Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 2, Number 13; April-June, 2015 pp. 1128-1134
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http://www.krishisanskriti.org/jbaer.html

Applications of Hydrological Model SWAT on the Upper Watershed of River Subarnarekha with Special Reference to Model Performance and its Evaluation

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Abstract—*The effect of climate change on the geo-hydrological system of river basin has a significant impact on water balance component of an ecosystem. The major challenges faced today are the adequate allocation of water resource under changing conditions of land use and climate. In this scenario, the analysis of the impact of climate changes on river watershed has become very remarkable and can be addressed using various real time computer model. To study the potential impact of climate change on the river hydrology, a hydrological model, SWAT is applied on the upper watershed of river Subarnarekha of State Jharkhand. The SWAT model is simulated under monthly time step and the evaluation and interpretation of result is done with the help of statistical tools. According to the study, the Nash-Sutcliffe coefficient value for one of the hydrological observatory in consideration is 0.91(calibration and validation period) which suggest that the model performance is satisfactory. Modeling results also concludes that the model performs well in present study. Based on preliminary output of the model, it can be ascertained that it is an useful tool and can be used to analyze the potential impact of land-use and climate changes on river watershed of other region.*

1. INTRODUCTION

Water, one of the most precious natural resources has a unique relationship with earth's component. The continuous phase of redistribution of water through hydrological cycle is also responsible for climate of any place, like daily fluctuations of temperature, precipitation, and wind speed. In any ecosystem, adverse temperature and precipitation changes affect the hydrological cycle. These changes may be due to natural or anthropogenic activities, which may induce extreme aridity, excessive humidity, negligible rainfall, increased surface runoff, soil erosion, flood, and drought. Thus, the climate of any region plays a significant role in determining water availability for human and ecosystem use. Developing countries, like India, are susceptible to extreme weather events in present day climate variability, which may cause substantial economic damage (Monirul and Mirza, 2003). Hydrological model plays an important role in simulating the complex process of rainfall-runoff, soil erosion, under different situation. They reproduce physical processes within watersheds and yield a number of hydrological outputs that allow for the estimation of the impact of natural and anthropogenic processes on water resources (Neitsch et al., 2005b). Some of the prominent hydrological model are (CREAMS) Chemicals, Run-off, and Erosion from Agricultural Management System (Kinsel 1980), (OFESSD) Overland Flow, Erosion, Sediment Routing and Surface Degradation (Ewing and Mitchell 1986), (SPUR) Simulation of Production and Utilization of Rangelands (Wignt and Skiles 1987), (KYERMO) Kentucky Erosion Model (Hirschi and Barfield 1988), (ANSWERS) Area Non-point Source Watershed Environment Response Simulation (Baesley 1997).

In this study, hydrological model, SWAT (Soil and Water Assessment Tool) model is used to simulate the surface run-off for river Subarnarekha in State, Jharkhand, India. The SWAT is a physically based continuous time hydrological model with ARC GIS interface developed by the Blackland Research and Extension Center and the USDA-ARS Grassland Soil and Water Research Laboratory for pre- and post-processing of the data and outputs (Arnold et al., 1998). The SWAT model can simulates the hydrological cycle in daily or monthly time steps. It can be easily applied to the large watershed, the output of which can be used for the study of soil erosion, surface run-off, and utilization of land for agricultural purpose. Initially, SWAT was extensively used for agricultural purposes, but nowadays it has been widely used to study the impacts of natural and anthropogenic changes on water resources in numerous environments (Abbaspour et al., 2009; Rahman et al., 2010). Application of SWAT has been widely used for studying the hydrology of Indian rivers by many researchers. (Kaur et al., 2003, Gosain et al., 2006; Immerzeel et al., 2008). It is applied to simulate the surface run-off from an agricultural watershed in Chilka Lake, Odisha (Santra et al., 2013). In Karso watershed of Hazaribagh, India, suitable sites for soil and water conservation was studied using SWAT model and GIS techniques (Pandey et al., 2011) The Impact of climate change on the stream flow of the lower Brahmaputra is carried out by SWAT model (Gain et al., 2011). In southern India, SWAT is used for assessing water availability in a semi-arid watershed (J. Perrin ET al.2012). In Nagwa agricultural watershed in Jharkhand, India, SWAT is applied for the prediction of sediment yield (A. Singh et al., 2011). In neighboring countries like Nepal, SWAT is used to study the hydrological changes on river Baghmati (Sharma et al., 2006). Undoubtedly, the use of simulated computer model integrated with techniques of GIS tools provides a platform for studying the hydrology of watersheds. With this view, in the present study SWAT hydrological model is applied to river Subarnarekha, Jharkhand, India for the assessment of hydrological parameters.

