Hydrologic Assessment in Uri River Basin, using SWAT Model

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Abstract—*River basin is considered to be perfect unit for management of the natural resources. Utilizing Remote Sensing and Geographical Information System (GIS) technique with mathematical models to assess the hydrologic parameters for the basin is being practiced widely now a day. In this work SWAT (Soil and Water Assessment Tool) having an interface with Arc MAP GIS software was used for the estimation of runoff yield of Uri river basin tributary of Narmada basin. The developed model was calibrated from the year 1999 to 2006 and validated for the period of 2008 to 2014. The coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) for the monthly runoff was obtained as 0.71 and 0.70 respectively for the calibration period and 0.70 and 0.69 respectively for the validation period.*

Keywords—Arc Map, Coefficient of Determination GIS, SWAT, Nash-Sutcliffe.

I. INTODUCTION

Although India is rich in water resources but the growth of population, industrialization, agricultural productivity, urbanization and global warming has led to the scarcity of water in the country. Thus the optimum management of water resources for development and growing needs has become the prime necessity of the hour. National water policy of India (2002) says that water resources development and management needs a nationwide sensible way of developing and conserving the scarce water resources in an integrated and environmentally sound manner. A scientific data base regarding availability of water is a pre-requisite for achieving both development and management of water resources. However availability of accurate long term hydrological data required for planning a water resource project is not readily available. Hence hydrological modeling is being resorted in order to generate such data.

Modeling of the hydrologic system is required by the water resource engineers for proper planning, development and management of water resource. Hydrologic models are mathematical formulation of various assumed functions to represent the different components of hydrologic cycle. The distribution of water in a hydrological cycle depends mainly upon two factors, catchment characteristics and the land use pattern. All hydrological models try to evaluate the effect of these factors on the precipitation received by a catchment and thus determine what fraction of water is available for human use.

Several well developed models for hydrological modeling of watersheds such as MIKE, NAM, HEC-HMS, HPSF, SWAT etc. are available which can be used for comprehensive estimation of various hydrological parameters. In the present work SWAT model has been used for the hydrological modeling of Uri basin.

II. SWAT

SWAT (Soil and Water Assessment Tool) is a basic numerical model of the hydrological cycle developed by United States Department of Agriculture – Agriculture Research Services (USDA-ARS). It is a physically based distribution model which works on the principal of water balance applied on the watershed scale to estimate the various components of hydrological cycle. The water balance equation used in the SWAT is as follows:

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

Where, SW_t is final soil water content in mm of H_2O, SW_o is initial soil water content in mm of H_2O, t is time in days, R_{day} is amount of precipitation of i^{th} day in mm of H_2O, Q_{surf} is amount of surface runoff of i^{th} day in mm of H_2O, E_a is amount of evaporation of i^{th} day in mm of H_2O, W_{seep} is amount of water entering the vadose zone from the soil profile of i^{th} day in mm of H_2O and Q_{gw} is amount of return flow of i^{th} day in mm of H_2O.

To estimate surface runoffSCS curve number and the Green and Ampt infiltration methods are available. SCS curve number method has been used in the present study. According to this method runoff is given by the equation

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

Where, Q_{surf} is the depth accumulated runoff or rainfall excess, R_{day} is the depth of precipitation for the day, I_a is the initial abstraction, and S is the retention parameter. The retention parameter changes with land use, soil, slope and is given by equation

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

Where, CN is the curve number. The initial abstraction, I_a is initially approximated to 0.2S.

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

S. k Jain et al (2010) used the SWAT model for simulating runoff and sediment for Himalayan region. They calibrated the model for the year 1993 and 1994 and validation was done for the years 1995, 1996 and 1997. Kaviya B (2012) has applied SWAT model for runoff estimation in Brahmani-Baitarani river basin. The modeled duration was from 2002-2005, of which 2002-2004 was used for calibration and 2004-2005 for validation on daily measured flow data. VikasShivhare et al (2014) applied SWAT for surface runoff simulation of Burhanpur watershed in upper Tapi sub-catchment. The model was developed to simulate the mean monthly runoff for the basin. The model was calibrated for the period 1992 to 1996 and validated from 1996-1997 with available monthly flow data.

