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ORIGINAL ARTICLE

Hydrological modeling of the Simly Dam watershed (Pakistan) using GIS and SWAT model

Shimaa M. Ghoraba

Irrigation and Hydraulics Engineering Department, Faculty of Engineering, Tanta University, Egypt

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KEYWORDS

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Water balance

Abstract Modern mathematical models have been developed for studying the complex hydrological processes of a watershed and their direct relation to weather, topography, geology and land use. In this study the hydrology of Simly Dam watershed located in Saon River basin at the north-east of Islamabad is modeled, using the Soil and Water Assessment Tool (SWAT). It aims to simulate the stream flow, establish the water balance and estimate the monthly volume inflow to Simly Dam in order to help the managers to plan and handle this important reservoir. The ArcSWAT interface implemented in the ArcGIS software was used to delineate the study area and its sub-components, combine the data layers and edit the model database. The model was calibrated from 1990 to 2001 and evaluated from 2002 to 2011. Based on four recommended statistical coefficients, the evaluation indicates a good performance for both calibration and validation periods and acceptable agreement between measured and simulated values of both annual and monthly scale discharge. The water balance components were correctly estimated and the Simly Dam inflow was successfully reproduced with Coefficient of Determination (R^2) of 0.75. These results revealed that if properly calibrated, SWAT model can be used efficiently in semi-arid regions to support water management policies.

1. Introduction

Water is an essential element for survival of living things. It is vital factor for economic development and augmenting 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. To deal with water management issues, one must analyze and quantify the different elements of hydrologic processes taking place within the area of interest. Obviously, this analysis must be carried out on a watershed basis because all these processes are taking place within individual microwatersheds. Hydrological processes and their local scattering have always direct relation to weather, topography, geology and land use of watershed in addition to the impact of human activities. A watershed is comprised of land areas and channels and may have lakes, ponds or other water bodies. The flow of water on land areas occurs not only over the surface but also below it in the unsaturated zone and further below in the saturated zone, Singh and Frevert [1]. The use of a watershed model to simulate these processes plays a

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E-mail address: Shimaaegypt75@yahoo.com

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fundamental role in addressing a range of water resources and environmental and social problems.

The development of remote sensing (RS) techniques and Geographic Information System (GIS) capabilities has encouraged and improved the expanded use of watershed models worldwide. GIS is a suitable tool for the efficient management of large and complex database and to provide a digital representation of watershed characteristics used in hydrologic modeling. It has added confidence in the accuracy of modeling by providing more practical approach toward the watershed conditions, defining watershed characteristics, improving the efficiency of the modeling process and ultimately increasing the estimation capabilities of hydrological modeling, Bhuyan et al. [2].

Pakistan is one of the world's most arid countries, with an average rainfall of under 240 mm a year. The balance between population and available water already makes Pakistan one of the most water stressed countries of the world. The problem of increasing water scarcity in Pakistan is multifaceted. Agriculture in Pakistan uses well over 95% of the freshwater resources in addition to the high losses in the sprawling irrigation system. Rapid and unsustainable development, too, has polluted and disturbed some major watersheds and river plains, Ali [3]. The objective of modeling Simly Dam watershed in Soan River basin, is to set up and calibrate the adapted model in order to simulate the functioning of the entire area and therefore predict its response to phenomena and risks it confronts such as erosion, inundations, drought, and pollution. Specifically, the purpose is to estimate the volume inflow to the Simly Dam located at the outlet of the watershed in order to develop an efficient decision framework to facilitate, plan and assess the management of this important reservoir. Indeed, Simly Dam has a crucial role because it is the source of freshwater of Islamabad, the Federal Capital of Pakistan.

In this study, the GIS based watershed model, Soil and Water Assessment Tool (SWAT) was applied. SWAT is a river basin, or watershed, scale model which has the capableness to simulate both the spatial heterogeneity 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 researches as computationally efficient in its prediction, Neitsch et al. [4]. 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 Upper Indus River Basin by Khan et al. [5] and in other regions in Asia by Nasrin et al. [6] and Cindy and Koichiro [7]. It was tested and used in many regions of Africa by Fadil et al. [8], Ashagre [9] and Schuol et al. [10]. It also applied to simulate St. Joseph River watershed in US by Kieser et al. [11]. Swat model was used successfully to estimate the water balance components in South eastern Ethiopia by Shawul et al. [12] and in Nigeria by Adeniyi et al. [13].

2. Materials and methods

Soil and Water Assessment Tool (SWAT) is applied to model the hydrology of Simly Dam watershed in Soan river basin. The methodologies used for this study include a description of the study area, hydrological model and the special dataset which used in the simulation are given in the following sections with details.

2.1. Description of the study area

The Soan River is an important stream of the Pothohar region of Pakistan. It originates from Murree hills and passes through the steep slopes (about 3.78%) and enters the plains near Chirah. Simly Dam is located 13.0 km upstream of Chirah on Soan River. The Simly reservoir is recognized as an essential constituent of the bulk water supply scheme for Islamabad, Fig. 1. Water released from the reservoir to Islamabad is the cheapest source of fresh drinking water for the city. Simly Dam is an 80 m high earthen embankment dam located in 33° 43′ 08″ N, 73° 20′ 25″ E at 30 km northeast of Islamabad and Rawalpindi in Rawalpindi District, Punjab and was constructed in 1983, IUCN Pakistan [14]. Simly Dam catchment area receives heavy precipitation in the form of snow and rainfall. The average yearly precipitation is about 1233 mm, most of which occurs during July–September and February–April. The highest and lowest mean minimum values of air temperature were observed to be 15.52 °C (2000) and 4.62 °C (1993) at Islamabad respectively, from 1990 to 2001, whereas, the highest and lowest mean maximum values of temperatures were remained 30.3 °C (2001) and 17.3 °C (1996) at the same period. The average volume inflow from Simly Dam is estimated at 190.3 mm^3/year, from 1990 to 2001 according to a gauged point on the Dam location.

2.2. Description of SWAT model

SWAT is a river basin or watershed, scale model. It is a continuous time model that operates on daily time steps and uses a command structure for routing runoff and chemical through watershed. It developed by Agricultural Research Services of United States Department of Agriculture to predict the impact of land management practices on water, sediment, and agriculture chemical yields in large and complex watersheds with varying soil, land use, and management conditions over long periods of time, Arnold et al. [15]. ArcSWAT (Arc GIS-SWAT) is the latest available version which is used as an interface between ArcGIS and the SWAT model. ArcSWAT version 2.3.4 which was built for ArcMap 9.3 is used in this study, Winchell et al. [16]. Spatial data (DEM, soil and land use) are used in the preprocessing phase and fed into the SWAT model through the interface. The soil and land cover make important responding units and the same is accomplished by SWAT model by subdividing the watershed into areas having unique land use and soil combination which are called Hydrological Response Units (HRU) during the process of runoff generation. 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 ground and their ecological processes in lands and soils. Climate, precipitation and stream flow data are sourced and prepared according to SWAT input requirements. Fig. 2 shows the global view of SWAT model components including input, output, the spatial datasets, and GIS parts and summarizes its methodology.

