RUNOFF ESTIMATION USING SWAT MODEL IN BRAHMANI-BAITARANI RIVER BASIN

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Abstract: *Water is undoubtedly the most vital natural resource. Water use management is one of the greatest challenges that face humanity. The demand for water is continuously growing because of the population growth, the intensive urbanization and the development of industrial and agricultural activities. To face the increasing pressure on this vital resource, it is so necessary to set up the adequate instruments to ensure a rational and efficient management of this resource. In this context, the hydrological modeling is largely used as an instrument to assess the functioning of these resources at basin scale. In addition, the use of spatial models let to depict and simulate the watershed processes at small spatial and heterogeneous scales that reflect the field reality more accurate and more realistic as possible. However, the use of spatial models requires geospatial data that must be gathered at very fine scales. The study area is Brahmani-Baitarani which extends from 20º29'00"N to 23º37'47".The objective of the study is to compute the runoff using SWAT hydrological model in Brahmani-Baitarani basin. The study has been executed using remote sensing data and other geo-spatial database, and other field data using semi-distributed hydrological models. In this study water balance component Runoff have been computed and its results have been calibrated and validated and finally the performance of the model is valuated. The daily calibration gives NSE above 0.6.*

1. INTRODUCTION

Land and water resources and their management are crucial for improving food security in the country. Although, India has adequate water resources, the factors associated with population growth, increased urbanization and industrialization, energy use, irrigation integrated with advances in agriculture productivity, desertification, global warming and poor water quality have made water, a scarce resource in the country. Water management in India in future must shift its emphasis from social good as at present to economic good, and use of market mechanisms with the participation of the business sector. Such a change will achieve a more efficient and effective allocation, use and management of water, and their roles of both public and private sectors in managing water resources must be defined. Therefore, both development and management of water resources with scientific data base is a pre-requisite for achieving sustainable development. Application of models has become an indispensable tool for the understanding of the hydrological processes occurring at the watershed scale as the models provide accurate estimate of components of water balance thereby availability of water resources. This report explains the application of hydrological models for one combined basin (Brahmani-Baitarni) and compares the results with observed data to assess the model performance. Soil Water Assessment Tool (SWAT) which is semi-empirical and semi-physical watershed scale model use as micro scale. SWAT consists of major water budget components such as weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth, irrigation water transfer, groundwater flow, and channel routing.

1.2 OBJECTIVE

The main objective of the study is

- To compute the runoff of the Brahmani-Baitarni basin using SWAT model.
- To calibrate and validate the model using observed data

2. STUDY AREA

2.1 INTRODUCTION

The Brahmani-Baitarni basin extends over states of Orissa, Jharkhand, and Chattisgarh having an area of 52,822 km which is nearly 1.7% of total geographical area of the country with a maximum length and width of403 and 193 km. It lies between 83º55’ to 87º3’ east longitudes 20º28’ to 23º 38’north latitudes. The Brahmani sub basin covers 39,033 sq. km and has a long sausage shape and the Baitarani basin covers 12,789 sq. km and is circular in shape. The Brahmani known as South koel in its upper reaches rises near Nagri village in Ranchi district of Jharkhand at an elevation of 600m.The river has a total length of 799km.In its tail reach the river is known as Maipura. The Baitarani River rises near Dumuria village in the hill ranges of Kendujhar district of Orissa at an elevation of about 900m and has a length of about 355km.The river is known as Dhamra in its lower reaches. The important tributaries of Brahmani joining it from left are the Karo, Kand the Sankh whereas the Tikra joins from right. The main tributaries of Baitarni joining from left are the Salandi and the Matai. Brahmani and Baitarni form common delta area before out falling into Bay of Bengal. The major part of basin is covered with agricultural land accounting to 52.04% of the total area and 2.95% of the basin is covered by water bodies.

