Assessment for Runoff of Upper Betwa Basin by using SWAT Model

Md. Jafri Ahsan, R. K. Issac, Mohd. Imtiyaz

Abstract- ***A distributed parameter model, AVSWAT (Arc View soil and water Assessment Tool) was calibrated and validated on monthly basis for the upper Betwa Basin. India extraction of river basin characteristics like land use/ land cover, soil map, digital elevation model (DEM), drainage information of the study area using remote sensing, GIS and collateral data. The main objective was to validate the performance of SWAT and the feasibility of using the model as a simulator of runoff processes at a catchment area Berasia, Bhopal, Raisen and Vidisha of upper Betwa basin. All hydrological and meterological data, were collected from Indian water portal. Land use map of the area were collected from National Bureau of Soil Survey and Land Use Planning, Nagpur, Monthly surface runoff for the monsoon months (1993-2002) were collected for Berasia, Bhopal, Raisen and Vidisha. The model was calibrated and validated for the monsoon seasons of 1993-99 and 2000-02 respectively. The performance of the model was evaluated using statistical and graphical methods to decide the capability of the model simulating the runoff of upper Betwa basin. The calibration period reported coefficient of determination R^2 of Berasia, Bhopal, Raisen and Vidisha are 0.97, 0.96, 0.94 and 0.98 respectively. The relative error was obtained as 6.68, 8.00, 10.17 and 15.97 respectively. The value of Nash Sutcliffe model efficiency obtained was 0.98, 0.97, 0.99 and 0.93 of Berasia, Bhopal, Raisen and Vidisha respectively. The validation period reported R^2 of 0.98, 0.97, 0.95 and 0.76 of Berasia, Bhopal, Raisen and Vidisha respectively. The relative error are 6.77, 10.61, 7.91 and 10.56 respectively. The value of Nash Sutcliffe model efficiency obtained was 0.99, 0.99, 0.95 and 0.99 of Berasia, Bhopal, Raisen and Vidisha for monthly observed and simulated runoff. Calibration and validation results revealed that model was/ predicting total surface runoff, at Berasia, Bhopal, Raisen and Vidisha of Upper Betwa Basin accurately. The calibrated and validated model will be used for both long – term and storm event water quantity and quality evaluations throughout the basin.***

Keywords: - AVSWATX, land use / land cover, runoff, calibration, validation, Image processing, Remote Sensing and GIS

I. INTRODUCTION

Watershed characteristics, such as land use/land cover, slope, and soil attributes, affect hydrologic and water quality processes and hence regulate sediment and chemical concentration. Knowledge of the basic hydrologic processes occurring in watershed give a better understanding of land use impacts on soil and water resources.

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Change in land use/land cover is considered as an important hydrologic factor affecting storm runoff generation and sediment yield (Naef *et al.* 2002). This is especially true for humid and sub-humid subtropical areas in India which are affected by heavy monsoon rains during four to five rainy months. This effect can be assessed by rainfall – runoff model simulation . SWAT is one such model which employs the Curve Number (CN) method for estimating runoff and the modified Universal Soil Loss Equation (MUSLE) for estimating sediment yield. Thus SWAT can assess the effect of different topographic, soil and land cover combination on runoff and sediment yield. Under Indian conditions, an average soil loss value of 16.4 t/ha–yr. (Narayana 1993) may be considered as the limit for identifying critical watershed areas.(Singh *et al.*1992), categorized soil loss ranges into six soil erosion classes: slight (0-5 t/ha – yr), medium (5-10 t/ha – yr), high (10-20 t/ha-yr), very high (20-40 t/ha-yr), severe (40-80 t/ha-yr) and very severe (>80 t/ha-yr). The soil and water assessment tool (SWAT) is a watershed scale model developed by USDA-ARS for predicting impact of land management practices on water, sediment and agricultural chemical yields in large complex watershed having varying soils, and use and management conditions over long periods of time (Arnold *et al.* 1998). The model is a physical based, continuous time model, and simulates surface runoff evapotranspiration, infiltration, percolation losses, channel transmission losses, channel routing, lateral flow and shallow and deep aquifer flow. The SWAT model allows considerable flexibility in basin decomposition. The basin can be divided into a number of Hydrological Response Unit (HRU) or grid cells or sub-basins. Different parts of the basin can be divided differently. The new routing structure of the SWAT model routes and adds flows down through the basin reaches and reservoirs. Apart from this, changes were incorporated to simulate lateral flow, ground water flow, reach routing transmission losses, and sediment and chemical movement through ponds, reservoirs, streams and valleys. The SWAT model is capable of simulating hundreds of sub-basins for the periods of 100 years or more. The major components of the model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow, and agricultural management.