The hydrologic cycle of the SWAT model is based on the water balance equation, which considers the unsaturated zone

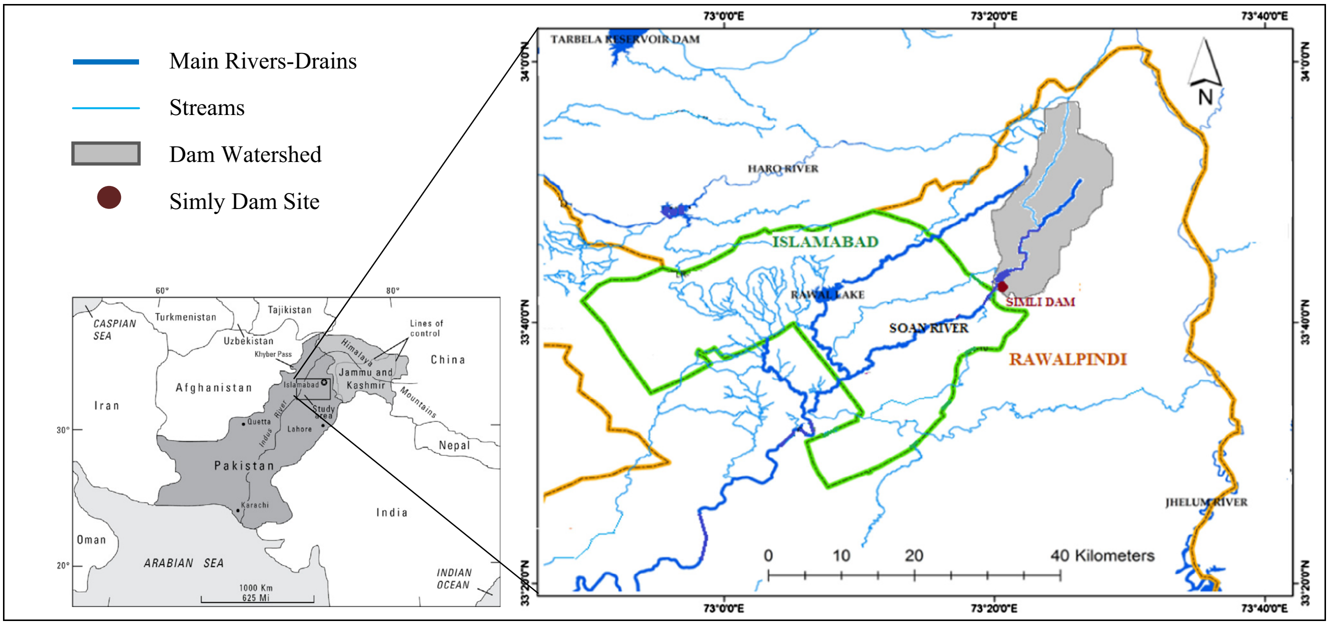

Figure 1 Location map of the Simly Dam watershed area in Pakistan.

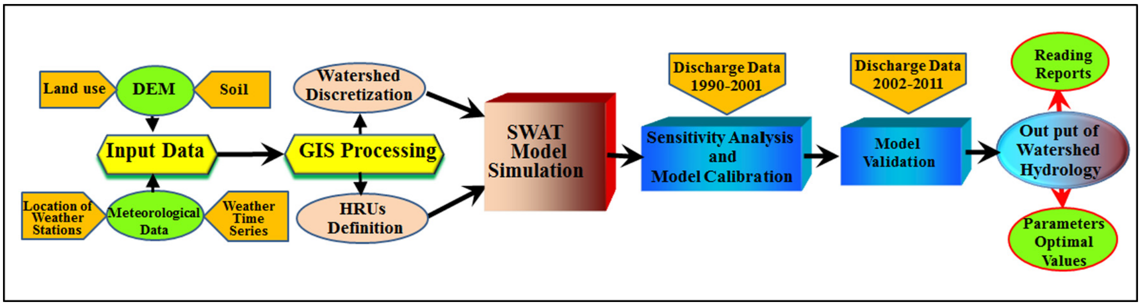

Figure 2 Global view of SWAT model components and methodology.

and shallow aquifer above the impermeable layer as a unit. Eq. (1) is the important equation to predict the watershed of hydrology used by SWAT.

$$\mathrm{SW}_t = \mathrm{SW}_o + \sum_{i=1}^{t}\left(R_{\mathrm{day}} - Q_{\mathrm{surf}} - E_a - w_{\mathrm{seep}} - Q_{\mathrm{gw}}\right)_i \qquad (1)$$

where t is the time in days, SW_t and SW_o are the final and initial soil water content respectively (mm), R_{day} is amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm).

The estimation of surface runoff can be performed by the model using the Soil Conservation Service (SCS) curve number method, Arnold et al. [15]. This method is a widely used for the prediction of approximate amount of runoff from a given rainfall event. It is mainly based on the soil properties, land use and hydrologic conditions. The SCS curve number equation is

$$Q_{\mathrm{surf}} = \frac{(R_{\mathrm{day}} - 0.2S)^2}{(R_{\mathrm{day}} + 0.8S)} \qquad (2)$$

where Q_{surf} is the daily surface runoff (mm), R_{day} is the rainfall depth for the day (mm), and S is the retention parameter (mm). The retention parameter S and the prediction of lateral flow by SWAT model are defined in Eq. (3):

$$S = 25.4\left(\frac{1000}{\mathrm{CN}} - 10\right) \qquad (3)$$

where S = drainable volume of soil water per unit area of saturated thickness (mm/day); CN = curve number.

SCS defines three antecedent moisture conditions: I – dry (wilting point), II – average moisture and III – wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the Eqs. (4) and (5), respectively.

$$\mathrm{CN1} = \mathrm{CN2} - \frac{20(100 - \mathrm{CN2})}{\left(100 - \mathrm{CN2} + e^{[2.533 - 0.0636*(100 - \mathrm{CN2})]}\right)} \qquad (4)$$

$$\mathrm{CN3} = \mathrm{CN2} * e^{[0.00673(100 - \mathrm{CN2})]} \qquad (5)$$

where CN1 is the moisture condition I curve number, CN2 is the moisture condition II curve number, and CN3 is the moisture condition III curve number.

