INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

IJARIIT

ISSN: 2454-132X

Impact factor: 4.295

(Volume 4, Issue 2)

Available online at: www.ijariit.com

Hydrological Modelling in Narmada Basin using Remote Sensing and GIS with SWAT model and Runoff Prediction in Patan Watershed

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ABSTRACT

Future runoff prediction is linked to a prior knowledge of future probable precipitation amounts. Hydrological models are a way that can enable transforming observed precipitations into stream flow. In this work a GIS based hydrologic model, SWAT is used in an Upper Narmada River basin at Patan in Jabalpur (M.P). The importance of this thesis comes due to Upper Narmada River is a river in which every year the discharge amount varies according to the weather condition. Some of the months the river is flooded and in some of the years the river is in drought condition. Due to this reason it will be very useful if we can roughly predict the runoff amount. Depending upon the river discharge amount we can decide whether there will be flood or drought condition in the watershed.

The catchment area for this watershed has an approximate drainage area of 3950 km2, which is divided into 97 sub basins and 907 HRUs. SWAT model is developed to evaluate different parameters of the water resources like rainfall runoff modelling, sedimentation, eco-hydrological behavior of the watershed. SWAT tool with QGIS software to simulate water runoff for PATAN Watershed in Narmada river basin. It is concluded that the value of R^2 can be considered reasonably satisfactory for estimating a watershed runoff. The value of R^2 is 0.715.

The results from the SUFI-2 calibration process indicated a good performance with a PBIAS value of 12.6% and R^2 value was 0.83 indicating a good correlation between observed and simulated values. For the validation these value of R^2 and PBIAS are 0.79 and 10.6 % respectively. Results showed that the annual mean flow discharge for the period 1996 to 2005 was 612.52 m3/s which agreed with the model result which shows that the average annual basin simulation values was 524.92 m3/s for the same period. While result simulation for the period 2016 to 2050 gave 414.70 m3/s which mean there is a reduction in mean flow discharge between two periods about 20.99%.

Keywords: *Rainfall-Runoff Modeling, SWAT, SWAT-CUP, QGIS.*

1. INTRODUCTION

A number of models were developed in the past few decades and are presently used for the water resource management. SWAT model (Soil and Water Assessment Tool) is one of the models that is used the most in the present time. SWAT model was developed by United States Department of Agriculture-Agricultural Research Service (USDA-ARS) to predict the effect of land management practices on water, agricultural chemical yields and sediment in small as well as large watersheds. SWAT comprises of many components such as soil water percolation, interception, sub surface runoff, surface runoff, transpiration, infiltration, lateral flow, evapotranspiration, evaporation, sediment loading, groundwater flow and channel routing processes which is generating major water budget. The model runs on a daily, monthly, annually time step for short or long term predictions and functions in a semi-distributed manner to account for spatial differences in geography, soils, slope, land use, crops, channel and stream morphology, and environmental and climate conditions. The data sets are managed spatially using GIS tools, QSWAT interface, which is a QGIS extension, was used. Due to the ease of the model algorithm and less number of data requirement, it is easy to choose the Soil and

Water Assessment Tool. Also; there are numerous advantages as regards SWAT model such as model is computationally effective, it is able to study long-term influence, it can simulate many and particular (bacterial growth) physical procedures compared to any other single physically based model, it can also work with small number of input data. The objective of this study is to construct a hydrological river basin model for the Upper Narmada River basin at Patan (Jabalpur) to estimate and forecast runoff. Runoff forecasting is related to a previous knowledge of upcoming possible rainfall amounts. Hydrological models are methods that can enable converting observed precipitations into stream flow. In this work a GIS based hydrologic model, SWAT is used in an Upper Narmada River basin at Patan watershed for runoff forecasting. The importance of this work is because by calculating the runoff in the area of the Upper Narmada river basin, the human life can be made better and we can predict whether there will be flood or drought in the basin area.