II. MATERIALS AND METHODS

The Soil and Water Assessment Tool (ArcSWAT 2009.93.4) having an interface with ArcGIS 9.3 software was selected for hydrological modeling of Betwa Basin, located in Madhya Pradesh, India.

Study Area

The study area is located in Betwa sub-basin falling between

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Bhopal and Vidisha in Madhya Pradesh (India), which covers a catchment area of 46580 km^2 out of the total catchment area 4122 sq.km area is taken in the present study. Betwa river rises in the Raisen district of Madhya Pradesh near village Barkhare, south west of Bhopal at an elevation of about 576 m above mean sea level and flows in a north-easterly direction for 232 km through Madhya Pradesh and enters the Jhansi district of Uttar Pradesh. After running for a further distance of about 261 km. in Jhansi, Jalaun, and Hamirpur districts of Uttar Pradesh, it joins river Yamuna near Hamirpur at about 106 m above mean sea level. The total length of the river from its origin to its confluence with the Yamuna is about 590 km, about 232 km in Madhya Pradesh and the balance in Uttar Pradesh.

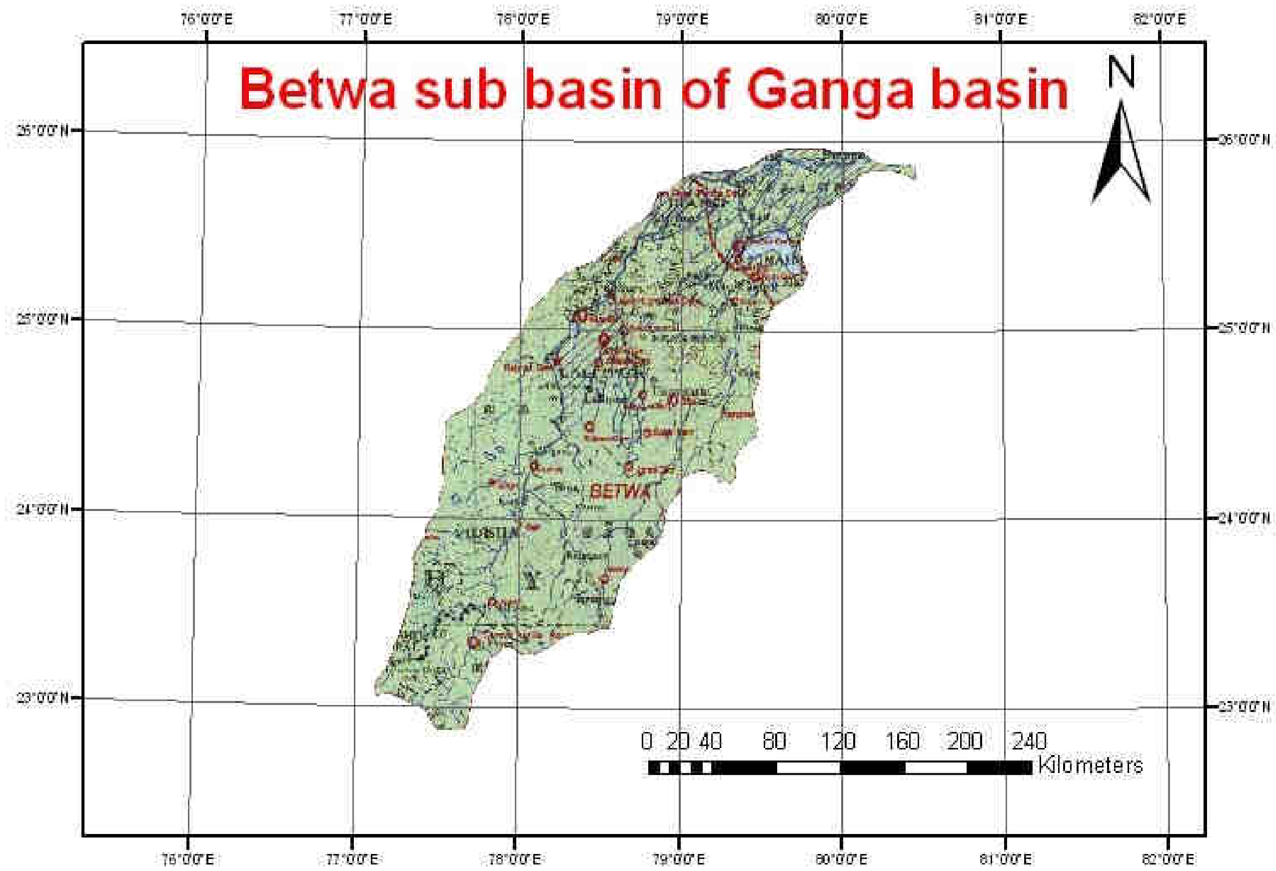

Fig. 1: Location map of the Study area

SWAT model setup

The model setup involved seven steps and spatial data sets (DEM, Land use/Land cover map, soil map and slope map) were projected to UTM 49 South and WGS84 datum. Reprojection was done using ArcGIS 9.3 raster and vector standard world reproject tool. ArcSWAT requires all data to be in the same projection before any GIS processing can take place. The DEM was used to delineate the basin and to analyze the drainage patterns of the land surface terrain. We have used DEM mask that was superimposed on the DEM since the model uses only the masked area for stream delineation. The Land use/Land cover spatial data were reclassified into SWAT land cover/plant types. A user look up table was created that identifies the SWAT code for the different categories of land cover/land use on the map as per the required format. The soil map was linked with the user soil data-base. The spatially distributed data (GIS input) needed for the Arc SWAT interface include the Digital Elevation Model (DEM), soil data, land use, slope and weather data.