Lateral flow is predicted by

$$q_{\text{lat}} = 0.024\frac{(2\text{SSC}\sin\alpha)}{\theta_d L} \tag{6}$$

where q_{lat} = lateral flow (mm/day); S = drainable volume of soil water per unit area of saturated thickness (mm/day); SC = saturated hydraulic conductivity (mm/h); L = flow length (m), α = slope of the land, θ_d = drainable porosity.

2.3. Creation of database

The simulation of the water balance of an area by SWAT model requires a large amount of special and time series datasets in order to establish the water balance Eq. (1). The main sets of data used are briefly explained below.

2.3.1. Special datasets

The topography, land use/land cover and soil characteristics are spatial datasets which defines the land system of any area and the most requirement of the hydrological model. The input part of SWAT model includes a section from land system in the form of DEM, land use and soil.

- Digital Elevation Model (DEM)

The SRTM DEM of 90 m resolution (HTML: CGIAR-CSI) [17] was processed for the extraction of flow direction, flow accumulation, stream network generation and delineation of the watershed and sub-basins, Fig. 3. The topographic parameters such as terrain slope, channel slope or reach length were also derived from the DEM. From the present study SWAT model, the Simly Dam watershed covers an area of 172.2 km^2 with an elevation ranging from 695 m (Simly outlet) to 2250 m at the north and northeast mountains. The whole Watershed is segmented in a total number of 25 sub-basins depending on topographic characteristics, Fig. 4(a).

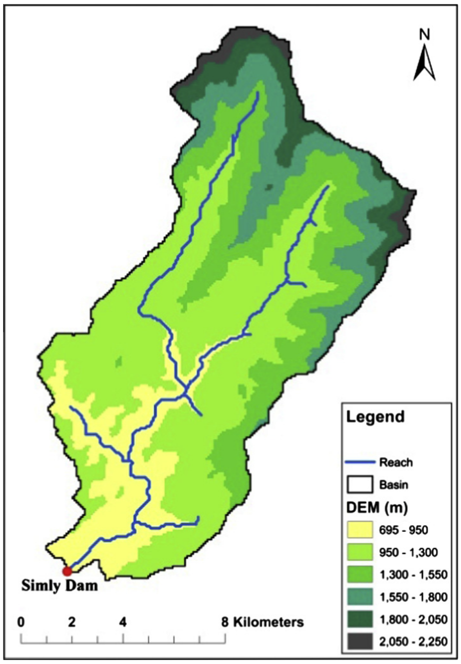

Figure 3 Digital Elevation Model (DEM) of the watershed area.

- Land Use

Changes in land use and vegetation affect the water cycle and its influence is a function of the density of plant cover and morphology of plant species. The European Union Global Environmental Monitoring land use/land cover datasets (HTML: EU-GEM, 2000) [18] have been used in this study, Fig. 4(b). Four major classes are so identified. The dominant categories are Oak; 37.38%, Pine; 17.087%, Forest-Deciduous; 10.346% and Agricultural Land-Close-grown; 35.187%. The land use classes were converted from original land use classes to SWAT classes and defined using a lookup table. These conversions are shown in Table 1.

- Soil Data

The soil map, Fig. 4(c), was obtained mainly from the United Nation Food and Agriculture Organization (HTMAL: FAO-AGL, 2003) [19]. The FAO regional scale soil vector maps were used where each cartographic unit was associated with one or two delineations corresponding to subsoil group of USDA, Dyke Paull et al. [20]. Due to soil limitations, the USA soils were compared with the watershed area to use their properties to define HRUs. Two soils delineated in the catchment; M-RM and GRV-CL have their corresponding USA series of Merino (LP) and Brewster (CM) respectively. The Simly catchment covers 83.92% by Brewster (CM) and 16.08% by Merino (LP).

The Merino series: consists of very shallow and shallow, well drained soils formed in residuum and colluvium from monzonite and other granitic rocks, gneiss, tuff, and breccia. Merino soils are on undulating plateaus, ridgetops, and side slopes of intermontane basins and on mountainsides and mountain ridges. Slope ranges from 5% to 65%. The mean annual precipitation is about 22 in., and the mean annual temperature is about 38 °F.

The Brewster series: consists of very shallow or shallow, well drained, moderately permeable soils that formed in loamy materials weathered from igneous bedrock. These soils are on rolling to very steep hills and mountains. Slopes range from 5% to 60%, Khan et al. [5]. The soil units were then extracted and completed by additional information from the soil properties listed in Table 2.

Land use classes and soil types were overlaid to define the Hydrologic Response Units (HRUs) for each of the sub-watersheds for the SWAT model. Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy of load predictions and provides a much better physical description of the water balance, Winchell et al. [16].

2.3.2. Temporal datasets

The climate data are required by SWAT to provide the moisture and energy inputs that control the water balance and determine the relative importance of the different component of the hydrology cycle. Rivers in the hydrological regimes may differ significantly in their runoff response to changes in the driving variables of temperature and precipitation.