SWAT models the physical process associated with water movement in the different phase of hydrological cycle on the basis of input parameters specific to the watershed. Hence all the properties which affect the movement of water in the watershed such as vegetative cover, soil properties, topography etc. as well as metrological condition are required to be given as input to the model.Watersheds are heterogeneous entities with their properties showing large spatial variation hence for accuracy in modeling SWAT divides the whole basin into multiple sub-watersheds and then further into hydrological Response Unit (HRUs), which have homogenous slope, land use and soil characteristics. Runoff from each HRU is calculated and then combined to get the total runoff. Due to the large requirement of data SWAT is used in integration with GIS for hydrological modeling. The main objective of the present study is to develop a Runoff model for Uri basin at the gauging site Dhulsar, using SWAT model in integration with ArcGIS database for estimation of surface flow.

III. STUDY AREA

The catchment of Uri Riverup to Dhulsar gauging stationhas been selected for this study. Uri River is one of the 41 main tributaries of Narmada River basin. It originates from Vindhya Ranges near Bhilkheri Village in Sardarpur Tehsil of Dhar District of Madhya Pradesh and meets the Narmada River 13Km downstream of Barwani. The total length of the river from its origin to its confluence with Narmada River is about 74.6 Km. The catchment area of Uri basin up to the study location i.e. Dhulsar is 787 sq. Km. The geographical limits of the area lie between 74˚47' to 75˚03' E longitudes and 22˚11' to 22˚37' N latitudes. Uri catchment has hilly terrain and undulating topography, thus producing high drainage density.

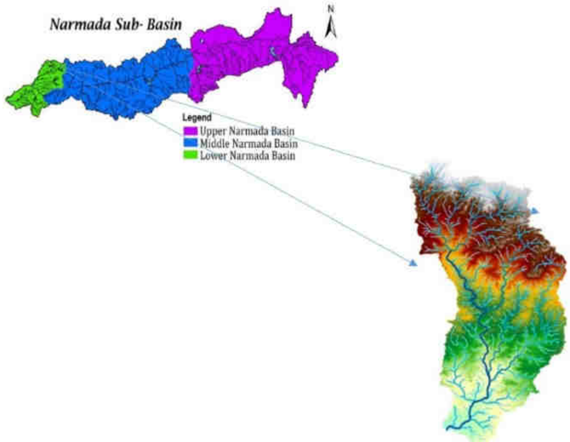

Fig.1: Location Map of Study Area

The climate of the basin is tropical and humid. It receives nearly 60% of the annual rainfall during the months of July and August. Another 30% is received in the months of June, September and October. The annual rainfall of the basin varies from 750mm to 1000mm.The rainfall is heavy in the upper hilly plains of the basin, it gradually decreases toward the lower plains and again increases towards the coast and south western portion of the basin. In the cold weather the mean annual temperature varies from 5˚C to 21˚C and in the hot weather from 33˚C to 48˚C. During the south west monsoon the temperature ranges between 25˚C to 27.5˚C.The value ofrelative humidity measured in fractions ranges from 0.2 to 0.6 and mean annual wind speed varies from 2 to 3 km/hr for the basin. The mean annual normal deviation in the solar radiation of the study area is in the range of15 to 25MJ/m^2/day.

IV. INPUT DATA

All hydrological modeling tools are very data intensive. Arc SWAT model requires detailed data regarding spatial variation of topography, land use/ land cover, soil type etc. in order to define Hydrological Response Units.

A. Digital Elevation Model (DEM):

Digital Elevation Model(DEM) is used fordefiningthe topography of an area by describing the elevation of any point at a given location and specific spatial resolution. DEM is an essential input for the SWAT and is used for delineating the watershed and its sub basins.