2.1.1 River System

The Brahmani River rises near Nagri village in Ranchi district of Jharkhand at an elevation of about 600 m and has a total length of 799 km. The Baitarani river rises in the hill ranges of Keonjhar district of Orissa at an elevation of about 900 m and has length of about 365 km. Both river systems outfall into the Bay of Bengal forming a common delta area. The important tributaries of Brahmani are the Karo, the Sankh, and the Tirka and those of Baitarani are the Salandi and the Matai

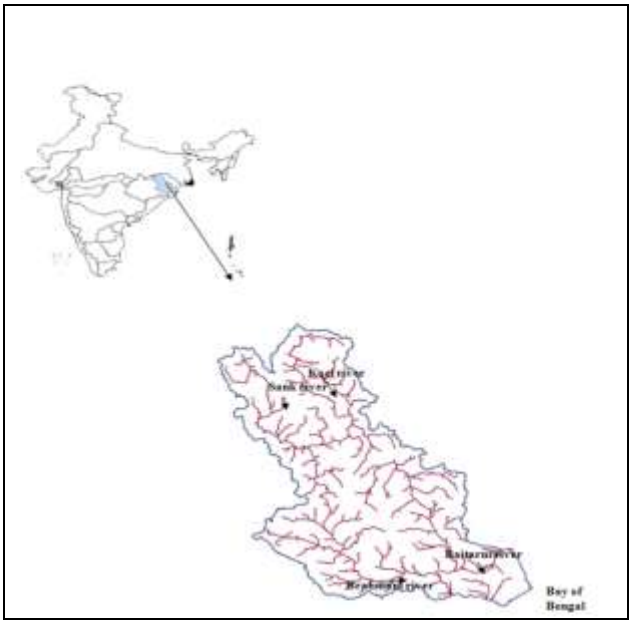

Fig.2.1 River network map of Brahmani-Baitarni basin

2.1.2Rainfall

Rainfall varies spatially and temporally in the Brahmani-Baitarni basin. There are 41 rain gauge stations in the catchment area of river Brahmani and 15 in the Baitarani basin for which daily rainfall data are available. A study of rainfall based on data from 1901 to 1950 (IMD, 1962) in and around the Brahman and Baitarani basins reveals, that the area is more or less homogeneous. About 80% of the annual normal rainfall occurs during the 4 months of south-west monsoon season (June to September). The annual normal rainfall varies from 1250 mm to 1750 mm over the Brahmani basin and from 1250 mm to 1500 mm over the Baitarani basin. The coefficient of variation of annual rainfall is only about 20%, which shows that the rainfall in the region is fairly dependable.

2.1.3 Temperature and humidity distribution

The mean maximum temperature varies from 35°C to 42.5°C over the catchment areas of rivers Brahmani and Baitarani in the month of May. The mean minimum temperature varies from 15°C to 10°C Brahmani catchment and from

15°C to 12.5°C over Baitarani catchment in the month of January. However,the extreme temperatures in summer (max.)and winter (min.) recorded in May and January are of the order of 47.5°C and 5°Crespectively. The humidity is about 80 to 90% during monsoon season and 40 to 70%during non-monsoon season, the higher humidity being over the coastal region.

2.1.4 Soil

The main soil types found in the basin are red soil, red and yellow soils, red sandy and loamy soils, mixed red and black soils and coastal alluvium. The coastal plains consist of fertile delta area highly suited for intensive cultivation. The soils are classified based on the soil textural information as sandy, loamy, loamy skeletal, clayey and clay skeletal.

2.1.5 Land use/Land Cover

The major portion of the basin is covered by forest(31.9%),followed by crop area (29.15%)and then current fallow(28.25%).The remaining portion of the basin is covered by built-up land, plantation, littoral swamp, grassland, gullied land ,scrubland and water bodies. The crop land is further classified into Kharif only, Rabi only and Zaid only.

2.1.6 Description of SWAT Model

Soil and Water Assessment Tool (SWAT) was applied in the BB basin to assess the hydrological components. The SWAT model is embodied in ArcGIS that can integrate various readily available geospatial data to accurately represent the characteristics of the watershed. The SWAT watershed model is one of the most recent models developed by the USDA-ARS to predict the impacts of land management practices on water, sediment and agricultural chemicals yields in watersheds with varying soils, land use and management practices over long periods of time (Neitsch, *et al*, 2005). The model is a physical based, semi-distributed, continuous time, and operating on daily time step (Neitsch, *et al*, 2005). As a physical based model, SWAT uses Hydrological Response Units (HRUs) to describe spatial heterogeneity in terms of land use, soil types and slope with in a watershed. In order to simulate hydrological processes in a watershed, SWAT divides the watershed in to sub watersheds based upon drainage areas of the tributaries. The sub watersheds are further divided into smaller spatial modeling units known as HRUs, depending on land use and land cover, soil and slope characteristics. One of the main advantages of SWAT is that it can be used to model watersheds with less monitoring data. For simulation, SWAT needs digital elevation model, land use and land cover map, soil data and climate data of the study area. These data are used as an input for the analysis of hydrological simulation of surface runoff and groundwater recharge. SWAT splits hydrological simulations of a watershed in to two major phases: the land phase and the routing phase. The land phase of the hydrological cycle controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub watershed. While the routing phase considers the movement of water, sediment and agricultural chemicals through the channel network to the watershed outlet.