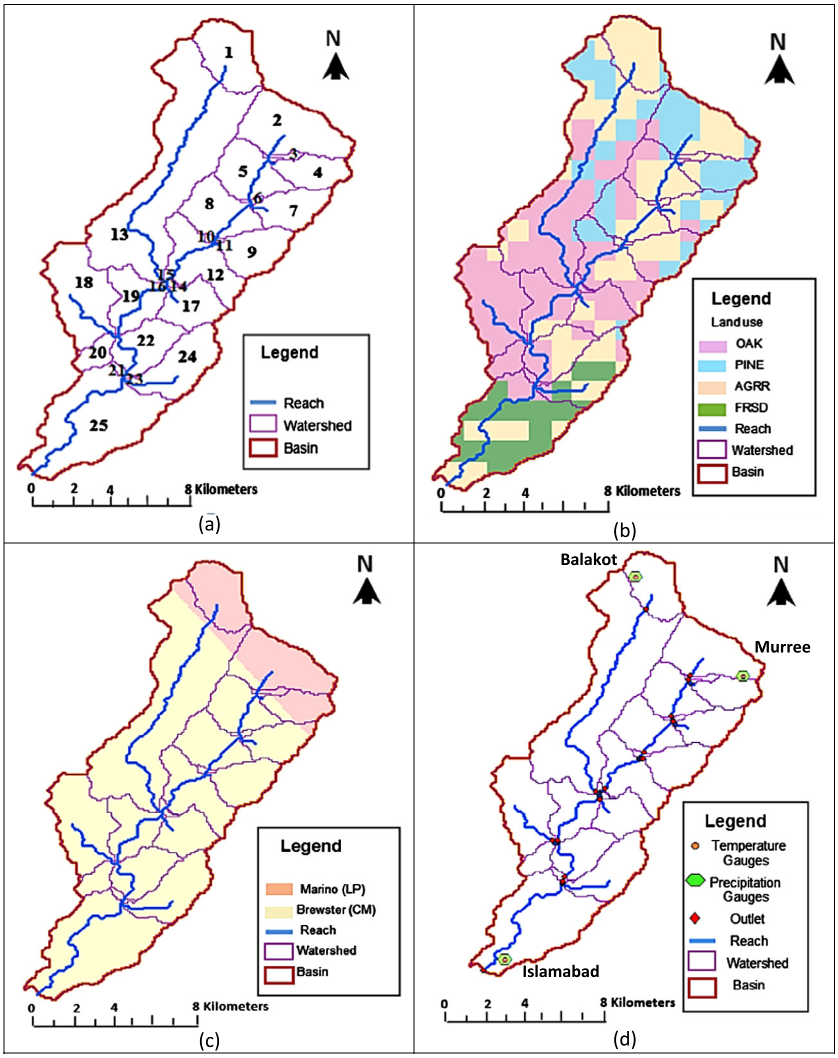

Figure 4 Basic spatial and weather data input. (a) Delineation of sub-basins of watershed; (b) Land use map; (c) Soil map; (d) Location of weather stations.

Table 1 Land use–land cover classes used for ArcSWAT in Simly Dam watershed.

Land use–land cover class	SWAT classes	% Watershed area
Oak	OAK	37.38
Pine	PINE	17.087
Forest-Deciduous	FRSD	10.346
Agricultural Land-Close-grown	AGRR	35.187

- Meteorological Data

The long term 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 minimum mandatory inputs and the other parameters are optional. The model has the capability of weather generation to itself generate the data against these parameters. The observation data of three weather stations inside the study area were collected from Pakistan Meteorology Department (PMD), Fig. 4(d). These stations which are listed in Table 3 gave the daily maximum and minimum temperature and the daily precipitation for the studied calibration and validation periods.

The climate datasets were processed against the model input format. A code is written for each of precipitation and temperature file for its conversion by Microsoft Access 2003 to make them dbf files which are actually required for SWAT model.

- Hydrological Data

For calibration and validation, hydrological datasets of Soan River flow are required. The data have been collected from the concerned agency, Water and Power Development Authority (WAPDA). A long term flow data of Soan river were gauged at Chirah (located in 33° 39′ 25″ N, 73° 18′ 15″ E) which is a very close control point downstream the Simly Dam. The historic daily flow data were available for the period 1990–2001 for calibration and the period 2002–2011 for

Table 2 Derived Soil properties delineated in the catchment.

Soil name	Merino	Brewster
Soil hydrologic group	A	A
Maximum rooting depth (mm)	2000	2000
Porosity fraction from which anions are excluded	0.50	0.50
Crack volume potential of soil	000	0.00
Texture 1	Grv_SL	Grv-CL
Depth (mm)	330 mm	300 mm
Bulk density moist (g/cc)	1.38	1.61
Ave. AW Incl. Rock Frag	0.13	0.10
Ksat. (est.) (mm/h)	883	672
Organic carbon (weight %)	0.5	1.25
Clay (weight %)	16	27
Silt (weight %)	40	38
Sand (weight %)	44	35
Rock fragments (vol.%)	27	47
Soil albedo (moist)	0.1	0.1
Erosion K	0.18	0.13
Salinity (EC, Form 5)	0.00	0

validation of flow simulations. The observed monthly inflow to Simly Dam was measured at a station situated at the dam location.

3. Model simulation

Hydrologic modeling of Simly Dam watershed was carried out using the ArcSWAT version 2.3.4. After preparing data files and completing all model inputs, the model is ready for simulation. The simulation is done for a period of 12 years from 1990 to 2001 which is the same period of availability of climate data. The hydrology simulation by SWAT is based on more than 39 parameters that have to be calibrated and adjusted. In such case, the calibration process becomes complex and computationally extensive. Hence, parameter reduction by filtering out the less influential ones is essential before calibration. The sensitivity analysis is so used to identify and rank the most responsive hydrological parameters that have significant impact on specific model output which is the outflow in this case, Saltelli et al. [21]. The sensitivity analysis was made using a built-in SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT), Van Griensven [22]. The model is simulated many times by changing the evapotranspiration calculation method and the value of hydrological parameters that ranked by the model to get the best match between model output and observed flow data. These parameters are Curve Number (CN2), Soil Evaporation Compensation (ESCO), Groundwater Re-evaporation (GW_REEVAP), Available water capacity of the soil layer (Sol_Awc) and Slope.

4. Model efficiency

There are many methods to access and evaluate the accuracy of results produced by the model. The calibration and the validation were carried out using the Coefficient of Determination (R^2) and three commonly statistic coefficients, Moriasi et al. [23] and Fadil et al. [8]. These statistic operators are Nash–Sutcliffe Efficiency index (NSE), Percent Bias (PBIAS), and RMSE-observations standard deviation ratio (RSR).

4.1. Coefficient of Determination (R^2)

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, Santhi et al. [24] and Van Liew et al. [25].

4.2. Nash–Sutcliffe Efficiency (NSE)

NSE is a normalized statistic method used for the prediction of relative amount of noise compared with information. It is presented by Nash and Sutcliffe [26] and is calculated from the following equation:

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{sim}}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{mean}}\right)^2}\right] \tag{7}$$

where Y_i^{obs} is the ith observation (stream flow), Y_i^{sim} is the ith simulated value, Y^{mean} is the mean of observed data and n is the total number of observations.

NSE ranges from $-\infty$ and 1.0 (1 inclusive), with NSE $= 1$ being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance. Generally, the model simulation is considered as satisfactory if NES > 0.5, Moriasi et al. [23].

4.3. Percent Bias (PBIAS)

PBIAS measures the average tendency of the simulated values to be larger or smaller than their observed ones, Gupta et al. [27]. It is defined by the range -10 to 10. The optimal value of PBIAS is 0.0, with low magnitude values indicating accurate model simulation. Negative values indicate overestimation bias, whereas positive values indicate model underestimation bias. The formulas of these coefficients are

$$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{sim}}\right) * 100}{\sum_{i=1}^{n}\left(Y_i^{\mathrm{obs}}\right)}\right] \tag{8}$$

where PBIAS is the deviation of data being evaluated and expressed as a percentage.

Table 3 List of stations used for meteorological datasets.

