in the Upper Tarnak watershed. The material and methodology used for this study including a description of the study area, runoff model, and data used for this simulation.

A. Study Area

The Tarnak River basin that located in the south part of Afghanistan has covered an area nearby 8,220 sq. kilometers.it is one of the fourth main tributes of Arghandab River basin. The Tarnak River is that flow through Ghazni, Zabul and Kandahar provinces of Afghanistan, which rises around 70km from southwest of Ghazni city, it flows towards the south-west of the country about 415 km before it joins the Dori and Arghandab river approximately 25 km downstream of the Dori-Arghastan confluence, and 37 km upstream of the Dori-Arghandab confluence. The watershed can be subdivided into two sub-watershed upper and lower Tarnak watershed. The upper Tarnak sub-watershed has covered 2,887 sq. kilometers, which is the area of interest for this study and lie between 67° 25’ E to 68° 03’ E and 32° 26’ N to 33° 16’ as shown in Figure 1.

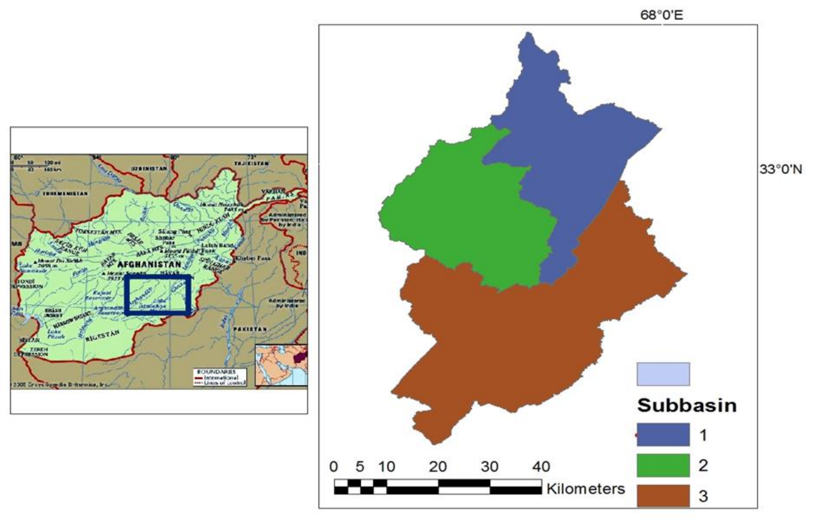

Fig 1: Location of the Upper Tarnak River basin

B. Model description

The Soil and Water Assessment Tool (SWAT) is a river basin scale. continuous time and spatially distributed physically based model developed by United States Department of Agriculture (USDA) to predict the impact of land management practices on water, sediment and agricultural chemical yields in complex catchments with varying soils, land use and management conditions over long periods of time (Arnold *et al*., 1998 [1]; Neitsch *et al*., 2009 [8]. SWAT’s conceptual basis operates by dividing a catchment into sub-basins. Each sub-basin is connected by a stream channel and further divided into a hydrologic response unit (HRU). The HUR is a unique combination of soil, vegetation type and slope in a sub-basin. SWAT simulates hydrology, vegetation growth and management practices at the HRU level. The model has interfaced with Arc-GIS-ArcView (Arc SWAT) extension software that provides capabilities to streamline GIS processes tailored toward hydrologic modeling (Rory Coffey *et al*., 2010) [3].

SWAT requires an assortment of input data layers for model setup and watershed simulations. The topography of watershed is defined by a Digital Elevation Model (DEM). It is used to calculate sub-basin parameters such as slope and to define the stream network.

The soil data are required to define soil characteristics and attributes. The land-cover data provide vegetation information on the ground and their ecological processes in lands and soils. Climate, precipitation, and streamflow data are sourced and prepared according to SWAT input requirements. The hydrologic cycle of the SWAT model is based on the water balance equation, which considers the unsaturated zone and shallow aquifer above the impermeable layer as a unit. The SWAT model based on the principles of the water balance:

$$SW\,t = SW\,0 + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw) \quad \ldots\ldots\ldots\ldots 1.1$$

Where SWt is the soil water content [mm], SW0 is the initial soil water content on day 1 [mm] t is the time [days]. Rday is the daily precipitation [mm], Qsurf is the amount of surface runoff [mm]. Ea is the evapotranspiration [mm], ωseep is the amount of water entering the unsaturated zone [mm] (consists of the infiltration rate minus the capillary rise), and Qgw is the amount of return flow [mm].