2. STUDY AREA

The present study is conducted for river Subarnarekha that lies in the eastern part of India. The Upper watershed of river Subarnarekha lies within 23° 10’ to 23° 40’ N and 85° 10’ to 85° 40’ E in the state of Jharkhand, India., and selected watershed covers an area of 12831 Km^2, in the state of Jharkhand, India (Fig. 1). The Survey of India

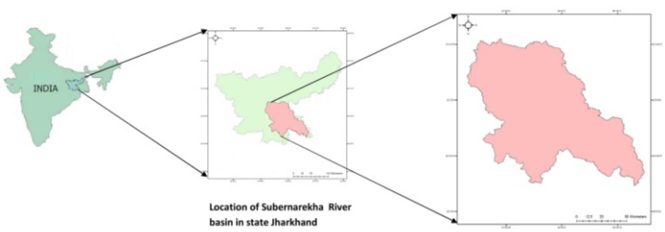


Fig. 1: location of Upper watershed of River Subarnarekha, in Jharkhand.

(SoI) topographical maps no. 72E is used for ascertaining various information, like stream network, tributaries, contours, vegetation cover, etc. Its main tributaries are Kanchi, Karkari, Kharkai, Raru, Garru, Dulang. Apart from this, the river is joined by numerous small streams, on both the banks. The river originates near Nagri village, which is about 16 km west of Ranchi town. After originating and flowing through the Ranchi plateau, it descends down to the plain catchment towards south-east making a fall named Hundru fall (243 feet). In this plateau region, it flows over the phyllite and mice-schist plain and horn-blende-schists. The elevation ranges from 48 m to 1048 m above the sea level. This region is predominately called as “Chhotanagpur” plateau, which is characterized by numerous small streams and isolated hillocks. Thus, the topography of Subarnarekha basin chiefly consists of steep undulating and flat plains with deposits of red and laterite soil. The river course consists of gorges and waterfalls with exposed rocks of granite, genesis, pegamatite (Gupta D.B, 2004). The patches of older alluvium and limestone rock exist in northernmost portion of the basin. According to two types of aquifers, weathered aquifer, and fractured aquifers exist in the study area in which the thickness of weathered aquifers varies from 10 to 25 m in granite terrain and 30 to 60 m in the lateritic terrain. In weathered aquifers, groundwater occurs in unconfined condition, while in fractured aquifer groundwater occurs in semi-confined to confined conditions, (Krishna et al., 2014). Rocky exposure of Archean era, both of Dharwars and post Dharwars, constitute the geological structure of this region. The area is rich in mineral resource like iron ore, bauxite, kaolin. The bed of the river is a mix of sand, rocks, boulders and tertiary gravel and small and fragmented blocks of coal. The sediments erosion and transportation is significantly affected by the sharp meandering of the river. This region is predominantly represented through continued erosion that can be observed as removal of superincumbent load of overlying rocks, (Rasool et. al., 2011). This river basin is totally rain-fed, and water availability depends on monsoon. During summer months, the river does not dry up but contain a stagnant pool of water. Since the topography is undulating with plateau region dominates, no flood situation occur unlike the plains areas, but with the onset of monsoon and after heavy rainfall, the stream is swollen up to large volumes. According to Köppen Climate Classification, this area is classified as “Humid Subtropical”. The summer is hot and starts from the month of March and end up to June, where as the winter is cold, which starts from the month of November to and end up to February. The average monthly temperature is 40.5° C in the month of May and 9. °C in December. Annual mean maximum and minimum temperatures vary from 32.4° C to 18.0°C respectively. This basin receives its rainfall from the South-West monsoon, which starts from July and ends in October. The average annual rainfall in the basin is around 1800 mm (Gupta et. al., 2004). Due to the varied hydro geological characteristics of this region, the availability of groundwater differs significantly from one location to another. Since this riverbank cater some of the industrial cluster and township like, Namkum, Tupudana, Jamshedpur, and Adityapur, so it plays an important role in the economic development of the people of this region.