The hydrologic cycle as simulate by SWAT is based on the water balance equation.

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} i{=}1 - E_a - w_{seep} - Q_{gw})$$

Where, SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is time (days), R_{day} is amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), W_{seep} is the amount of percolation and by pass exiting the soil profile bottom on day i (mm H_2O), Q_{gw} is the amount of return flow on day i (mm H_2O). Since the model maintains a continuous water balance, the subdivision of the watershed enable the model to reflect differences in evapotranspiration for various crops and soils. Thus runoff is predicted separately for each sub area and routed to obtain the total runoff for the basin. This increases the accuracy and gives a much better physical description of the water balance. Surface runoff component simulates the surface runoff volume and the peak runoff rates provided daily

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rainfall data are fed. Surface runoff is computed using a modification of the SCS curve number (USDA Soil Conservation Services, 1972) or the Green and Ampt infiltration method (green and Ampt, 1911). In the curve number of method, the curve number varies non linearly with the moisture content of the soil the curve number drops as the soil approaches the wilting point and increases to near 100 as the soil approached saturation. The green and Ampt method requires sub-daily precipitation data and calculates infiltration as a function of the wetting front matric potential and effective hydraulic conductivity. Surface runoff volume predicted in SWAT using SCS curve number of method is given below

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

Where Q_{surf} is the accumulated runoff or rainfall excess (mm H_2O), R_{day} is the rainfall depth for the day (mm H_2O), and S is the retention parameter (mm H_2O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

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

Where CN is the curve number for the day. The initial abstractions, I_a, is commonly approximated as 0.2*S* and equation becomes.