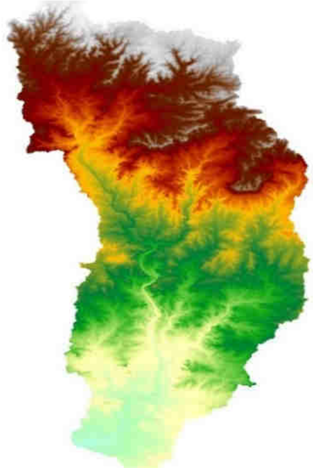

Fig.2: DEM of Study Area

DEM of 30M resolution for the study area was obtained from Bhuvan database maintained by National Remote Sensing Agency (NRSC), Hyderabad for the record period 2012. Sub-basin parameters such as slope and the stream network characteristics such as length and width were derivedwith the help of DEM only. For the present analysis DEM was projected to WGS1984_UTM_Zone_43N co-ordinate system for use in Arc SWAT. DEM of the Uri River basin is shown in the Figure2

B. Land Use Map:

Land use pattern of catchment is very important as it affects the distribution of precipitation on the catchment and hence in turn the evapotranspiration, sedimentation and the runoff generated. Land use/ Land cover data is required by the model for defining the HRUs and subsequently for assigning the Curve Number (CN) to the land area for the computation of runoff.Land use/ land cover map for Uri Basin was prepared usingLiss-III image for the study area which was obtained from the Bhuvan database for record period of 2012. The Liss-III data was in four band data set and a composite of all the bands was prepared and classified with the help of classification tool of Arc Map. This tool uses a training sample and prepares a maximum likelihood classification of the area putting area with similar properties in one category. Each land use category is defined by a four digit code related to the grid values in SWAT.Land use map of the Uri River basin is shown in the Figure3.The various land use categories and their coverage in the study watershed are presented in Table 1.

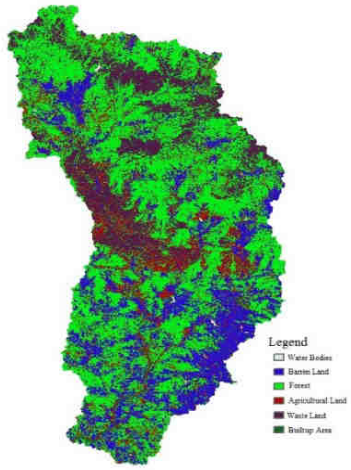

Fig.3: Land Use Map of Study Area

Table.1: Land Use/ Land Cover type for SWAT Model of Uri Basin

S. No.	Category	SWAT Land use Class	Percentage of Total
1	Water bodies	WATR	0.20
2	Barren Land	BARR	19.42
3	Forest	FRST	47.44
4	Agricultural Land	AGRL	12.82
5	Waste Land	RNGB	17.68
6	Built of Area	URBN	2.44

C. Soil Dataset:

Soil is composed of several organic matter which differ from its parent material. The type of soil and its distribution in the basin is also an important factor in runoff estimation from a basin as it affects the rate of infiltration. SWAT model requires soil texture and physiochemical properties of soil such as no of Soil Layer, Texture (i.e. Sand, Silt, Clay, and Rock fragments), structure, bulk density, available water content, porosity fractions, organic carbon content and hydraulic conductivity of each soil type.

In the present study the soil map prepared by FAO (Food and Agriculture Organization) classification system was used. The major soil type in the basin is clayey-loam while clay is also present in some region. The soil classification map of the Uri River basin is shown in the Figure4.The soil categories and their coverage in the study watershed are presented in Table 2.

Fig.4:Soil Map of Study Area

Table.2: Soil type for SWAT Model of Uri Basin

S. No.	Category	SWAT Soil class	Percentage of Total
1	CLAY-LOAM	Bv12-3b-3696	78.47
2	CLAY	Vc43-3ab-3861	21.53

D. Metrological Data:

SWAT model requires the daily metrological data (Rainfall, Minimum and Maximum temperature, Relative Humidity, Solar Radiation, and Wind Speed). The data of 12 weather stations was collected for the period 1999-2014 from global data website.According to the database the basin receives 90% of its annual rainfall during the monsoon months i.e. July to September and records maximum temperature in May and minimum in December.

V. SIMULATION MODEL

Arc SWAT 2012 has been used for the simulation in present study. The projection system for all the spatial data (DEM, Land use/ land cover, Soil map) is used in the simulation model was set to UTM_43N and WGS_1984 datum. The various steps involved in setting up the model as discussed below.