The surface runoff volume predicted in SWAT using the SCS curve number method. The SCS curve number equation is:

$$Q\,surf = \frac{(Rday - 0.2S)2}{(Rday + 0.8S)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.2$$

R>0.2S

Where Q $_{surf}$ is the daily surface runoff (mm), R $_{day}$ is the rainfall depth for the day (mm), and S is retention parameter (mm). The runoff will occur when R $_{day}$ > 0.2S, the retention parameter S is varied due to changing water content in soil, and the prediction of lateral flow by SWAT model are defined as follow.

$$S = 254\left(\frac{100}{CN} - 1\right) \ldots\ldots\ldots\ldots\ldots\ldots \quad 1.3$$

Where CN is Curve Number and the constant 254 used to express in mm.

$$CN = {}^{25400}/_{(S + 254)} \ldots\ldots\ldots\ldots\ldots \quad 1.4$$

Moreover, has a range of 100≥ CN ≥ 0. A CN value of 100 represents a condition of zero potential retention, and CN zero value represent a condition of an infinitely abstracting catchment with, S= ∞. Antecedent Moisture condition is another important factor which has an effect on CN, and it denotes the presence of soil moisture content prior of rainfall even under consideration. SCS define for the purpose of practical application three level of AMC; AMC-1 dry condition, AMC-2 average condition, and AMC-3 for wet condition.

The CN value always documented for the case of AMC-II, to convert the CN-II for the cases of other AMCs conditions the following equations are used.

For AMC-1 $CNI = \frac{CNII}{2.281 - 0.01281CNII} \ldots\ldots\ldots \quad 1.5$

For AMC-III $CNIII = \frac{CNII}{0.427 + 0.00573CNII}$ ……   1.6

C. Input Data

DEM is the raster data consisting of an array of cells or pixels having elevation values. DEM is used to delineate the networks of river streams, sub-watershed, and parameters like slopes for HRUs. Data has been downloaded from Advanced Space born Thermal Emission and Reflection Radiometer (ASTER) with (DEM) of 30-meter resolution. In the present study, DEM is projected to coordinate the system (WGS 1984 UTM Zone 42N) and used for further processed. From the present study SWAT model, the Upper Tarnak watershed covers an area of 2887 km2 with an elevation ranging from 1840 m to 3753 m from mean sea level. The watershed is further divided in three sub-watershed depending on topographic characteristics, Figure 2

D. Land Use / Land Cover

Land cover is a composition of characteristics of the elements that cover the land surface such as (urban, transportation, residential, water, forest, agriculture etc.). The study area's land use and land cover data were obtained from European Union Global Environmental Monitoring land use/land cover data. Generally, Land use and land cover data used for HRU definition and then given (CN) to land areas for runoff calculation and hydrological analysis. Overall, eight mainland uses classes for the study area as shown in Figure 2.

E. Soil Map

The soil data are required to define soil characteristics, attributes, and is another important aspect that has extremely effect on the runoff response of a catchment. The study area's soil map was obtained from ISRIC- World Soil Property Estimates for Broad-Scale Modeling (WISE30sec) as illustrate in Figure 2. Four main classes are so identified that the dominant categories are CARADIGAN; 85%, NELLS; 9.6%, WEIDER; 3.54% and MACHIAS; 1.78%.

F. Meteorological Data

The long-standing meteorological datasets of precipitation, temperature, wind speed.

Solar radiation, and relative humidity are required for the hydrological modeling. For SWAT model, the records of precipitation and temperature are the mandatory inputs and the other Parameters are elective. The model has the capability of weather generation itself, to generate the data against these parameters.

Due to luck availability of the meteorological records for this watershed, Global Weather Data has been used for runoff modeling of Tarnak watershed.