S. no.	Station name	Data range		Location		
		Calibration	Validation	Long (deg.)	Lat. (deg.)	Elev. (ft)
1	Islamabad	1990–2001	2002–2011	73.336	33.7	543
2	Murree	1990–2001	2002–2011	73.41	33.9	2167
3	Balakot	1990–2001	2002–2011	73.472	33.852	1615

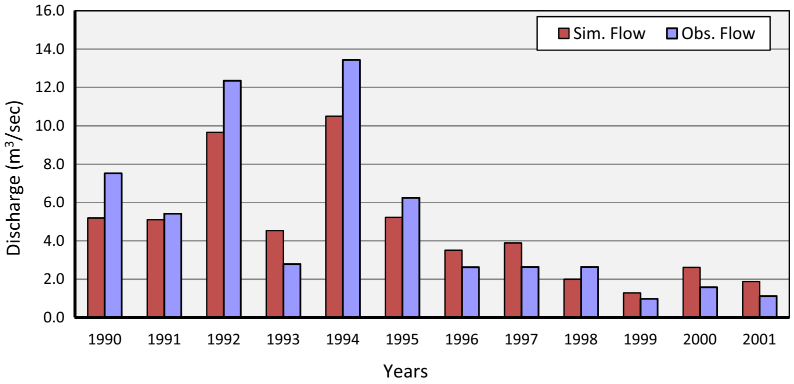

Figure 5 Annual observed and simulated stream flow for the calibration period (1990–2001).

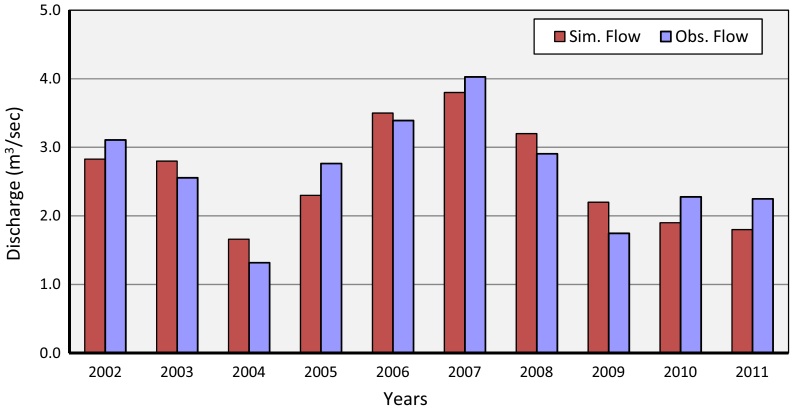

Figure 6 Annual observed and simulated stream flow for the validation period (2002–2011).

4.4. RMSE-observations standard deviation ratio (RSR)

Based on the recommendation by Singh et al. [28], a model evaluation statistic, named the RMSE-observations standard deviation ratio (RSR) was developed. RSR is computed as shown in Eq. (9) as follows:

$$\mathrm{RSR} = \frac{\sqrt{\sum_{i=1}^{n}\left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{sim}}\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(Y_i^{\mathrm{obs}} - Y_i^{\mathrm{mean}}\right)^2}} \tag{9}$$

The range from 0 which is the optimal value to 0.5 for RSR means a very good performance rating for both calibration and validation periods. The lower value of RSR indicates the lower of the root mean square error normalized by the observations standard deviation which indicates the rightness of the model simulation.

5. Results and discussion

Model calibration and validation are indispensable for simulation process, which are used to assess Model prediction results. The details, discussions and model evaluation are given as follows.

5.1. Model calibration and validation

Physically based distributed watershed models should be calibrated before they are made use in the simulation of hydrologic processes. This is to reduce the uncertainty associated with the model prediction. Calibration was performed by comparing the simulated and observed surface runoff. Monitoring data were used only to verify the general range and magnitude of values simulated by the model. After achieving a reasonable runoff data, the same value of calibrated hydrological parameters was used for validation. The validation has been done thereafter to evaluate the performance of the model with calibrated parameters to simulate the hydrological functioning of the watershed over another time period that has not been used in the calibration phase. Flow calibration and validation were based on the observed flow data collected by WAPDA at Chirah gauge station downstream the Simly Dam on Soan river. The available measurements were used for comparison with the predicted results in order to test the SWAT simulation efficiency. Calibration took place in yearly where outflow data are existed from 1990 to 2001 and then the parameters were validated from 2002 to 2011.

The Hargreaves method was selected for estimation of potential evapotranspiration for adjustment of mass balance components in the process of calibration. Five model parameters are adjusted to bring simulated values close to the observed values. The Curve Number (CN2) is increased by 4 in all sub-watersheds; Soil Evaporation Compensation (ESCO) is increased by 0.8; and Groundwater Re-evaporation (GW_REEVAP) is adjusted as 0.4. The initial parameters of Available water capacity of the soil layer (Sol_Awc) and Slope are multiplied by 1.2 and 0.3 respectively.

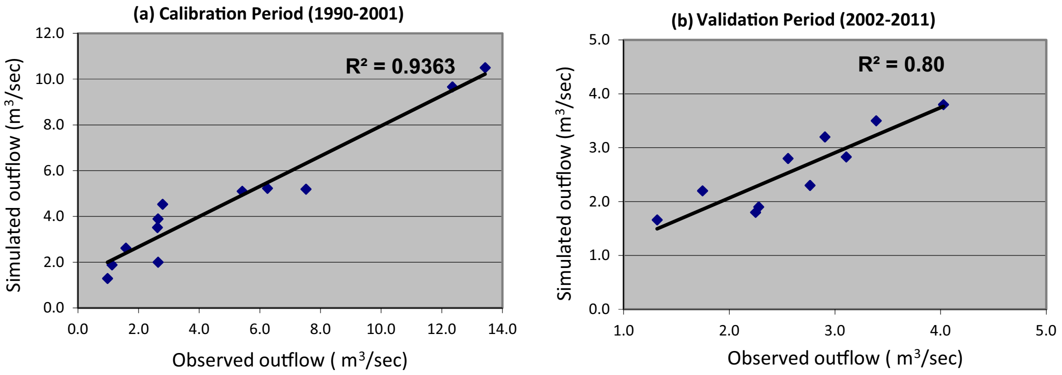

Figure 7 Comparison of annually observed and simulated dam outflow for the calibration and validation period.

Table 4 Statistic evaluation of simulated versus observed annual stream flow data.

Coefficient	Calibration period (1990–2001)		Validation period (2002–2011)	
	Obs. flow (m^3/s)	Sim. flow (m^3/s)	Obs. flow (m^3/s)	Sim. flow (m^3/s)
Mean	4.9	4.6	2.63	2.59
R^2	0.93		0.80	
NSE	0.85		0.79	
PBIAS	6.7		1.3	
RSR	0.39		0.45	

The model calibration for various water balance components yielded good agreement. Fig. 5 represents the graphical comparison between predicted and observed annual flows during calibration period. For the flow calibration result, the average flow for the simulation period is 4.62 m^3/s whereas the average observed flow during the same period is about 4.9 m^3/s. The peak flow is observed in the year 1994 and the lowest flow is received in the year 1999. The simulation results show a very good match with peak and low flow periods depending on the meteorological datasets received from PMD.