2. LITERARURE REVIEW

Vilaysanea et al. (2012) applied the Soil for Water Assessment Tool (SWAT) demonstrate in the Xedone River basin, covering a region of 7,224.61 km2, in the southern piece of Laos. The model is aligned and approved for two periods: 1993-2000 and 2001-2008, individually, by utilizing the SUFI-2 method in this examination The adjusted model can be used for further investigation of the impacts of the atmosphere and land use change, water quality investigation and dregs yield investigation; besides, the displaying can be connected for arranging dam development later on and surge catastrophe hazard administration and accordingly is valuable for the reasonable advancement of the nation. the SWAT show creates great reproduction aftereffects of day by day, month to month time steps, which are valuable for the water resources administration in this basin. Dechmi. F, and Skhiri. et al (2013) A used hydrological modeling of a SWAT with the application of three days weather forecast from the numerical weather prediction (NWP) which provided temperature, rainfall, relative humidity, sunshine and wind speed. Both data from NWP and SWAT were used to simulate the runoff from the Nan River in the last 10 years (2000-2010). The results shows that the simulated flow rate for the main streams using the NWP data was more than the observations at N64 and N1 stations and the ratios of maximum simulated flow rate to the observation were about 108% and 118% respectively . In contrast the tributaries flow rate simulated were lower than observations, but within the acceptable values not more than 20% and the ratio of maximum simulated were 90.0%, 83.0% and 86.0%, respectively. The reason for the rainfall from NWP model being higher than measured rainfall is due to the rainfall distributed over all area, but the measured data was in specific points. Huicheng Chien et al (2013) represented a close survey to adjust and support a spread hydrologic modelling, the Soil and Water Assessment Tool (SWAT), utilizing approved river information (1978–2009), and to evaluate the potential effects of characteristic change on future river (2051–2060 and 2086–2095) for the Rock River (RRW), Illinois River (IRW), Kaskaskia River (KRW), and Wabash River (WRW) watersheds in the Midwestern United States. In a general sense it Occurs because of model demonstrate sensible spatial and basic figures of river, recommending that a multi-site modification structure is fundamental to completely forecast spatial combination in watershed hydrology. This paper recommend that developed temperature could change the rate of evapotranspiration and the type of precipitation, thus influencing month to month river arranges. Mohammed Hassan et al.(2014) applied The Soil Water Assessment Tool (SWAT) demonstrate, aligned and approved to reproduce normal day by day steam river in month was used to predict river within the period 1992 to 2000 under the individual land use hones in view of the years 1984, 2000 and 2010 for the Naro-Moru waterway catchment, Kenya. The catchment use data was collected for the years 1984, 2000 and 2010. Satellite pictures were acquired for the years 1984 and 2010 and handled to deduce reach. It distinguish that valuation of changes in catchment hydrologic reaction under changing area use is critical in the management of water resources in a watershed. Shimaa M.Ghoraba et al. (2015) described that SWAT demonstrate has been very much reported as a successful water resources administration device. The productivity of the model has been tried by coefficient of assurance, Nash Sutcliffe Efficiency (NSE) notwithstanding another two prescribed static coefficients: Percent Bias and RMSE-perception standard deviation proportion. In this review the hydrology of Simly Dam watershed situated in Saon River basin at the north-east of Islamabad is displayed and the month to month inflow to Simly Dam has been evaluated by the model and the mimicked values have demonstrated close concurrence with their deliberate counterparts.

3. STUDY AREA AND MATERIALS USED

3.1 Study AREA

The study area is PATAN catchment of Narmada basin 30kms far from Jabalpur district of the Madhya Pradesh in India, according to Survey of India (SOI). The elevation of the Patan town is 652 m from the sea level. 32°C The average temperature of this watershed is 32°C. Patan watershed is to be found between 23°00’N to 23°45’N and 79°25’ E to 80°30’ E. The main river of this watershed is Heran (Hiran) that is a tributary of the Narmada Basin. The outlet point of this watershed is at 23.3011°N latitude and 79.6636°E longitude.

Figure 1. PATAN watershed in Madhya Pradesh

3.2 Software used

Swat Model

Swat model is a soil water assessment tool. The model was produced by Jeff Arnold for the (USDA) farming exploration benefit. Swat is multitasking program .Swat was developed to predict the effect of land management practice on water, sediments and sediment yield. Swat is a physically based model that requires two kind of information i.e. spatial information and meteorological data.