G. Hydrological Data

For calibration and validation, hydrological datasets of Tarnak River flow are required. The data have been collected from the concerned agency, Department of Water Resources Ministry of Energy and Water/Afghanistan. A long-term flow data of Tarnak river were gauged at Shahjuy district of Zabul province (located in 32˚ 32' N, 67˚ 27' E) the historic monthly flow data were available for the period 1970–1980 and has been used for calibration periods.

3. Model simulation

Hydrologic modeling of Upper Tarnak watershed was carried out using the Arc SWAT version 2012.10_2.19.The simulation has been done for two years, from 1979 to 1980, because only two years overlap climate and observe data for this particular watershed was available. The hydrology simulation by SWAT is based on more about 39 parameters and some of them need to be adjusted in the calibration phase.

In such case, the calibration process becomes complex and computationally extensive. The sensitivity analysis is used in order to recognize and rank the most responsive hydrological parameters that have an important impact on specific model output, which is the outflow, in this case, Saltelli *et al*. [10].

The model is simulated many times by changing the value of hydrological parameters that ranked by the model to get the best match between model output and observed flow data. Thereafter, adjusted parameters have been used for another period to calculate streamflow of Upper Tarnak watershed for 20-years as illustrate in Table 2.

4. Performance Evaluation

Adaptability performance and accuracy of the model must be assessed to check whether the result produced by the model is in the range of the satisfaction or not, the methods that are sued to evaluate the result accuracy of the model are discussed below.

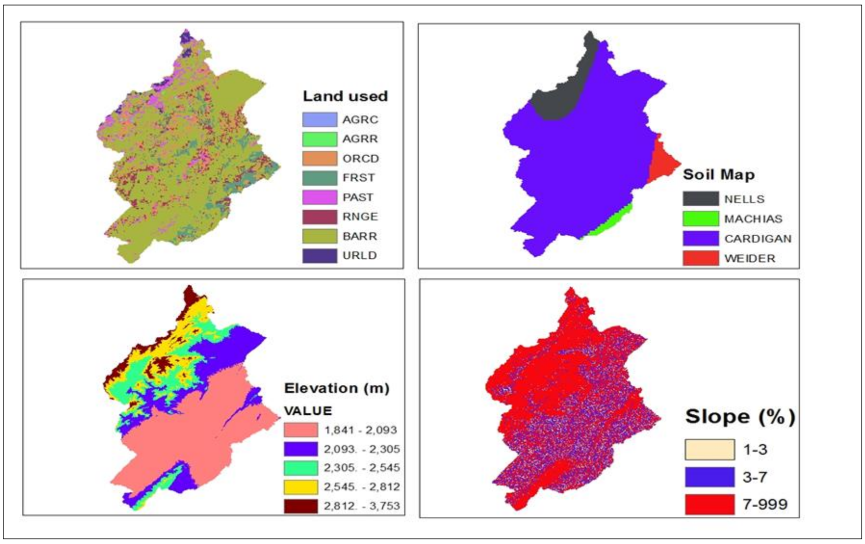

Fig 2: Elevation, Slope, Land use and Soil map of Upper Tarnak sub-watershed

A. Coefficient of Determination (R2*)*

It is a good method to signify the consistency among observed and simulated data by following a best-fit line. It ranges from zero to 1.0 with higher values indicating less error variance, and values greater than 0.50 are considered acceptable (Moriasi *et al.*, 2007) [7].

$$R2 = \left[\frac{\sum_{i=1}^{t}(Oi-Oa)(Si-Sa)}{\left[\sum_{i=1}^{N}(Oi-Oa)^2\right]^{0.5}\left[\sum_{i=1}^{N}(Si-Sa)^2\right]^{0.5}}\right]^2 \ldots \qquad 2.1$$

Oi = observed discharge, Oa = average observe discharge, Si = simulated discharge, Sa = mean simulated discharge.

B. Nash–Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970) and is calculated from the following equation

$$NSE = 1 - \left[\frac{\sum_{i=1}^{T}(Oi-Pi)^2}{\sum_{i=0}^{T}(Oi-Om)^2}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 2.2$$

Where, NSE = Nash-Sutcliffe coefficient, Oi = observed discharge, Pi = modeled discharge, Om= mean observed discharge.