The land phase of the hydrologic cycle is modeled in SWAT based on the water balance equation(4.2) (Neitsch, *et al*, 2005):

$$SW_t = SW_0 - R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \qquad (2.1)$$

where,

SW_t is the final soil water content (mm)

SW_0 is the initial water content (mm)

*t*is the time (days)

Rday is the amount of precipitation on day i (mm)

Qsurf is the amount of surface runoff on day i (mm)

Ea is the amount of evapotranspiration on day i (mm)

*Wseep*i s the amount of water entering the vadose zone from the soil profile on day i (mm), and

Qgw is the amount of return flow on day i (mm).

2.1.7 Surface Runoff

Surface runoff refers to the portion of rainwater that is not lost to interception, infiltration, and evapotranspiration (Solomon, 2005). Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating the surface runoff the Soil Conservation Service (SCS) curve number method (USDA-SCS, 1972) or the Green &Ampt infiltration method (Green and Ampt, 1911). The Green and Ampt method needs sub-daily time step rainfall which made it difficult to be used for this study due to unavailability of sub-daily rainfall data. Therefore, the SCS curve number method was adopted for this study.

The general equation for the SCS curve number method is expressed by the equation(4.3):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{R_{day} - I_a + S} \qquad (2.2)$$

Where,

Q_{surf} is the accumulated runoff or rainfall excess (mm),

R_{day} is the rainfall depth for the day (mm water),

I_a is initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water),

S is retention parameter (mm water).

The retention parameter varies spatially due to changes with land surface features such as soils, land use, slope and management practices. This parameter can also be affected temporally due to changes in soil water content. It is mathematically expressed as equation(4.4):

$$S = 25.4 * \left(\frac{1000}{CN} - 10\right) \qquad (2.3)$$

Where, CN is the curve number for the day and its value is the function of land use practice, soil permeability and soil hydrologic group.

The initial abstraction, Ia, is commonly approximated as 0.2S and the equation (4.5)becomes:

$$Q_{surf} - (R_{day} - 0.2S)/(R_{day} + 0.8S) \quad (2.4)$$

For the definition of hydrological groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified in to four hydrologic groups (A, B, C, and D) based on infiltration which represent high, moderate, slow, and very slow infiltration rates, respectively.

2.1.8 Potential Evapotranspiration

Potential Evapotranspiration is a collective term that includes evaporation from the plant (transpiration) and evaporation from the water bodies and soil. Evaporation is the primary mechanism by which water is removed from a watershed. An accurate estimation of evapotranspiration is critical in the assessment of water resources. There are many methods that are developed to estimate potential evapotranspiration (PET). SWAT provides three options for PET calculation: Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972), and Hargreaves (Hargreaves *et al.*, 1985) methods. The methods have various data needs of climate variables. Penman- Monteith method requires solar radiation, air temperature, relative humidity and wind sped; Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only. For this study, the Penman-Monteith method was selected as this method was widely used for many studies.

2.1.9 Flow Routing Phase

The second component of the simulation of the hydrology of a watershed is the routing phase of the hydrologic cycle. It consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network.

Two options are available to route the flow in the channel network, the variable storage and Muskingum methods. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. In this study Muskingum routing method is adopted.