For validation period, the result of flow shows a good correlation of observed and model simulated as represented in Fig. 6. The average annual flow for the simulation is 2.59 m^3/s whereas the average observed flow during the same period is about 2.63 m^3/s which show very close similarity. The results suggest that the model can, very well, be used to predict the average annual values of river flow. The statistic evaluators showed a good correlation between the annually observed and simulated river discharge as follows.

The values of Coefficient of Determination (R^2) for both calibration and validation recognize the accuracy of the results as shown in Fig. 7(a) and (b). The value R^2 test stands 0.93 and 0.80 for calibration and validation respectively. It indicates that model results produced for the flow are very good for both periods.

According to NSE method, the model results both of 0.85 for calibration and 0.79 for validation are quite acceptable. The annual stream flow results of the model showed PBIAS of 6.7 for the calibration period and 1.3 for validation period. These values indicate that the model had overestimated the stream flow during the validation period with less accurate model simulation for the calibration period. The results showed RSR of 0.39 for the calibration period and 0.45 for validation period. The statistic evaluation of simulated versus observed annual stream flow data is summarized in Table 4. After applying the recommended model evaluation by statistical techniques mentioned above, it is found that the model is quite efficient and results that are produced are reliable.

The model results of monthly flow are also produced in Figs. 8 and 9 which are quite reasonable. The simulation

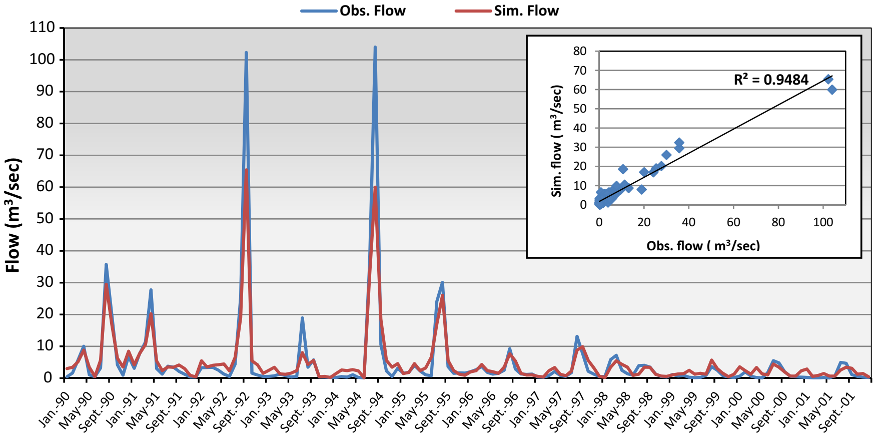

Figure 8 Comparison of monthly observed and simulated stream flow for the calibration period (1990–2001).

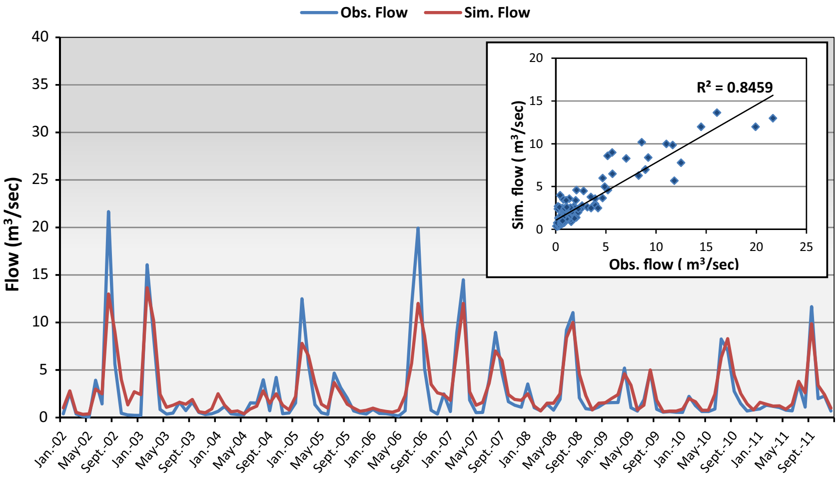

Figure 9 Comparison of monthly observed and simulated stream flow for the validation period (2002–2011).

Table 5 Statistic evaluation of simulated versus observed average monthly stream flow data.

Coefficient	Calibration period (1990–2001)		Validation period (2002–2011)	
	Obs. flow (m^3/s)	Sim. flow (m^3/s)	Obs. flow (m^3/s)	Sim. flow (m^3/s)
Mean	4.92	4.83	2.66	2.8
R^2	0.95		0.84	
NSE	0.84		0.8	
PBIAS	1.9		−7.3	
RSR	0.4		0.44	

underpredict the peak values of flow experienced in the month of January, May and September. The peaks position was generally well respected and depicted for both calibration and validation periods. It is clear that if the more reliable precipitation and temperature data sets of the meteorological observatories with good special coverage of the study area are available, the results of the model could be equally improved with excellent accuracy. The underprediction of flow during peak events by the SWAT model has been reported in many studies, Jayakrishnan et al. [29]; Gassman et al. [30]; and Fadil et al. [8]. The descriptive statistics of average monthly flow is summarized in Table 5.

Table 6 Average annual simulated water balance.

Water balance component	Calibration period (1990–2001)	Validation period (2002–2011)
Precipitation; Precip (mm)	1421.6	983.2
Potential evapotranspiration; PET (mm)	1401.9	945.5
Actual evapotranspiration; ET (mm)	514.9	287.8
Water yield; WYLD	841	583
Surface runoff; Sur_Q (mm)	455.2	295
Soil water; SW (mm)	15.3	50.15
Lateral flow; Lat_Q (mm)	266.6	163.9
Contribution of groundwater to stream flow; Gw_Q (mm)	199.3	186.8

5.2. Water balance components

In order to deal with water management issues, it is ideal to analyze and quantify the different elements of hydrological processes occurring within the area of interest. The SWAT model estimated other relevant water balance components in addition to the annually and monthly flow. Reference Sathian and Syamala [31] asserted that the most important elements of water balance of a basin are precipitation, surface runoff, lateral flow, base flow and evapotranspiration. Among these, all the variables, except precipitation, need prediction for quantifying as their measurement is not easy.