3. METHODOLOGY: USE OF SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL

The SWAT model (Arnold et al., 1998) is used to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds with varying soils, land use and management conditions over long periods. It is also used to assess the impact of climate change on the hydrological response by adjusting the climate parameters based on future prediction (Neitsch et al., 2005).

SWAT simulates different hydrological processes in a watershed, which comprises of land phase and water. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings in the main channel in each sub basin. The water phase of hydrological cycle controls the movement of water, sediments, etc. through the channel network of the watershed to the outlet. The sub-catchment components can be categorized into hydrology, weather, sediment transport, soil temperature, crop growth, nutrients, pesticides, and agriculture management (Arnold et al., 1998). Water balance is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. For the land phase water balance, it can be calculated by one of the three methods: Hargreaves (Hargreaves and Samani 1985), Priestley-Taylor (Priestley and Taylor 1972) and Penman-Monteith (Monteith 1965). For surface runoff calculations, the more frequently method used is Soil Conservation Service Curve Number (SCS CN) procedure because the CN method is lumped over time

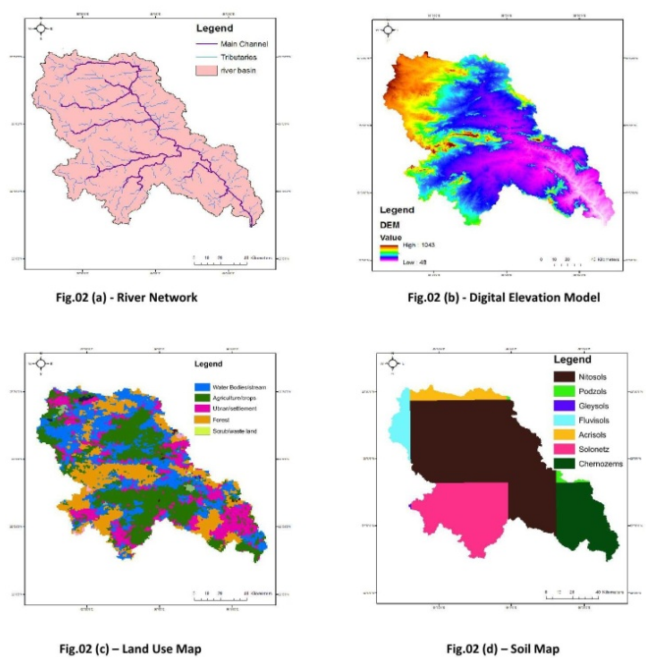


Fig. 2: Input data for Subarnarekha watershed in State, Jharkahnd

(Johnson, 1998): the SCS CN approach can typically be applied using daily rainfall values. Similarly, various other mathematical methods are used to calculate climatic parameters; like, the kinematic storage model (Sloan et al., 1984) is used to simulate the percolation process to predict the flow through each soil layer. While the base flow is predicted by creating a shallow aquifer storage, streamflow routing uses either the variable storage coefficient method (Williams 1969) or the Muskingum method. Latin Hypercube Sampling (LHS) (Hardyanto and Merkel 2007) and One at Time (OAT) (Van Griensven et al., 2006a) is used in SWAT to perform sensitivity analysis.