(i) Spatial Data

- DEM (Grid Format)
- Land Use Map (Grid Format)
- Soil Map (Grid Format)

(ii)Meteorological data

- Daily Rainfall (mm)
- Daily Min and Max temperature (^{0}C)
- Daily Relative Humidity Data(Optional)
- Daily Wind Speed Data (Optional)
- Daily Solar Radiation Data

All the physical procedures like sediment development and runoff development are precisely displayed by swat utilizing this information and therefore a restoration can be achieved without contributing time and economy. The different hydrological models generated by the model are precipitation, infiltration, sub surface run-off, evapotranspiration, level stream and percolation. The model uses a typical structure as hydrological model (HYMO) [William and Hann 1978] for runoff measurement. Particular model that contributed in the progress of swat model were CREAMS (Chemical Runoff and Erosion from Agricultural Management system) [Leonard et.al 1987] and EPIC (Erosion Productivity Impact Calculator) [William et.al 1984].

Swat simulation is based on water balanced equation-

$$SW_t = SW_o + \sum_{i=1}^{N} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad (1)$$

Where SW_t = final soil water content in mm of water
SW_o = initial soil water content in mm of water
T = time in days
R_{day} = Amount of precipitation of ith day in mm of water
Q_{surf} = Amount of surface runoff of ith day in mm of water
E_a= Amount of evaporation of ith day in mm
W_{seep}= Amount of water entering the vadose zone from the soil profile of ith day in mm of H_2O
Q_{gw}= Amount of return flow of ith day in mm of H_2O.

For calculating the surface runoff the SCS curve number (CN) is used in the model. There are two equations. First equation expresses the relation between runoff, rainfall and retention parameters whereas the second equation relates the retention parameters to curve number (CN).

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

$$S = 25.4\left[\frac{100}{CN} - 10\right] \qquad (3)$$

Where-
R_{day} = Amount of precipitation of i^{th} day in mm of H_2O
S = Retention parameter

Calibration by SWAT CUP:

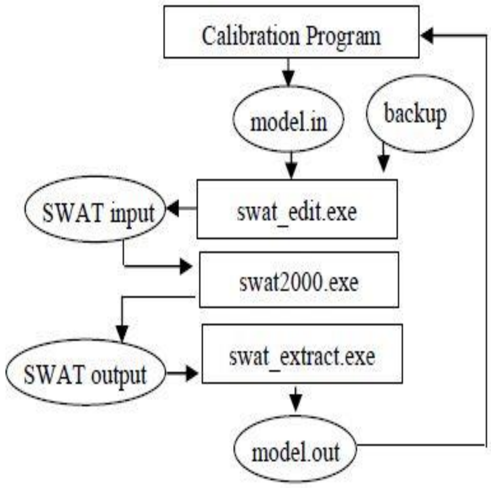

Figure 2.Relation between SWAT and SWAT-CUP

Swat cup is combine program of calibration and uncertainty procedures. It is tool that helps in the calibration, validation and sensitivity analysis of the swat model. Sufi2, PSO, Glue, Parasol, and MCMC are the various method available for calibration by Swat-Cup. In the process of calibration all the programs like sufi2 and glue etc. utilizes the swat input file and modifies the given parameters according to the inputs [Abbaspour et.al 2007].GLUE was invented partly to allow the non-uniqueness of the parameter sets in the estimation of model parameters in over parameterized models. The procedure of GLUE uses some assumption that there is no inverse solution in over parameterized model hence the value of unique set of parameters which optimize goodness of fitting criteria is not possible. The technique is based on the estimation of the weights or the probabilities associated with different parameter set. GLUE is one kind of method which measure expressed as the *Nash-Sutcliffe* coefficient. PARASOL method combines the objective function into a global optimization criterion (GOC) and then minimizes this objective function or a GOC using SCE-UA algorithm. This algorithm is a well-known algorithm to minimize a single function for up to 16 parameters. *SUFI2 (The* Sequential Uncertainty Fitting ver. 2) program is same as GLUE in concept but it utilizes a different methodology to obtain posterior parameters from previous. The degree of uncertainties in the model is denoted as P factor which is the measured data bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution. Another measure that shows the strength of the calibration is d factor or R factor which is the ratio of the average thickness of 95ppu band and the standard deviation of the measured data. For a good calibration in SUFI2 this parameter should be close to 0. For an ideal situation P *factor* should be 100% and a *d-factor should be near* to zero. There are acceptable valve of *d-factor* and *p-factor*. If these values are within the acceptable range, then the parameter uncertainties are the desired parameter ranges. Further goodness of fit can be quantified by the R^2 or Nash-Sutcliff (NS) coefficient between the observations and the final best simulation.SUFI-2
In the present study Sufi2 was used for the calibration of SWAT model. Sequential uncertainty fitting version 2 is known as sufi2. The program is similar to that of GLUE except sufi2 accounts all type of uncertainty such as uncertainty in variable, uncertainty in the concept of the model parameters and measured data. The measurement of all uncertainty is expressed in terms of P factor. Among the various methods of calibration provided by the Swat Cup tool the Sufi2 algorithm is being used in this study area since this method is easy to execute and it requires minimum no. of runs and hence produces the better results.