C. Percent Bias (PBIAS)

PBIAS values indicate overestimation and underestimation bias of the model, Gupta *et al.*, [5]. It is defined by the range -10 to 10. The formulas of this coefficients is,

$$\text{PBAIS} = \left[\frac{\sum_{i=1}^{n}(Oi-Pi)*100}{\sum_{i=0}^{n}(Oi)}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 5.3$$

Where PBIAS is the deviation of data being evaluated and expressed as a percentage, and Oi = observed discharge, Pi = modeled discharge

3. Results and Discussions

A. Sensitivity Analysis

Parameter sensitivities are determined by performing a multiple regression analysis, which regresses the parameters generated by Latin Hypercube against the objective function [13]. t-test and p-value are used to identify each parameter's relative significance. The t-stat is the ratio of parameter coefficient to its standard error.

Parameters with a p-value less than or equal to 0.05 are taken as most sensitive. About 10 parameters have been considered for sensitivity analysis, Saturated hydraulic conductivity SOL_K, Groundwater Re-evaporation coefficient GW_REVAP and Curve number condition 2 CN2 were more sensitive parameters compare to others as shown in Table 1.

A. Calibration

Two-year calibration from 1979 to 1980 was done for the model at the outlet of the watershed, the calibration was done based on the comparison of the simulated runoff with the observe streamflow record. The monthly streamflow record of Shahjuy water-gage station that was active from 1970 to 1980 has been used for this study as shown in Figure 3.

To bring simulated values close to the observed values five-model parameters such as; SOL_K Saturated hydraulic conductivity of first layer, GW_REVAP Groundwater revap coefficient, CN2.mgt Curve number condition 2, CH_N2 Manning coefficient for the channel, CH_K2 Effective hydraulic conductivity in the channel, several time had been adjusted. the values of coefficient of determination R2 for calibration period is about 0.769 as demonstrating in Figure 6, it indicates a good correlation between observe and simulated value, generally, the accepted range of the R2 value is >0.5.

The Nash–Sutcliffe Efficiency (NSE) for the calibration period is about 0.81, and overall the performance rating is considered to be very good for the 0.75<NSE >1 Moriasi *et al.*, 2007 [7].

The value of PBIAS is -9.31 for a model that indicating around 9% overestimation from the observed value. PBIAS is used show the average tendency of the model to be larger or smaller from the observe value, and the accepted range for present bias value is from -10 to 10, Seong *et al.*, 2015. [11].

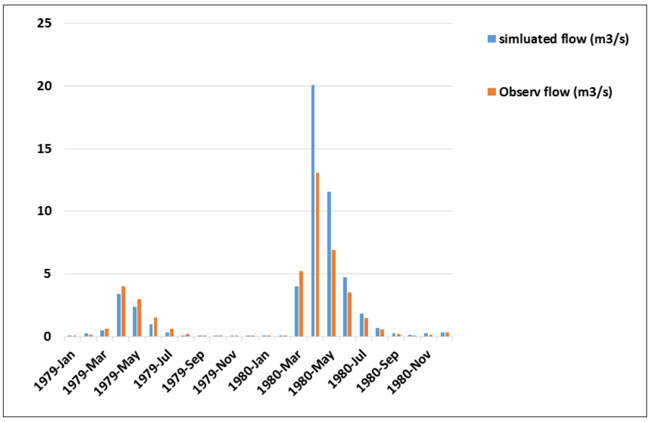

Fig 3: Observe and Simulated streamflow at the outlet of the Upper Tarnak

Table 1: List of the parameter that used for sensitivity analysis

Sensitivity Order	Parameter	Full name of the parameters	t-Stat	P-Value
1	R__SOL_K (...).sol	Saturated hydraulic conductivity	2.6	0.06
2	V__GW_REVAP.gw	Groundwater Re-evaporation coefficient	-2.22	0.09
3	R__CN2.mgt	Curve number condition 2	-1.09	0.34
4	V__CH_N2.rte	Manning coefficient for channel	0.87	0.43
5	V__CH_K2.rte	Effective hydraulic conductivity in channel	-0.47	0.67
6	V__ALPHA_BF.gw	Base flow recession constant	-0.13	0.90
7	V__ESCO.hru	Soil evaporation compensation factor	0.09	0.93
8	R__SOL_AWC (...).sol	Soil available water capacity	-0.07	0.95
9	V__GW_DELAY.gw	Ground water delay time (d)	-0.05	0.96
10	V__GWQMN.gw	Threshold water level in shallow aquifer for base flow	0.04	0.97