3.0 Model Setup

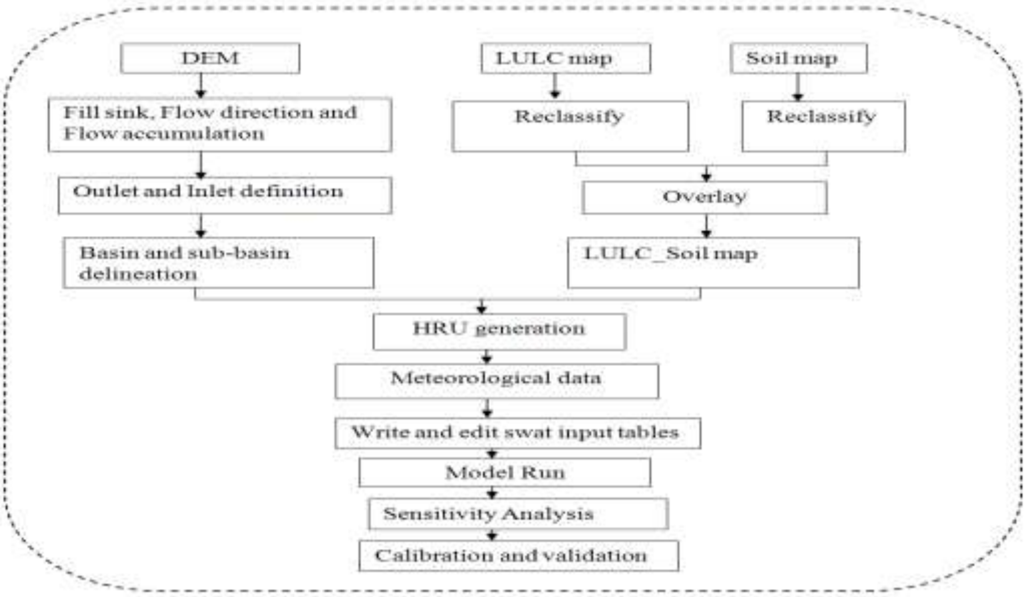

Fig.3.1 Model setup flow chart for SWAT

3.1.1 Watershed Delineation

The watershed and sub watershed delineation was performed using 30 m resolution DEM data using Arc SWAT model watershed delineation function. First, the SWAT project set up was created. The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters.

Once, the DEM setup was completed and the location of outlet was specified on the DEM, the model automatically calculates the flow direction and flow accumulation. Subsequently, stream networks, sub watersheds and topographic parameters were calculated using the respective tools. The stream definition and the size of sub basins were carefully determined by selecting threshold area or minimum drainage area required to form the origin of the streams. Using a threshold value (1,50,000

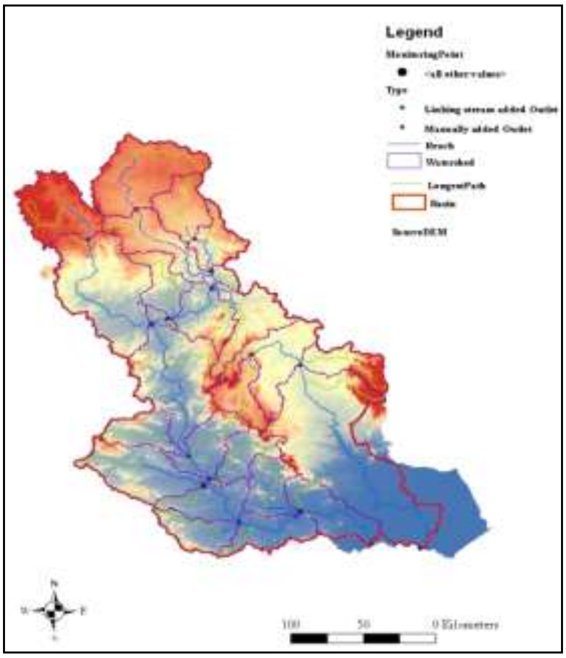

Fig.3.2 SWAT delineated watershed

hectares), the Brahmani-Baitarni watershed was delineated in to 17 sub watersheds having an estimated total area of 47111.5sq.km During the watershed delineation process, the topographic parameters (elevation, slope) of the watershed and its sub watershed were also generated from the DEM data. Accordingly the elevation of the watershed ranges from 1m to 1176m.The upper part of the basin is surrounded by hilly and forest areas while the lower part is deltaic region.