4. METHODOLGY AND SWAT MODEL INPUT

4.1. DEM (digital elevation model) is the spatial data for the swat. The DEM for the Patan watershed was downloaded from the USGS earth-explorer website https://earthexplorer.usgs.gov. Study area Patan watershed lies between 23.3011° N latitude and 79.6636° E longitude. For cover up whole Patan watershed two tiles of the DEM was downloaded. These tiles are (n23e0791Q.tif) and (n23e0801Qv3.tif.). Theses tiles are then combined and clipped to make a single tile in which whole Patan watershed is covered using QGIS. The DEM downloaded from the USGS website is then projected in the WGS 84 / UTM zone 44N zone. This zone is decided on the basis of the UTM world.

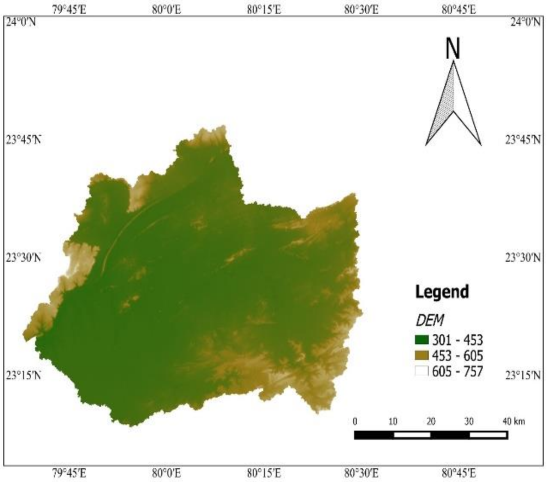

Figure 3. DEM of the Patan Watershed

4.2. Land Use/ Land Cover Map

Land use data and Soil data comes under geographical data .Basically Patan watershed suited in Jabalpur district of the Madhya Pradesh region. Land use is one of the most significant factors that affect surface erosion, runoff and evapotranspiration in any basin. The land use map of the study area was obtained from National Remote Sensing Agency, Hyderabad which are geo-referenced and digitize by using ERDAS software. It shows that more than 50% of the Middle Narmada basin is used for agriculture. Farming area is for the most part utilized for the creation of sustenance and fiber. In the review territory of this theory over half range is secured with woods deciduous and backwoods evergreen exercises. Timberland arrive loaded with firmly developed trees that are by and large utilized as the timber and wood production. They can be sub categorized as Deciduous, Evergreen and Mixed. In our study area 29.53% of area is present as forest. Water estimation is depends upon the scale and resolution of the remote sensing study that can be used for various purposes like runoff and precipitation studies. The water bodies of any study area may be categorized as streams, canals, reservoir, lake, bays etc. In the study area totally 7.062 % of area is being covered up by the water bodies. Wetland is the area in which water table is at near or above the land surface for a larger area. Barren land is the land having vegetation less than one third of the total area the soil found in such area is generally dry and sandy. The percentage of the various land use available in the study area is given in the table below and also shown in figure.