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

Runoff will only occur when $R_{day} > I_a$.

The runoff coefficeint is the ratio of the inflow rate, i area, to the peak discharge rate, q peak. The coefficient will vary from storm to storm and is calculated with the equation.

$$C = \frac{Q_{surf}}{R_{day}}$$

Where Q_{surf} is the surface runoff (mm H_2O) and R_{day} is the rainfall for the day (mm H_2O).

Model calibration

Model evaluation is the adjustment of model parameters, within recommended ranges, to optimize the agreement between observed and simulated results. The evaluation tool of SWAT provided different parameters for adjustment through user intervention. Different data of various scenarios will be used for the calibration of the model.

Model validation

Validation of the calibrated model is essential to test its simulation performance. Calibrated model will be validated using a different set of data recorded during the given time period of the data. The simulated values of specified location will be compared with the observed values for validation of the model. Besides such comparison, validation can also been tested using different established indices. (1) The coefficient of determination (R^2) describe the proportion of the total variance in the measured data that can be explained by the model. It range from 0.0 to 1.0 with higher values indicating better agreement, and is given by,

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

Where, O (i) is the ith observed parameter, Oavg is the mean of the observed parameter, S (i) is the ith simulated parameter, Savg is the mean of model simulated parameter and N is the total number of events. (2) coefficient of simulation efficiency (COE), also known as the Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970) recommended by ASCE Task committee (1993) is the second basic goodness-of-fit criterion used to evaluate the model performance. The equation is as follows.

$$E = 1 - \frac{\sum_{t=1}^{T}(Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_o^t - \overline{Q_o})^2}$$

where Q_o is the mean of observed discharges, and Q_m is modeled discharge. Q_o^t is observed discharge at time *t*.The values for C_{OE} can be varied form 0 to 1, with 1 indicating a perfect fit. A value for C_{OE} equal to zero indicates that the model was simulating no better than.

III. RESULTS AND DISCUSSION

Calibration

The SWAT model was calibarated with the observed discharge measured at the upper betwa basin (Berasia, Bhopal, Raisen and Vidisha) outlet for the year 1993-1999. After calibration the model was used for prediction of runoff. Calibrated model results for runoff is presented in figures 1 to 4. Thus, in the present study, input parameter values required by the model were obtained from direct field and laboratory measurements, remote sensing, GIS or through the calibration process of the models, where selected model parameters were adjusted within an expected range and the discrepancies between the measured and

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model predictions could be minimized the performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the runoff from the. Study area. The observed and simulated monthly runoff values of upper betwa basin (Berasia, Bhopal, Raisen and Vidisha catchment) for the pre calibrated period (1993-1999) 1:1 line are shown in figure.5 to 8. it is observed from figure 5 to 8 that the simulated runoff values are not distributed uniformly about the 1:1 line for both the lower and higher values of the observed discharge. Descriptive statistics for the model result are presented in table 1to 4 , The high values of Nash Sutcliffe model efficiency of Berasia, Bhopal, Raisen and Vidisha is 0.98, 0.97, 0.99 and 0.93 respectively indicate that the calibrated model performance is good. Higher value of the coefficient of determination (0.97, 0.96, 0.94 and 0.98) indicate a close relationship between the measured and simulated runoff.

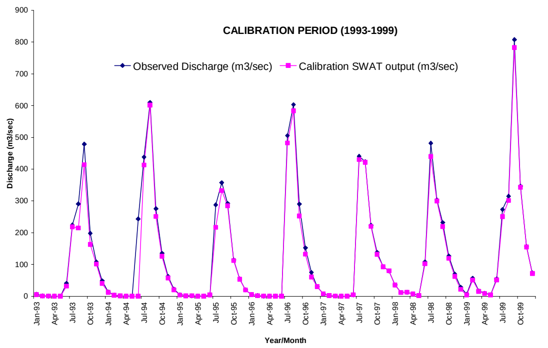

Fig. 4.1 Observed monthly discharge (1993-99) simulation result for calibration period of Berasia