A. Stream Definition/ Catchment Delineation:

First the stream network for the catchment was generated from the DEM using the spatial analyst tool for Arc SWAT. The streams were defined and their order determined on the basis of flow direction, flow accumulation and stream links. Thereafter using the watershed delineation tool. The watershed delineation was delineated into 21 sub basins. Stream Definition and Sub Watershed Map of Study Area is shown in Figure 5

B. Hydrological Response Unit:

After delineation of the sub basin the land use/ land cover, soil map and slope map were overlaid on the DEM. Then specifying a threshold value of 5% for land use, soil and slope, the HRUs were generated. A total of 257 were created over the 21 sub basin.

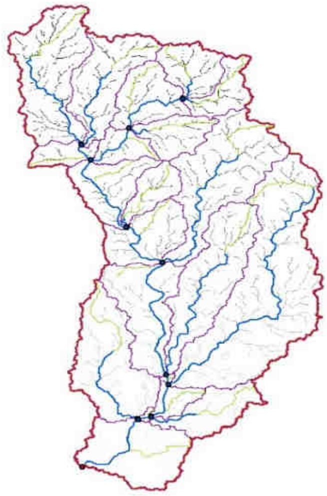

Fig.5: Stream Definition and Sub Watershed Map of Study Area

C. Model Input Setup:

After generation of HRUs the metrological data files are written and stored in the personal geodatabase of the model. Before SWAT model can be run the initial watershed input values have to be defined. These values were set automatically by activating the write all command based on the watershed delineation and land use/soil/slope characterization. In addition to this certain other key aspects have also to be specified, such as output time step-taken as monthly, simulation period-taken as June 1999 to May 2014, Rainfall distribution-selected as skewed normal and the method of runoff generated - selected as CN method.

D. Calibration and Validation

Model calibration is necessary for successful simulation of hydrologic processes. Calibration involves modification of the model parameters until the predicted values are in close agreement with the actual observed values. Initially the SWAT model was run with 24 parameters based on the sensitivity analysis 19 parameters showing greater influence on the simulation results were identified. Further calibration was done using only these parameters. The model was calibrated in SWAT-Cup using SUFI-2 algorithm.

E. Performance Evaluation of the Model

The developed model needs to be evaluated in order to determine the performance of the model. Many statistical parameters are available for evaluation of the hydrological model. The Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS})are the mostly used criteria for the estimation of accuracy. Hence in the present study R^2 and E_{NS}have been usedto evaluate the model.

$$R^2 = \left[\frac{\sum_{i=1}^{N}[O_{(i)} - O_{avg}][S_{(i)} - S_{avg}]}{\{\sum_{i=1}^{N}[O_{(i)} - O_{avg}]\}^{0.5}\{\sum_{i=1}^{N}[S_{(i)} - S_{avg}]\}^{0.5}}\right]^2$$

$$E_{NS} = \frac{\sum_{i=1}^{n}(O_i - O_{av})^2 - \sum_{i=1}^{n}(S_i - O_{av})^2}{\sum_{i=1}^{n}(O_i - O_{av})^2}$$

Where, $O_{(i)}$ is the i^{th} observed parameter, O_{avg} is the mean of the observed parameters, S (i) is the i^{th} stimulated parameter, and Savg is the mean of model simulated and N are the total number of events.

VI. RESULTS AND DISCUSSION

SWAT simulated output was calibrated in SWAT-Cup using SUF-2 algorithm. The model was calibrated using the monthly data of runoff recorded at the outlet of the watershed. The model was calibration was done on the basis of nineteen parametersobtained through sensitivity analysis. The relative sensitivity of the model parameters is shown in Figure 6. It is seen that most sensitive parameters giving the discharge are moist soil albedo, main channel conductivity, initial depth of shallow aquifer, surface runoff lag coefficient and soil available water storage capacity. This indicates that channel and soil parameters which affect the routing of the flow and the surface flow lag time are the most sensitive parameters

In the present study calibration of SWAT model was performed for the period June-1999 to May-2006using the surface runoff data recorded at the outlet of the watershed. Calibration was performed by adjusting the parameters with higher sensitivity. The calibration was continued with several simulation run until the difference between the observed water yield and modeled water yield is minimized. The best fitted values of the parameters is given in Table 3.