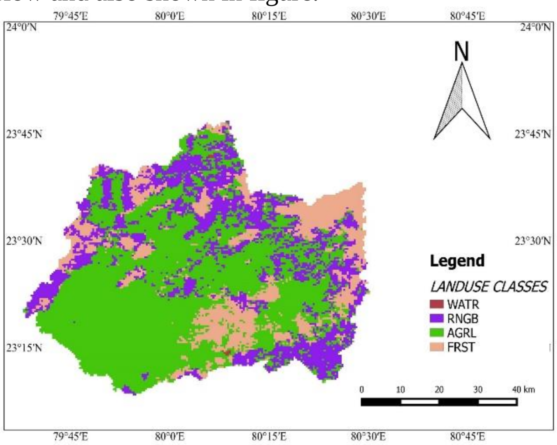

Figure 4. Land use map of Patan watershed

Table 1.Distribution of Land in Study Area

S.NO.	Category	Percentage of total area	Land class
1	Water	7.062	WATR
2	Shrub-land	12.113	RNGB
3	Agricultural	51.303	AGRL
4	Forest	29.522	FRST

4.3) Soil Data

Soil data is the spatial input data for SWAT model. Soils of this watershed varies according to the color, texture, composition and structure in different parts. In the MP state of India the residual soils are more predominate in an extensive area. The rock composition determines the composition of the soil in this area. It requires different soil textural and properties such as soil texture, void ratio, available moisture content, hydraulic conductivity, density and carbon content for different layers of each soil type. The

Soil Map of 1:50,000 scale and soil Characteristics data were obtained from the NBSS& LUP, Nagpur. Major soil types in the basin are Clayey, Loamy, and Loamy-Skeletal soil which are shown in above map

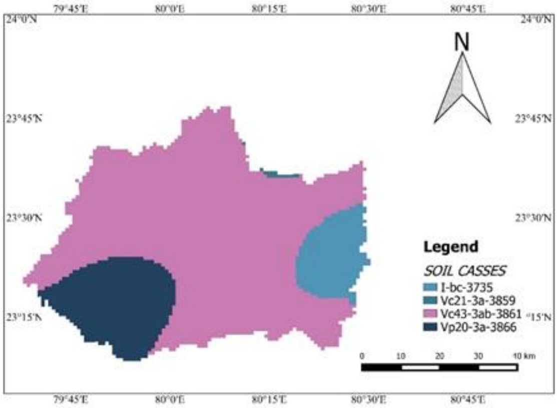

Figure 5. Soil Map of Patan Watershed

Table 2.Distribution of Soil in Study Area

S. N o.	Category	Classification	Percentage of total
1	I-bc-3735	Loam	0.3926
2	Vc21-3a-3859	Clay	20.1094
3	Vc43-3ab-3861	Clay + silt + sand	64.486
4	Vp20-3a-3866	Clay + water	15.012

4.4) Weather Data Madhya Pradesh lies closer to the equator Compared to other Indian states. Patan watershed suited in Madhya Pradesh, is basically a plateau area with variety of minerals found in it. It is enclosed by the low, rocky, barren hillocks. Because of this type of topographical features Patan has subtropical climate. The months (March-June) considered as summer .May is the hottest month of the whole year with the average temperature of 45°C. The monsoon season starts from end of June to early October. The rainy season is due to the South-west monsoon. From July to September the total rainfall is approximately 889 mm. average annual rainfall is approximately 1389 mm. Winter begins in November and is continued till the early March. January is the coldest month of the whole year and the average daily temperature of the January month is 15°C. Except of spatial data, Metrological data is also input data requires for setting out and ruining the SWAT model. Weather generator model was used to generate and read from measured data. The weather variables used in this study for driving the hydrological balance are daily rainfall, the website (http://globalweather.tamu.edu) has been used for downloading maximum minimum Temperature, Relative Humidity, and Solar radiation.

4.5) River Discharge

Daily River Discharge data has been taken from CWC, Bhopal for Narmada River at Hoshangabad and Rajghatwere. The stream flow (discharge) data is needed for both the calibration and validation of the SWAT-CUP model. Gauge Patan is a GDQ site and is located in Jabalpur district. The station code of the PATAN Ho is 0102145009. It suited in between 23°18'42" north and longitude is 79°39'49" E. The discharge data is available for the period of 1990-2016. The data downloaded is continuous. 5 years of this data is used as warm up period in SWAT model, 5 years of this period is used as calibration period and 5 years is used for validation.