3.1.2 Hydrologic Response Units Analysis

The sub watersheds were divided into HRUs by assigning the threshold values of land use and land cover, soil and slope percentage. Generally, the threshold level used to eliminate minor land use and land covers in sub basin, minor soil with in a land use and land cover area and minor slope classes with in a soil on specific land use and land cover area. Following minor elimination, the area of remaining land use and land covers, soils and slope classes are reapportioned so that 100 % of their respective areas are modeled by SWAT. Land use, soil and slope characterization for the BB watershed was performed using commands from the HRU analysis menu on the Arc SWAT Toolbar. These tools allowed loading land use and soil maps which are in raster format in to the current project, evaluates slope characteristics and determining the land use/soil/slope class combinations in the delineated sub watersheds.

In the model, there are two options in defining HRU distribution: assign a single HRU to each sub watershed or assign multiple HRUs to each sub watershed based on a certain threshold values. For this study, HRU definition with multiple options that accounts for 5% land use, 10% soil and 10% slope threshold combination was used. These threshold values indicate that land uses which form at least 5% of the sub watershed area and soils which form at least 10% of the area within each of the selected land uses will be considered in HRU. Hence, the BB watershed was divided in to 188 HRU's, each has a unique land use and soil combinations. The number of the HRU's varies with in the sub watersheds.

3.1.3Weather Generator

In developing countries, there is a lack of full and realistic long period of climatic data. Therefore, the weather generator solves this problem by generating data from the observed one .The Model requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years. This study uses measured data for precipitation and temperature. However, the weather data obtained for the stations in and around BB watershed had missed records in some of the variables. Weather data of ten stations with continuous records were used as an input to determine the values of the weather generator parameters. Hence, for weather generator data definition, the weather generator data file wgnstations.dbf was selected first. Subsequently, rain fall data, temperature data were selected and added to the model.

The SWAT Model contains weather generator model called WXGEN (Shapley and Williams, 1990). It is used in SWAT model to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data. From the values of weather generator parameters, the weather generator first separately generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated. Lastly, the wind speed is generated independently. To generate the data, weather parameters were developed by using the weather parameter calculator WXPARM and dew point temperature calculator DEW02, which were downloaded from the SWAT website. The WXPARM program calculates the monthly daily average and standard deviation as well as probability of wet and dry days, skew coefficient, and average number of precipitation days in the month by reading of the daily values of the variables from ten stations surrounding the basin. Average Daily Dew Point Temperature was calculated using the Dew point calculator (Dew02) from daily maximum temperature, daily minimum temperature and average relative humidity.

3.1.4 Sensitivity Analysis

After preprocessing of the required input for SWAT model, flow simulation was performed for an seven years of recording periods starting from 2002 to 2008.The first two years of which was used as a warm up period and the simulation was then used for sensitivity analysis of hydrologic parameters and for calibration of the model. 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,10 2005).

3.1.5 Calibration

Manual and automatic calibration method were applied. First the parameters were automatically calibrated for the period of 2002 to using Shuffled Complex Evolution Algorithm (SCE-UA) and a single objective function. The auto calibration tool in SWAT can be run in either the Parasol or the Parasol with uncertainty analysis mode. For this study, the Parameter Solution (Parasol) option was selected (Van Griensven*et al.*, 2006). This method was chosen for its applicability to both simple and complex hydrological models. In this procedure, by entering the Arc SWAT interface Auto-Calibration window, first the SWAT simulation was specified for performing the auto-calibration and the location of the sub basin where observed data could be compared against simulated output. Then, the desired parameters for optimization, observed data file, and methods of calibration were selected. Hence, 10 flow parameters were considered in the calibration process. After the auto calibration runs completed, the model was run using the best parameter output values and the simulations were compared with observed stream flow data using Nash and Sutcliffe coefficient of efficiency (ENS) and coefficient of determination (R2). Next, the mean parameter values generated during auto calibration was used as initial values for manual calibration for further improvement of the model performance.

Validation was also done to compare the model outputs with an independent data set without making further adjustment of the parameter values. Model validation is comparison of the model outputs with an independent data set without making further adjustment which may adjust during calibration process. The measured data of average monthly stream flow data of 2 years from June2007 to May 2008 were used for the model validation process

4. RESULTS AND DISCUSSIONS

GENERAL

In this study SWAT is run for daily and monthly simulation . In this study runoff is computed for Anandpur and Champua discharge site. The model is run for the period 2002-2005, while data pertaining to 2002-2004 is used for calibration and 2004-2005 is used for model validation.