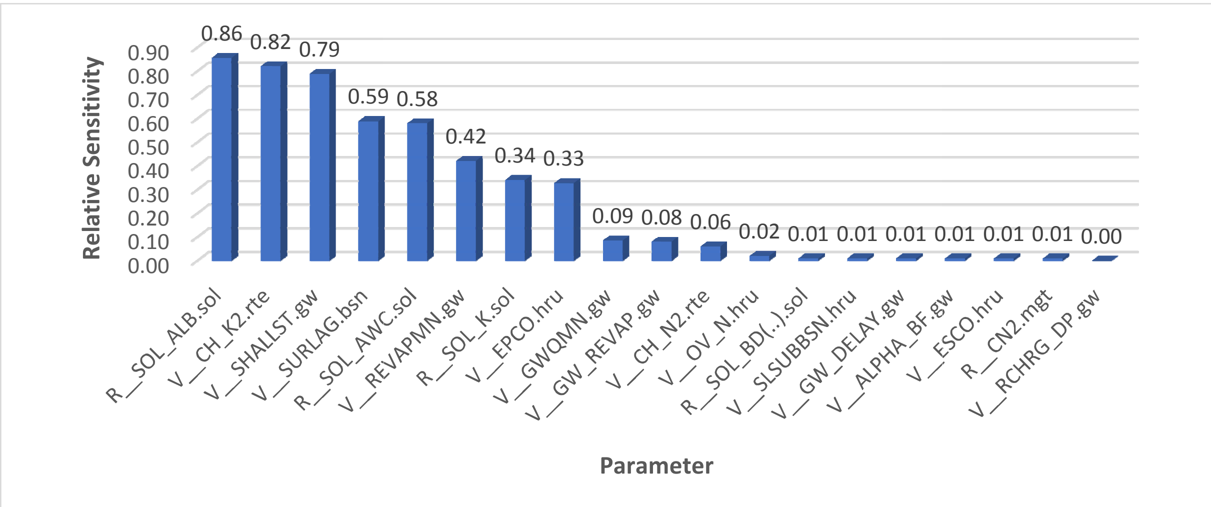

Fig.6: Relative Sensitivity of model Parameters

Table.3: Best fitted values of Model Parameters

Parameter Name	Description	Min value	Max value	Best Fitted Value
R__SOL_ALB.sol	Main channel conductivity	-0.5	0.5	-0.44975
V__CH_K2.rte	Surface runoff lag coefficient	0	5	3.26875
V__SHALLST.gw	Soil evaporation and compensation factor	0	1000	962.75
V__SURLAG.bsn	Manning's "n" value for main channel	1	24	5.42175
R__SOL_AWC.sol	Threshold water in shallow aquifer	-0.25	0.25	-0.22213

V__REVAPMN.gw	Soil hydraulic conductivity	0	100	72.725
R__SOL_K.sol	Moist soil albedo	-0.8	0.8	0.3484
V__EPCO.hru	Ground water delay time	0	1	0.04375
V__GWQMN.gw	Deep aquifer percolation fraction	0	5000	493.75
V__GW_REVAP.gw	Soil available water storage capacity	0.02	0.2	0.082775
V__CH_N2.rte	Manning's "n" value for overland flow	0	0.3	0.178425
V__OV_N.hru	Soil bulk density	0	0.8	0.7026
R__SOL_BD.sol	Curve number	-0.3	0.3	-0.11385
V__SLSUBBSN.hru	Average slope length	10	150	118.325
V__GW_DELAY.gw	Revap coefficient	30	450	35.145
V__ALPHA_BF.gw	Threshold depth of water in shallow aquifer required for return flow to occur	0	1	0.17125
V__ESCO.hru	Initial depth of water in shallow aquifer	0.01	1	0.872042
R__CN2.mgt	Plant uptake compensation factor	-0.25	0.25	-0.21213
V__RCHRG_DP.gw	Base flow alpha factor	0	1	0.02325

It is seen that in general the simulated flows obtained from the calibrated model matches quite well with the observed values (Figure 7 and 8). For evaluation of the model R^2 and NSEvalues were determined and were found to be 0.71 and 0.70 respectively. This suggests that the model can be used to predict the monthly flow values.