4.6) Slope map

The slope map for the Patan watershed indicate the change in elevation .It is also define the path of the flow. Slope map was generated using QGIS and SWAT model. Slope map shows the rate of change of elevation. Slope also shows the path of drainage and the direction of the flow. In swat it is also used to create HRU In this present study whole catchment area is divided into three slopes that is 0-2, 2-8 and 8-9999 shown in given below map.

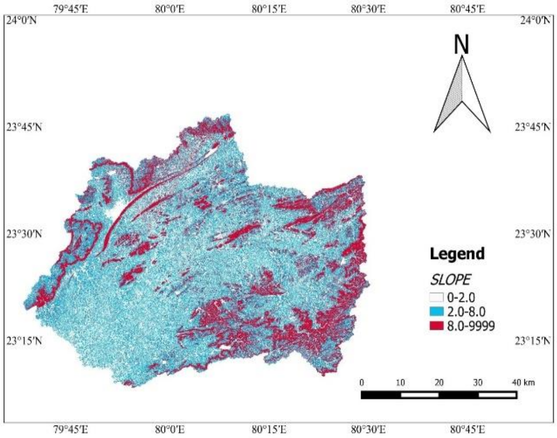

Figure 6: Slope Map of Patan Paten Watershed

5) SWAT MODEL SETUP AND SWAT-RUN

Soil and Water assessment Tool (SWAT) is a model that is developed in the year 1985 by Dr. Jeff Amold. He developed this software for USDA agricultural research services. SWAT model quantifies impact of land use practices in large as well as small scale. SWAT model was developed for following purposes:
(1)Impact of soil management practices on water bodies (2) Rainfall runoff modelling in any catchment.
(3)Sediment yield in any catchment depending on the properties of soil. (4)Agricultural chemical properties to define different chemicals found in the land. (5)To define geomorphological conditions for land use and management conditions. The components of the SWAT model are precipitation, evaporation, evapotranspiration, transpiration, infiltration, surface runoff, percolation, weather, return flow, crop growth and irrigation, ground water flow, nutrient and pesticide loading, reach routing and reservoir routing. SWAT is also assumed as Hydrological Transport Model. QSWAT, a version of SWAT that is integrated with the QGIS. QGIS allows SWAT to prepare an input and prepare the model to run within the framework. Swat model has to be set up before running all the input data discussed above helps in physiographic analysis on the selected topography then we define the flow direction and stream order by creating the shape file of the study area using GCS-WGS 1984 co-ordinate system. Then we do filling and calculate flow direction and flow accumulation by using hydrology section of special analyst tool and hence we draw the stream order of the watershed area. For running the setup of swat model we used the weather data of the various meteorological stations provided by the Global weather site.

Table 3. Time Periods for SWAT Model

Warm Up	1991-1995
Calibration	1996-2000
Validation	2001-2005
Prediction	2015-2050

6. RESULT AND DISCUSSION

6.1 Initial SWAT-RUN Result:

In starting the SWAT model was set up as defined in the earlier chapter on the basis of monthly data base. The initial model run was conducted for 15 years, from 1991 to 2005 with a 5 year warm up period. The warm up period was from 1991-1995. The preliminary simulated stream flow outcomes were compared with practical (observed) stream flow from the Patan rain gauge in Narmada basin. SWAT model run with good accuracy having R^2 value 0.71. The preliminary results specify that the SWAT model in general produces simulated flow that over estimates the peak measured flow and under estimate the measured flow all other times.

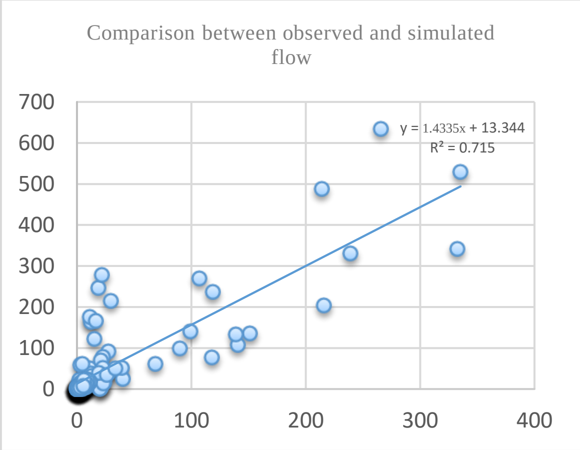

Figure 7: Comparison between observed and simulated value of SWAT-RUN

6.2 Calibration Results

Once the swat model run with good accuracy and sensitive parameters were recognized the model was calibrated for the inflow data of PATAN watershed for the period of 1996-2000. These best values of simulated flow shows the performance and the accuracy of the model. After the results it was seen that the observed and simulated values of the calibrated model matched reasonably well.