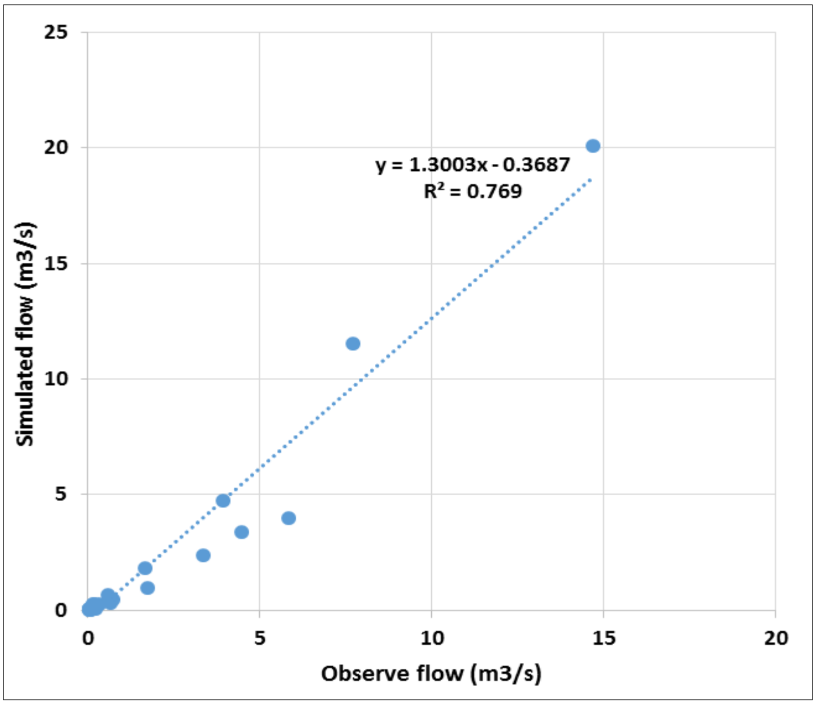

Fig 4: Coefficient of determination for the calibration period.

Table 2: Monthly basis streamflow of Upper Tarnak watershed for 20-years

Runoff of Upper Tarnak River Basin of 20-Years												
years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	0.2262	0.2776	8.757	11.17	5.51	2.272	0.858	0.32	0.14	0.08	0.06	0.05
1982	0.13	0.11	5.23	34.3	22.8	11.3	5.6	2.4	1.07	0.63	0.83	0.65
1983	0.42	0.34	5.9	18.3	16.53	9.7	5.01	2.4	1.24	0.56	0.32	0.21
1984	0.17	0.15	3.6	8.3	5.7	2.8	1.2	0.7	0.32	0.13	0.1	0.05
1985	0.051	0.08	1.2	3.52	3.99	3.17	1.37	0.83	0.46	0.2	0.092	0.08
1986	0.06	0.04	9.5	23.14	13.37	5.2	2	1.1	0.9	0.42	0.24	0.52
1987	0.36	0.19	1.32	3.11	1.8	2.1	1.28	0.5	0.19	0.078	0.04	0.022
1988	0.4	0.38	3.67	5.22	2.6	1.03	0.4	0.12	0.039	0.02	0.01	0.165
1989	0.7	0.4	5.7	14.5	8.4	3.5	1.5	0.62	0.3	0.16	0.11	0.24
1990	0.34	0.3	6.8	16.6	10.33	4.8	1.9	0.72	0.3	0.15	0.3	0.38
1991	0.9	5.64	14.6	42.2	28.9	14.5	7.5	3.6	1.8	0.93	0.6	0.52
1992	0.52	0.45	4.16	13.9	19.1	7.5	3.5	1.5	0.6	0.3	0.17	0.3
1993	0.42	0.29	7.1	12.3	6.7	2.9	1.1	0.4	0.16	0.08	0.06	0.05
1994	0.04	0.07	3.6	5.2	2.7	1.06	0.6	0.3	0.1	0.04	0.02	0.13
1995	0.15	0.08	0.48	2.73	2.5	1.17	0.5	0.5	0.3	0.12	0.123	0.06
1996	0.03	0.02	6.5	9.5	4.3	1.9	0.8	0.3	0.1	0.04	0.03	0.02
1997	0.02	0.02	2.6	7.6	4.4	1.88	0.67	0.3	0.09	0.1	0.36	0.288
1998	0.14	0.063	4.31	31	21.1	8.6	3.4	1.4	0.64	0.4	0.3	0.2
1999	0.15	0.34	0.55	0.38	0.16	0.05	0.02	0	0	0	0.05	0.1
2000	0.05	0.02	0.12	0.64	0.36	0.12	0.02	0	0	0	0	0.07