After calibration the prediction accuracy of the model of the model was validated for the surface runoff by applying different set of data i.e. from June 2008 to May 2014 which was not used during calibration. The data for two water year was not available i.e. from June-2006 to May-2008 hence the period has not been considered for validation and calibration. The graphical comparison for goodness of fit is shown in Figure 9 and 10. R^2 and NSE values for the validation period are 0.7 and 0.69. Hence the model shows good prediction efficiency.

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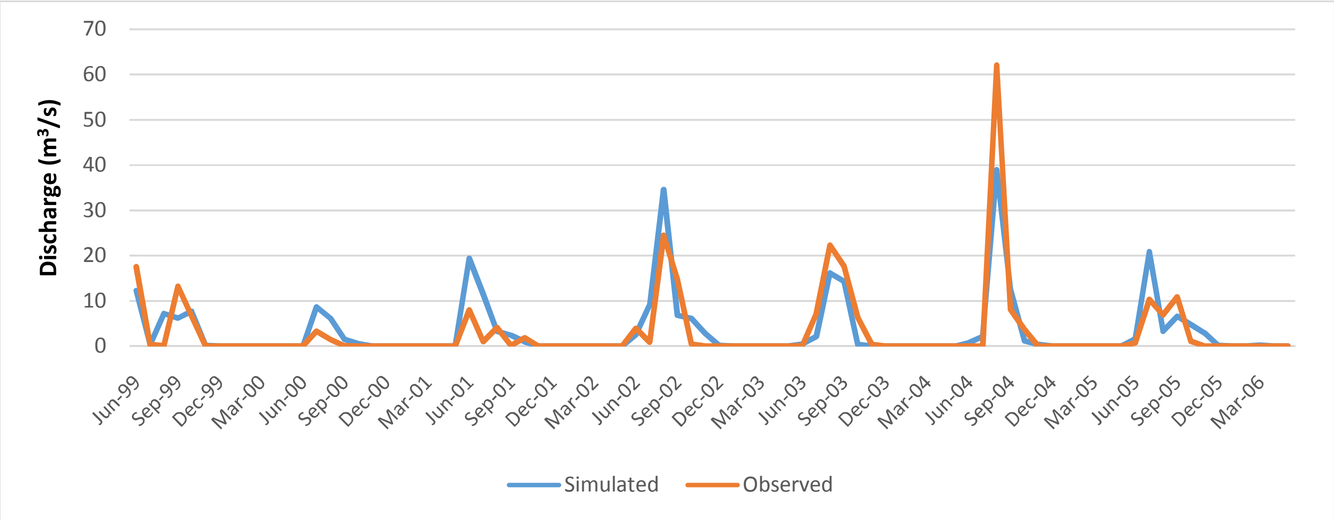

Fig.7: Simulated and Observed Monthly Flow Calibration Graph

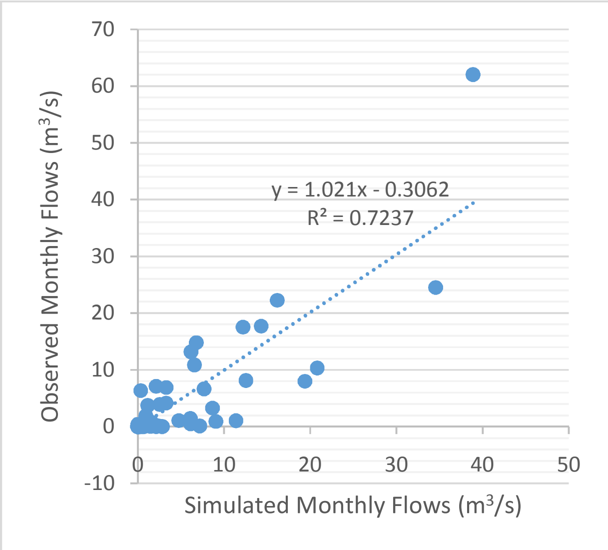

Fig.8: Goodness of fitduring Calibration (1999-2006)