Table 4. Parameters used in SWAT Model in Calibration

R2	NSE	P Factor	R Factor
0.82	0.69	0.75	0.44

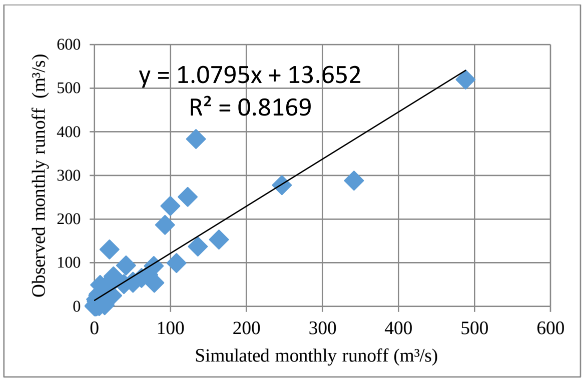

Figure 8: Observed versus simulated flow rate during calibration period

6.4 Validation Result

The validation of the results is done from 2001 to 2005. The comparison of observed and simulated flow is given and the time series plot of the monthly simulated data during the validation period of 1996-2000. The parameters that shows the accuracy of the model is given as below.

Table 5. Parameters used in SWAT Model in Validation

R2	NSE	P Factor	R Factor
0.82	0.69	0.75	0.44

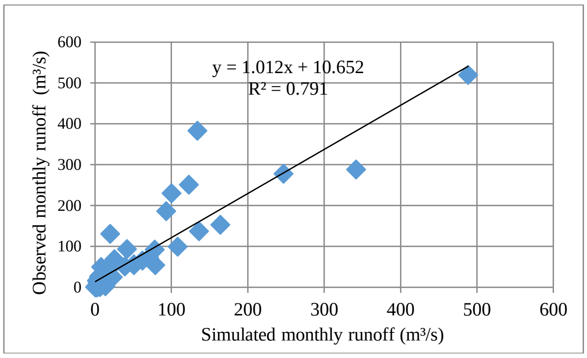

Figure 9: Observed versus simulated flow rate during validation period

6.5 Future Runoff of Patan Watershed

The catchment area for this watershed has an approximate drainage area of 3950 km2, which is divided into 97 sub basins. After apply the all spatial data DEM, land use, soil and slope information of PATAN watershed, 907 HRUs (Hydrologic Response Unit) were generated for entire basin. SWAT tool used performed reasonably satisfactory for estimating a watershed runoff. For calibration and validation SUFI-2 method was applied of SWAT 12 model.

The results from the SUFI-2 calibration process indicated a good performance with a PBIAS value of 12.6% and R^2 value was 0.83 indicating a good correlation between observed and simulated values. For the validation these value of R^2 and PBIAS are 0.79 and 10.6 % respectively.

Results showed that the annual mean flow discharge for the period 1996 to 2005 was 612.52 m3/s which agreed with the model result which shows that the average annual basin simulation values was 524.92 m3/s for the same period. While result simulation for the period 2016 to 2050 gave 414.70 m3/s which mean there is a reduction in mean flow discharge between two periods about 20.99%.

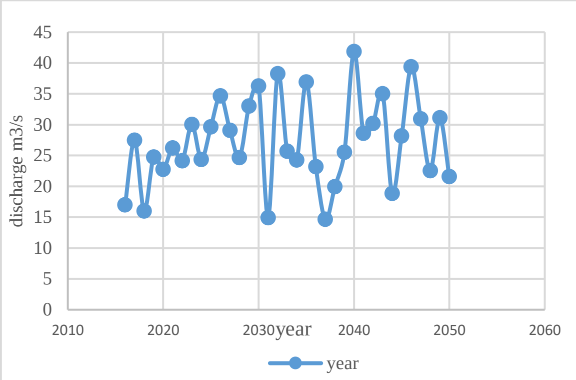

Figure 10. Predicted Runoff for Patan Watershed

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