The average annual basin values for different water balance components during both the calibration and the validation periods which simulated by the model are reported in Table 6 and calculated as a relative percentage to average annual rainfall in Fig. 10. From these components actual evapotranspiration (ET) contributed a larger amount of water loss from the watershed. High evapotranspiration rate predicted could be attributed to the type of vegetation cover and high temperature associated with the area. The values of the average annual evapotranspiration as a relative percentage to average annual rainfall range from 0.24 to 0.42 with a mean value 0.36 for calibration period and range from 0.2 to 0.34 with mean 0.29 for validation period. Total water yield (WYLD) is the amount of stream flow leaving the outlet of watershed during the time step. It can be seen that major portion of the rainfall received by the basin is lost as stream flow. In the other hand, the ratio of the simulated average annual surface runoff to average annual precipitation varies between 0.14 and 0.53 with mean 0.32 for calibration period and ranges from 0.19 to 0.46 with mean 0.30 for validation period. The terrain slope got tremendous impact on lateral flow (Lat_Q). The lateral flow, computed as a percentage of average annual rainfall varies greatly from 4.8% to 38% with mean 16.9% for calibration period and from 5% to 27% with mean 16.7% for validation period as slope increases. Hence, in sloping terrain, the major contributor of river flow is lateral flow. In shallow sloping terrain, its impact is very marginal. Groundwater contribution

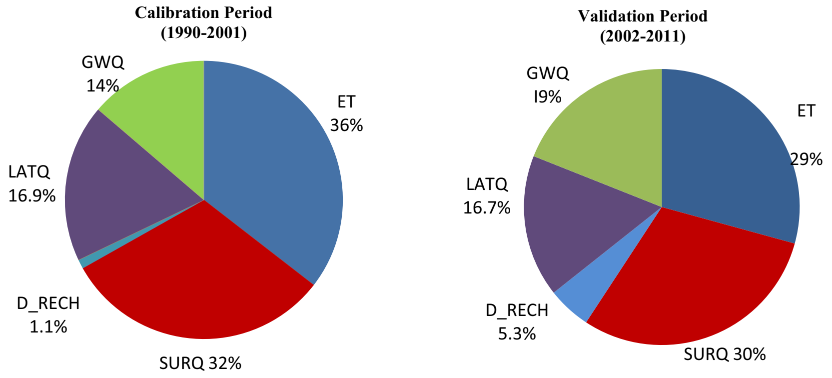

Figure 10 Average annual water balance as a relative percentage to precipitation for calibration and validation years.

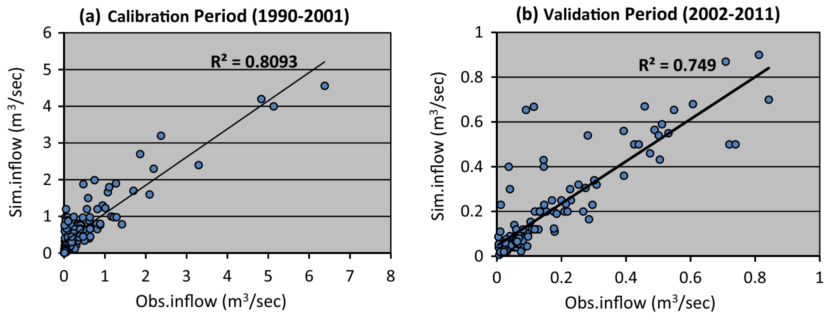

Figure 11 Comparison of monthly observed and simulated dam inflow for the calibration and validation periods.

to stream flow (GW_Q) is the water from the shallow aquifer that returns to the reach during the time step and it varies widely among streams. The average annual contribution of groundwater as a relative percentage to precipitation is 14% and 19% for both calibration and validation periods respectively. Deep aquifer recharge in all cases is very low with average percentage of 1.1% and 5.3% of the total rainfall for both simulated periods.

5.3. Estimation of Simly Dam inflow

One of the main objectives of this study is estimating the monthly inflow to Simly Dam in order to help the dam managers to plan and handle this import reservoir. The estimated monthly Simly Dam inflow by SWAT model based on the river discharge routed downstream to the whole watershed outlet. These simulated values were then compared with actual recorded inflow as shown in Fig 11(a) and (b) for calibration and validation periods respectively. The observed inflow data were collected from a gauge station at the dam location.

The results obtained showed a good correlation between the two patterns with R^2 of 0.81 for the calibration period and R^2 of 0.75 for the validation period. Therefore, the calibrated model can be used successfully to predict the volume inflow to the Simly Dam and facilitate the storage and release water management.

6. Conclusions

Watershed models have become a main tool in addressing a wide spectrum of environmental and water resources problems. The SWAT model has been well-documented as an effective water resources management tool. In this study the ArcSWAT interface implemented in the ArcGIS software was used in order to model the hydrology of Simly Dam watershed area. SWAT model was successfully calibrated. Manual calibration has been performed first on annual basis followed by monthly basis. The calibration and validation of the model produced good simulation results. The efficiency of the model has been tested by coefficient of determination, Nash Sutcliffe Efficiency (NSE) in addition to another two recommended static coefficients: Percent Bias and RMSE-observation standard deviation ratio. On monthly basis the Coefficient of Determination and Nash and Sutcliffe Efficiency (NSE) were 95% and 84%, respectively, for calibration, and 84% and 80%, respectively, for validation periods, which indicate very high predictive ability of the model. Water balance components such as surface runoff, lateral flow, base flow and evapotranspiration have also been simulated. The monthly inflow to Simly Dam has been estimated by the model and the simulated values have shown very close agreement with their measured counterparts.

The performances of the model can be enhanced furthermore by integration of some other climatic data such as solar radiation, humidity and wind. The calibrated model can be well used to understand and determine the different watershed hydrological processes that help in optimal utilization of dam reservoir water. It is recommended to use the calibrated model to assess and handle other watershed components such as the analysis of the impacts of land and climate changes on the water resources as well as the water quality, the sediment and agricultural chemical yields.

7. Recommendation

The efficiency of the proposed model has been tested by a good calibration (from 1990 to 2001) and validation (from 2002 to 2011) results produced by it. The model can be used successfully to predict the volume inflow to Simly Dam, facilitate the storage and release water management. A future understanding and determination of the different watershed hydrological processes that help in optimal utilization of the dam reservoir for a certain assumed period can be done. The model can be applied for different Climate Change Scenarios Data for Pakistan through the considered period. These Scenarios were developed by Research and Development Division, Pakistan Meteorological Department (PMD), Islamabad – Pakistan for decadal and monthly mean temperature (°C) and Precipitation (mm/day) through future projections from 2010 to 2100. The climate datasets should be processed against the model input format for the chosen studied periods.

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References

[1] V.P. Singh, D.K. Frevert, Mathematical Modeling of Watershed Hydrology. Chapter 1, in: Mathematical Models of Small Watershed Hydrology and Applications, Water Resources Publications, Littleton, Colorado, 2002, pp. 1–3.

[2] S.J. Bhuyan, J.K. Koelliker, L.J. Marzen, J.R. Harrington, An integrated approach for water quality assessment of Kansas watershed, Environ. Model. Softw. 18 (2003) 473–484.