4. INPUT DATA FOR THE SWAT MODEL

The input data, which are required for SWAT model, are digital elevation model (DEM), land use, river network, soil layer and weather data is either generated during the laboratory study or obtained from the concerned government departments.

4.1 Digital elevation model

The elevation data at a resolution of 90 m acquired through the shuttle radar topography mission (SRTM) is available for the globe (Rabus et al., 2003). The (SRTM) is an international research effort that obtained digital elevation models on a near-global scale from 56° S to 60° N, to generate the most complete high-resolution digital topographic database of Earth. The elevation data for the study area is downloaded from http: // srtm.csi.cgiar.org/. ARC GIS 10.1 is used to process the elevation data to obtain the digital elevation model (DEM) which defines the stream network (Fig. 2a). This elevation model helps in the assessment of the sub- slope and slope length. The elevation output, which shows the minimum and maximum elevation, is 48 m to 1043 m respectively is shown in (Fig. 2b).

4.2 Land use/land cover layer

The satellite image is downloaded from http://www.landsat.org, dated: *02.11.2001* and is used for the preparation of land use/ land cover layer. ERDAS IMAGINE version 8.0 is used to prepare the land use map. The classified land use map of the watershed is given in Fig.2c. The land use classes of the study area are agricultural land (33.68%), forested area with deciduous trees (23.68%) and water bodies (10.45%). The urban settlement and scrub / waster land accounts for 14.44 % and 17.75 % respectively. Since agriculture is the main activity in which rice is mainly grown during kharif season. Rabi crop like wheat is also grown, but the total sown up area is very less as compared to the total kharif crops.

4.3 Soil

Soil series map at 1:250,000 scales for Jharkhand state, published by National Bureau of Soil Survey & Land Use Planning (NBSS and LUP, 2005), is used as the source of soil database and soil grid. Detailed soil texture classification is given in Fig. 2d.

4.4 Hydrological and meteorological data

Weather data as an input required for the SWAT model are precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed. In the present study, daily weather data, including rainfall, maximum temperature, minimum temperature, relative humidity, and wind speed were collected from the weather station of Indian Meteorological Department (IMD). In case of missing data, weather generator tool from SWAT is used to estimate that data.

5. SWAT MODEL SETUP

The concept of hydrological modeling is applied to the river basin considering the discharge data of one CWC observatories (MURI). SWAT model uses different interface for its simulation. Some of the commonly used are MAP window, Arc GIS, etc. In this study, The ARC-GIS 10.1 is used as an interface for running SWAT.

5.1 Watershed delineation

Watershed delineation generates the sub-basins, which is the first level of subdivision of watershed area. The DEM is used to produce the stream network. Since the DEM generated from the ARC-GIS is in geographic coordinate system, so it is re-projected using projected coordinate system. The final watershed delineation is done using the watershed delineation tool of SWAT which generates the flow direction and accumulation, outlet and inlet definition and calculation of sub basin parameters. The total of the sub-basins which is generated and delineated is 23. Each sub basin within a watershed boundary contains at least one HRU (Hydrological response unit), a tributary channel and the main channel. The outflow of one sub-basin enters the next sub-basin. Thus, there is a particular spatial relationship among each sub-basin. Some water bodies like ponds, wetlands, are also defined by these sub-basins as these structures have a significant effect on the water balance components of the study area.

5.2 Hydrologic Response Unit (HRU)

Each hydrologic response unit is a total land area within a sub basin, which has a uniform land use and soil attributes. The SWAT model calculates sediment runoff and transportation from each HRU separately and then summed together to determine the total loadings from the sub basin. This increases the accuracy as it adds to the prediction of loadings from the sub basin. Di Luzio et al., (2002) evaluated that smaller the area assigned to each sub-basin, more is the number of sub basins and more detailed is the drainage network. The study by Bingner et al., (1997) concluded that the sub-watershed size dependency of the SWAT erosion model and reported that runoff volume is not appreciably affected by the number and size of sub-watersheds.