SWAT Runoff simulation:

Daily simulation

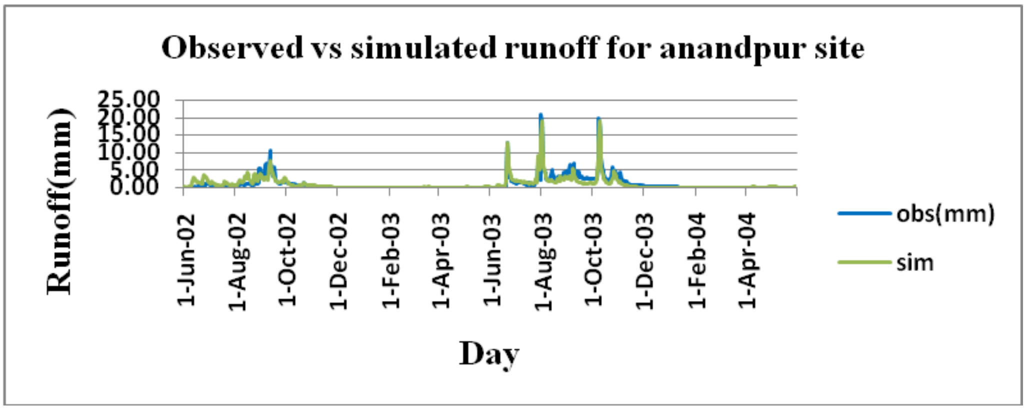

Fig 4.1 Comparison of daily Observed and simulated runoff

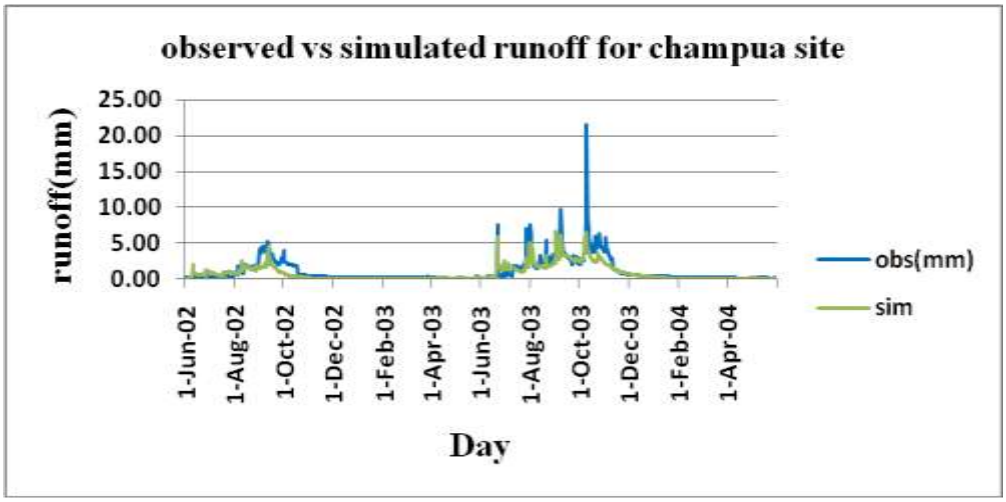

Fig 4.2 Comparison of daily Observed and simulated runof

Table 4.1 Model Performance during Calibration

Sub-basin	Indicators	SWAT	
		Daily	Monthly
Champua	NSE	0.64	0.78
	R^2	0.70	0.89
Anandpur	NSE	0.76	0.83
	R^2	0.82	0.84

SWAT model predicts better surface runoff. This is due to the fact SWAT has 28 flow parameters to be adjusted during calibration SWAT also has inbuilt weather generator data's if any missing data is there means the model will automatically adjust with the help of weather generator data. Auto calibration in swat will adjust the parameter values with respect to the observed data.

5.0 CONCLUSIONS

In runoff simulation SWAT performs better in all time steps SWAT model provides 70% accuracy for daily time step for all sub-basins .Improving the parameters in SWAT can provide better results. The model performed well when calibration parameters were extended to the validation year 2004-05.

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