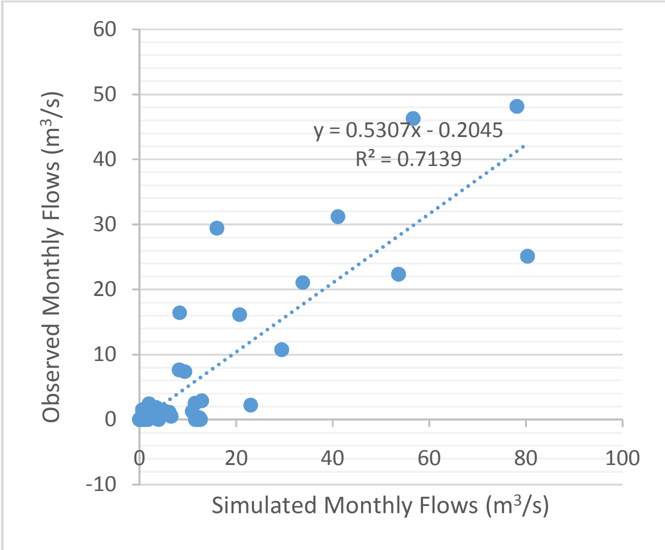

Fig.9: Goodness of fitduring Validation (2008-2014)

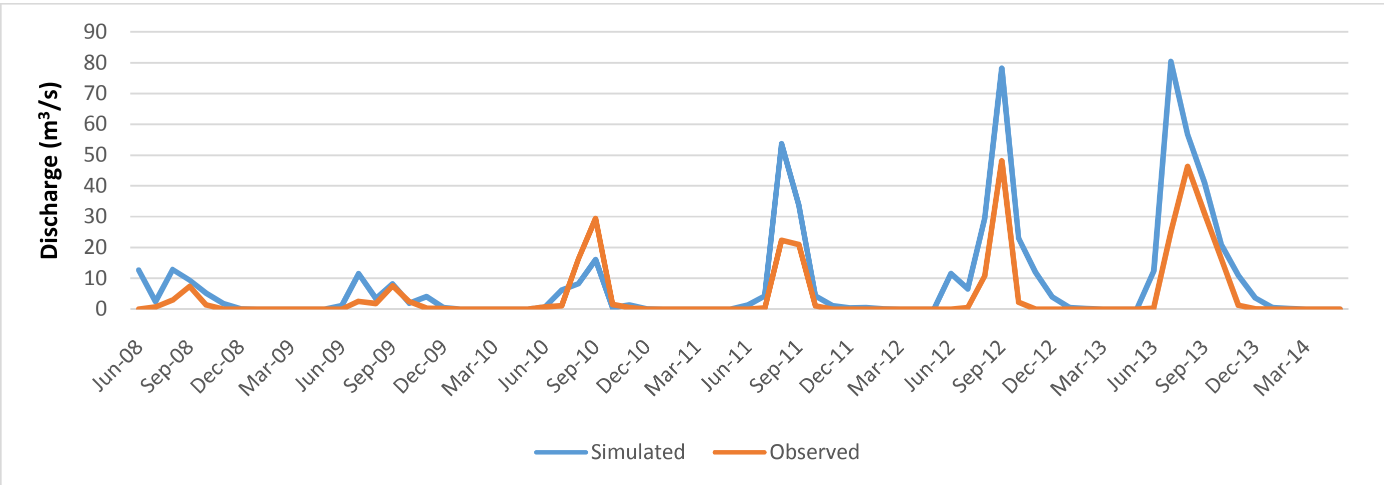

Fig.10: Simulated and Observed Monthly Flow Validation Graph

VII. CONCLUSION

A SWAT model for predicting the monthly runoff from Uri basin has been developed. The developed SWAT model has performed well during the calibration and validation periods. Sensitivity analysis was performed to identify the most effective parameters of the model for the basin. These parameters were then adjusted with the help of observed flow data for the calibration period from June1999 to May 2006.The calibration result showed that there is a good correlation (R^2=0.71, NS=0.70) between the predicted and observed monthly flows. Validation was carried out for flows from June 2008 to May 2014. For validation period the $R^2$and NSE were detected as 0.70 and 0.69.The developed SWAT model can simulate the monthly runoff for Uri basin with reasonable accuracy.

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