5.3 Sensitivity analysis

Sensitivity analysis is necessary to identify key parameters required for the calibration process (Ma et al., 2000). It helps in determining the rate of change in model output with respect to the changes in model inputs parameters. This is an important step, which is done prior to the calibration process. In this study, all the four gauging location is subject to sensitivity analysis. The eight most sensitive parameter which are obtained as output is used in calibration process. The sensitivity rank of most sensitive parameter is assigned using LH-OAT (Latin Hypercube Sampling- One at A Time analysis) (Van Griensven et al., 2006). In SWAT 2003, a method called as PARASOL (Parameter Solution Method) is applied for automated calibration to each of the four locations. This method is commonly used to select the best parameters from some set of available parameters. It calculates the objective function (OF) based on model outputs and observation time series for a selected parameter and aggregates several fitting criteria to a global optimization criterion (GOC). ParaSol minimizes the OF or a GOC using the Shuffled Complex Evolution Algorithm (SCE-UA) and performs uncertainty analysis using statistical tools, like $\chi 2$ statistics or Bayesian statistics (Van Griensven & Meixner, 2007). In ParaSol algorithm, the parameters, which are remarkable, as defined by user can be changed for the entire watershed or for selected sub basins or HRUs. There are certain predefined limits as assigned to each parameter, beyond which no parameters is allowed to be modified.

5.4 Calibration and Validation

Calibration involves the adjustments of model parameter so that the performance and result of the model matches the observed rates in the field. It is applied to the model to reduce the forecast uncertainty for a given set of selected condition. In the calibration process, the discharge data taken over time (time–series) from 2001-2005 from CWC hydrological observatory, Muri is used for calibration. The first two years (2001-02) of the modeling period were reserved for “model warm-up.” The next and final step is validation. The time series of discharge data from 2006-2010 is used for validation process, keeping the first two year (2006-07) as warm-up period. It involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration (Fig. 4). This process demonstrates the model’s capacity of making accurate simulations. A good model calibration and validation should involve multiple evaluation techniques as suggested by (Legates and McCabe, 1999).

5.5 Model performance evaluation

The efficiency and performance of the SWAT model calibration and validation can be accessed through nearly 20 potential statistical techniques (Coffey et al., 2004). However, the most commonly used tools are the Nash- Sutcliffe modeling efficiency coefficient (NSE), coefficient of determination (R^2), and the % of deviation from observed stream flow (PBIAS) (Fig. 03).

$$R^2 = \left[\frac{\sum_{i=1}^{n} (O_i - \overline{O})(S_i - \overline{S})}{\sqrt{\sum_{i=1}^{n} (O_i - \overline{O})^2} \sqrt{\sum_{i=1}^{n} (S_i - \overline{S})^2}} \right]^2$$

$$\text{PBIAS} = \frac{\sum_{i=1}^{n} (O_i - S_i)}{\sum_{i=1}^{n} O_i} \times 100$$

$$\text{EF} = \frac{\sum_{i=1}^{n} (O_i - \overline{O})^2 - \sum_{i=1}^{n} (S_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2}$$

Fig. 3: Statistical indicator for model evaluation:

Where, EF= Nash-Sutcliffe coefficient
R^2= Coefficient of determination
PBIAS = PBIAS value
Oi= observed stream flow, (m^3/s)
Si= simulated stream flow, (m^3/s)
O=mean observed stream flow during evaluation period, (m^3/s)

The coefficient limits of NSE values ranges between ∞ to 1 and it provides a measure how well the simulated result matches the observed data along line with slope equal to 1. NSE value of 1 indicates a perfect match between the simulated and observed data. NSE values less than 0 indicate that the observed data mean is a more accurate predictor than the simulated output data. NSE coefficient of 0 indicates that the model predictions are as accurate as the mean of the observed data. Thus, the higher the value the more efficient is the prediction. The coefficient of determination (R^2), values can range from 0 to 1, and it provides how the variance of observed values is replicated by the model predictions (Krause et al., 2005). The value of 0 indicates no correlation and 1 represents perfect correlation, a perfect fit also requires that the regression slope and intercept are equal to 1 and 0, respectively. For % of deviation from observed stream flow (PBIAS), the optimal value is 0; a negative value indicates an overestimation of observed discharge values, whereas a positive value indicates underestimation. According to Van Liew et al., (2005), PBIAS values of estimates, an absolute value less than 20% is considered as good whereas , the values lying between ±20% and ±40% are considered as "satisfactory "and the values greater than ±40% are considered as "not satisfactory"