4. Conclusions

Watershed models have turned into the main tool in addressing a wide range of environmental and water resources problems. The SWAT model has been well recognized as an effective water resources management tool. In this study, the SWAT software was used in order to model the streamflow of Upper Tarnak watershed. SWAT model has been successfully calibrated. Manual calibration has been done first on monthly basis. The calibration of the model made good simulation results. The efficiency of the model has been verified by the coefficient of determination, Nash-Sutcliffe Efficiency (NSE) and static coefficient of Percent Bias. On monthly basis, the Coefficient of Determination, Nash, and Sutcliffe Efficiency (NSE) were 0.769 and 0.81 respectively for calibration periods, which demonstrate the good predictive capability of the model. Water balance components such as surface runoff, lateral flow, base flow, and evapotranspiration have also been simulated. For about 20-years monthly basis stream flow from 1981 to 2000 has been analyzed for Upper Tarnak watershed, the performances of the model can be improved additionally by using more specific and exact land use/land cover, soil and climate data. It is recommended to use the calibrated model to evaluate and handle other watershed mechanisms such as the analysis of the impacts of land and climate changes on the water resources as well as the water quality, the sediment transport, and agricultural management.

References

1. Arnold Jeffrey G. "Large area hydrologic modeling and assessment part I: Model development1, 1989, 73-89.
2. Ashagre Biniam Biruk. SWAT to identify watershed management options: (Anjeni watershed, Blue Nile basin, Ethiopia). Diss. Cornell University, 2009.
3. Coffey Rory. "Analysis of the soil and water assessment tool (SWAT) to model Cryptosporidium in surface water sources." biosystems engineering. 2010; 106(3):303-314.
4. Fadil Abdelhamid. "Hydrologic modeling of the Bouregreg watershed (Morocco) using GIS and SWAT model." Journal of Geographic Information System. 2011; 3(04):279.
5. Gupta Hoshin Vijai, Soroosh Sorooshian, Patrice Ogou Yapo. "Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration." Journal of Hydrologic Engineerin. 1999; 4(2):135-143.
6. Khan AD. "Hydrological modeling of upper Indus Basin and assessment of deltaic ecology." International Journal of Modern Engineering Research (IJMER). 2013; 4(1):73-85.
7. Moriasi Daniel N. "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations." Trans. Asabe. 2015; 50(3):885-900.
8. Nasrin Z, Gholamabbas S, HS. Ebrahim. "Hydrological and sediment transport modeling in maroon dam catchment using soil and water assessment tool (SWAT)." International Journal of Agronomy and Plant Production. 2013; 4(10):2791-2795.
9. Neitsch Susan L. Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute, 2011.
10. Neitsch Susan L. Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute, 2011.
11. Saltelli, Andrea, Karen Chan, Marian Scott E. eds. Sensitivity analysis. Vol. 1. New York: Wiley, 2000.
12. Seong Chounghyun, Younggu Her, Brian L Benham. "Automatic calibration tool for Hydrologic Simulation Program-FORTRAN using a shuffled complex evolution algorithm." Water. 2015; 7(2):503-527.
13. Subramanya K. Engineering Hydrology, 4e. Tata McGraw-Hill Education, 2005.
14. Tibebe Degefie, Woldeamlak Bewket. "Surface runoff and soil erosion estimation using the SWAT model in the Keleta watershed, Ethiopia." Land Degradation & Development. 2011; 22(6):551-564.