[3] Syed M. Ali, Managing water resources in Pakistan, Pakistan Water Gateway, 2012 <http://waterinfo.net.pk/cms/?q=node/76>.

[4] S.L. Neitsch, J.G. Arnold, J.R. Kiniry, J.R. Williams, Soil and water assessment tool theoretical documentation version. Grass Land, Soil and Water Research Laboratory, Agricultural Research Service 808 East Blackland Road, Temple, Texas 76502; Blackland Research Centre, Texas Agricultural Experiment Station 720, East Blackland, Texas USA, 2005.

[5] A.D. Khan, Shimaa M. Ghoraba, J.G. Arnold, Mauro Di Luzio, Hydrological modeling of upper Indus Basin and assessment of deltaic ecology, Int. J. Modern Eng. Res. 4 (1) (2014) 73–85, This paper is indexed in ANED (American National Engineering Database). By ANED-DDL (Digital Data link) number is 02.6645/IJMER-AJ417385.

[6] Z. Nasrin, G.A. Sayyad, S.E. Hosseini, Hydrological and sediment transport modeling in maroon dam catchment using soil and water assessment tool (SWAT), Int. J. Agron. Plant Prod. 4 (10) (2013) 2791–2795.

[7] S. Cindy, O. Koichiro, Dam construction impacts on stream flow and nutrient transport in Kase River Basin, Int. J. Civil Environ. Eng. IJCEE-IJENS 12 (3) (2012).

[8] A. Fadil, Hassan Rhinane, K. Abdelhadi, K. Youness, Omar A. Bachir, Hydrologic modeling of the bouregreg watershed (morocco) using GIS and SWAT model, J. Geogr. Inform. Syst. 3 (2011) 279–289.

[9] B.B. Ashagre, SWAT to Identify Watershed Management Options: Anjeni Watershed, Blue Nile Basin, Ethiopia, Master's Thesis, Cornell University, New York, 2009.

[10] J. Schuol, K.C. Abbaspour, R. Srinivasan, H. Yang, Modeling blue and green water availability in Africa at monthly intervals and sub basin level, Water Resour. Res. 44 (2008) 1–18.

[11] Kieser & Associates for Environmental Science and Engineering, SWAT Modeling of the St. Joseph River Watershed, Michigan and Indian, Kieser & Associates Michigan Ave., Suite 300, Kalamazoo, Michigan 49007, 2005.

[12] A. Shawul, T. Alamirew, M.O. Dinka, Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, Southeastern Ethiopia, Hydrol. Earth Syst. Sci. Discuss 10 (2013) 13955–13978, http://dx.doi.org/10.5194/hessd-10-13955-2013.

[13] G.A. Adeniyi, F.S. Bolaji, W.S. Adebayo, O.D. Michael, Validation of SWAT model for prediction of water yield and water balance: case study of upstream catchment of Jebba Dam in Nigeria, World Acad. Sci. Eng. Technol. Int. J. Phys., Nucl. Sci. Eng. 8 (2) (2014) 57–63.

[14] IUCN Pakistan, Rapid Environmental Appraisal of Developments in and Around Murree Hills, IUCN, The World Conservation Union, May 2005.

[15] J.G. Arnold, R. Srinivasan, R.S. Muttiah, J.R. Williams, Largearea hydrologic modeling and assessment – Part 1: Model development, J. Am. Water Resour. Assoc. 34 (1) (1998) 73–89.

[16] M. Winchell, R. Srinivasan, M. Di Luzio, J.G. Arnold, ArcSWAT 2.3.4 Interface for SWAT2005: User's Guide, Version September 2009, Texas Agricultural Experiment Station and Agricultural Research Service – US Department of Agriculture, Temple, 2009.

[17] CGIAR-CSI, The CGIAR Consortium for Spatial Information <http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp> (accessed 10.03.13).

[18] EU-GEM, European Union Global Environmental Monitoring, 2000 <http://bioval.jrc.ec.europa.eu/products/glc2000/data_access.php> (accessed 20.03.13).

[19] FAO-AGL, United Nation Food and Agriculture Organization, 2003 <http://www.fao.org/ag/agl/agll/wrb/soilres.stm#down> (accessed 15.03.13).

[20] T. Dyke Paull, B. Mc Mahon, M. Nichols. Global Soils, 1:1Million Digital Soil Map of the World. To be published by Trexas Experimenta l Stataion/Blackland research centre. Temple Texas, 2001 <www.brc.tamous.edu>.

[21] A. Saltelli, E.M. Scott, K. Chan, S. Marian, Sensitivity Analysis, John Wiley & Sons Ltd., Chichester, 2000.

[22] Van Griensven A, Sensitivity, Auto-calibration, Uncertainty and Model Evaluation in SWAT, UNESCO-IHE, 2005, p. 48.

[23] D. Moriasi, J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, T.L. Veith, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Trans ASABE 50 (3) (2007) 885–900.

[24] C. Santhi, J.G. Arnold, J.R. Williams, W.A. Dugas, R. Srinivasan, L.M. Hauck, Validation of the SWAT model on a large river basin with point and non-point sources, J. Am. Water Resour. Assoc. 37 (5) (2001) 1169–1188.

[25] M.W. Van Liew, T.L. Veith, D.D. Bosch, J.G. Arnold, Suitability of SWAT for the conservation effects assessment project: a comparison on USDA-ARS experimental watersheds, J. Hydrol. Eng. 12 (2) (2007) 173–189.

[26] J.E. Nash, J.V. Sutcliffe, River flow forecasting through conceptual models, discussion of principles, J. Hydrol. 10 (3) (1970) 282–290.

[27] H.V. Gupta, S. Sorooshian, P.O. Yapo, Status of automatic calibration for hydrologic models: comparison with multilevel expert calibration, J. Hydrol. Eng. 4 (2) (1999) 135–143.

[28] J. Singh, H.V. Knapp, M. Demissie, Hydrologic modeling of the iroquois river watershed using HSPF and SWAT, J. Am. Water Resour. Assoc. 41 (2) (2004) 343–360, http://dx.doi.org/10.1111/j.1752-1688.2005.tb03740.x.

[29] R. Jayakrishnan, R. Srinivasan, C. Santhi, J.G. Arnold, Advances in the application of the SWAT model for water resources management, Hydrol. Process. 19 (3) (2005) 749–762.

[30] P.W. Gassman, M.R. Reyes, C.H. Green, J.G. Arnold, The soil and water assessment tool: historical development, applications and future research directions, Trans. ASABE 50 (4) (2007) 1211–1250.

[31] K.K. Sathian, P. Syamala, Application of GIS integrated SWAT model for basin level water balance <http://www.csre.iitb.ac.in/~csre/conf/wp-content/uploads/fullpapers/OS5/0S5_15.pdf>.