6. Result and discussion

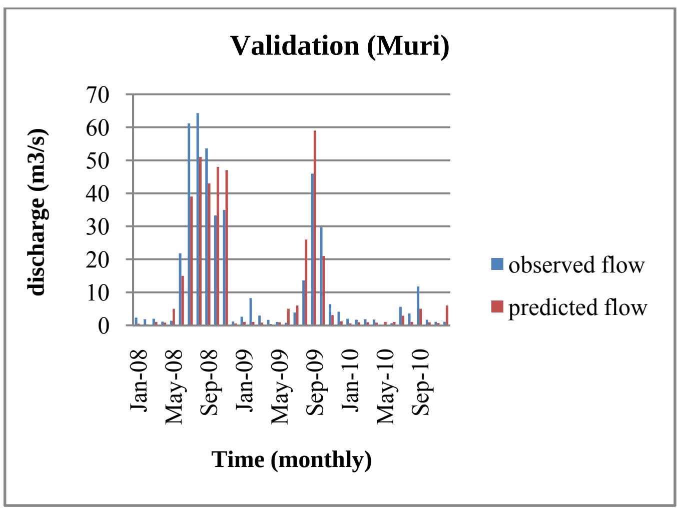
The SWAT model performance for Muri sub watershed can be interpreted from Table 01. The SWAT model performs best simulation on a daily time step, but in this study, the evaluation is done using monthly time series of observed discharge data from Muri observatory. SWAT model evaluation and interpretation of result is done with the help of statistical tools applied to the observed, calibrated and validated discharge time series outputs. As per the study, the Nash-Sutcliffe coefficient value for Muri is 0.91 for calibration and validation period, which suggest that the model configuration can be considered as satisfactory. The limiting factor of model results can be interpreted when long-term peak discharge is considered. The possible reason for this scenario may be the inadequate representation of rainfall or other meteorological input parameters or the insufficient availability of gauging station. The poor representation is due to the presence of typical vast dense forest over a large area, which may interfere with the establishments of rainfall and observatory station. Since the model performance is satisfactory, this can be interpreted from the sensitivity analysis rank (Table 02). The ESCO is a coefficient, which indicates the relationship between depth distribution (mm) and soil evaporative demand (mm H_2O). The value obtained is 0.0314. The low value of ESCO suggests that the lower soil level plays an important role in extraction of most evaporative demands. The lag time, i.e. GW_delay is low. This time lag defines the continuous capacity of surface water to move from bottom of the soil to deep aquifer. This is an indicator of ground water recharge potential. The low value suggests that recharge is ample. GW_REVAP is the movement of water from the zone of deep aquifer to root zone. The material overlying the aquifer and deep-rooted plants affects this coefficient. As GW_REVAP approaches 1, the rate of transfer from the deep aquifer to the root zone approaches the rate of potential evapotranspiration. The obtained value is 0.5, which suggest a fair balance between the movements of water from the shallow aquifer to the root zone. The value of RCHRG_DP is 0.7 representing a good amount of percolation from the root zone to deep aquifer. SOL_AWC is the available water capacity, which is affected by plant available water content. The value is expressed in percentage (SWAT 2009). The value of hydraulic conductivity (CH_K^2) and roughness coefficient (CH_N) is high. This high value may be attributed to the fact that the river basin is dominated by plateau regions, where the stream flows through hilly terrain. The riverbed is full of gravels and the area is rich in coal and iron ore. There is high variation in elevation throughout the flow of main channel. This variation has small and big waterfall, which off loads lot of silt and clay to its banks. Overall, the quantity of available water held under storage is very less, so it is estimated that there is huge amount of surface run off to the main channel.

Table 1: Statistical output of model performance based on model calibration and model validation

Statistical Index	CWC Site- Muri (Calib/valid)
Nash-Sutcliffe	0.91/0.91
Goodness of fit	0.96/0.91
PBIAS	17.51/5.22

Table 2: Sensitivity ranking of parameters

Parameters	Sensitivity rank	Range
ESCO	3	0-1
GWDELAY	2	0–50 days
GWQMN	4	0–5000 mm
GW_REVAP	6	0.02–0.20
RCHRG_DP	4	0.0-1.0
ALPHA_BF	8	0.1--1.0
SOL_AWC	7	–10% to 10 %
CN 2	1	–15% to 15%



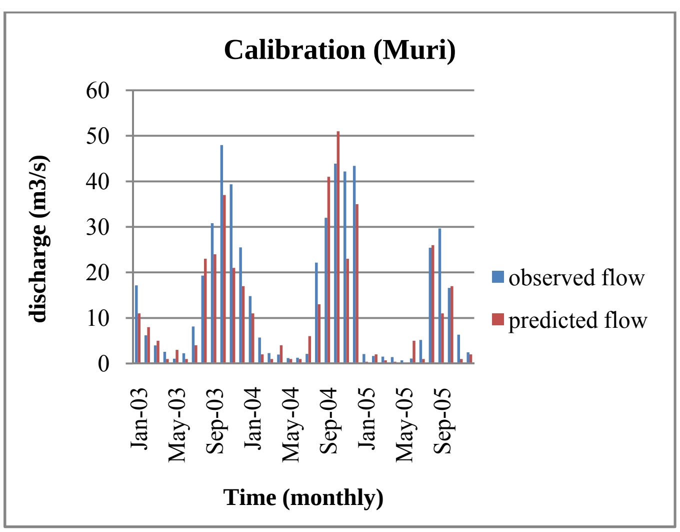


Fig. 4: Calibration and Validation result

6. CONCLUSION

SWAT is successfully applied to the river Subarnarekha in Jharkhand, India, which can easily be used to study the potential land-use and climate changes on the hydrogeology of the basin. The study area chosen for the study lies in the eastern part of India, which primarily consists of thick Sal (*Shore Robusta*) forest of deciduous type. The weather data prior to 1980 is not available with the concerned Meteorological department or the representation of gauging sites is not evenly distributed. The availability of data for over long period gives a chance for the SWAT user to develop more effective hydrological model. Similarly, the collection of ground truth data may hinders the empirical study to some extent because of inaccessible hilly terrain and thick forest cover. The limited data availability is one of the constrain in the effective hydrological modeling of any watershed. The preliminary assessments of result can be used as an indicator for further scope of study. It can be considered as the first step in the development of model for the entire river basin. The developed hydrological model with the help of SWAT and by using remote sensing and GIS technology, it is possible to ascertain water availability and flow. The factor like presence of plateau region with uneven elevation together with mighty waterfalls (Johna, Hundru) along the subernarekha stream network has a high hydropower generation potential. The output data of this SWAT model can also be easily applied to identify the hydro power potential of the basin (B.C. Kusre, et al., 2013, Pandey et.al., 2014). The Hadley centre (HADCM3) projected climate change data and the output of SWAT can also be used to analyses the climate change impact on the stream flow of river basins. The model can provide the increasing or decreasing future trend of annual precipitation, evapotranspiration. Thus, the study using SWAT model could provide an idea regarding water resource availability of the river basin, which can be used as a tool by environmentalist/ planner for decision-making.

7. ACKNOWLEDGEMENT

The author wish to express their sincere gratitute to the Dean, University School of Environment Management, and all organisation mentioned above who provided data for the present research work. The author also wish thanks to G.G.S.I P University for providing reseach fellowship.

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