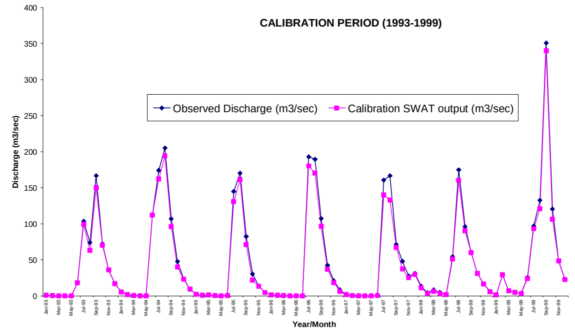

Fig. 4.2 Observed monthly discharge (1993-99) simulation result for calibration period of Bhopal

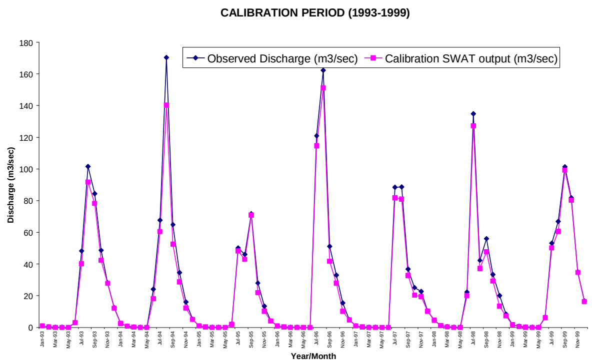

Fig. 4.3 Observed monthly discharge (1993-99) simulation result for calibration period of Raisen

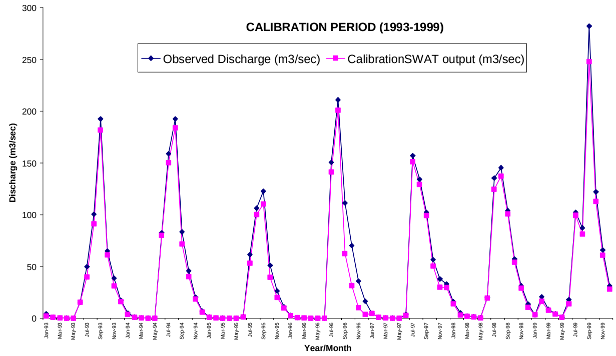

Fig. 4.4 Observed monthly discharge (1993-99) simulation result for calibration period of vidisha.

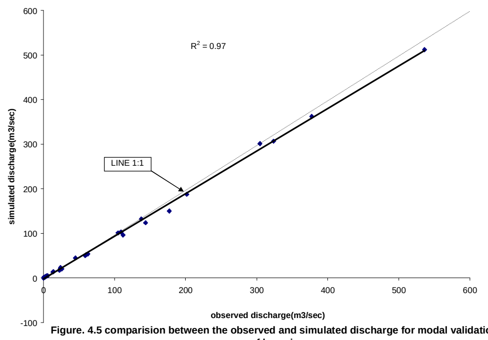

Figure. 4.5 comparision between the observed and simulated discharge for modal validation of berasia

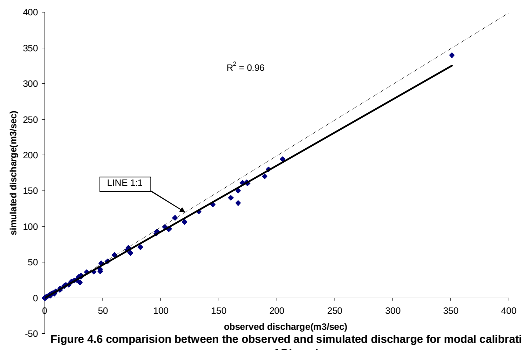

Figure 4.6 comparision between the observed and simulated discharge for modal calibration of Bhopal

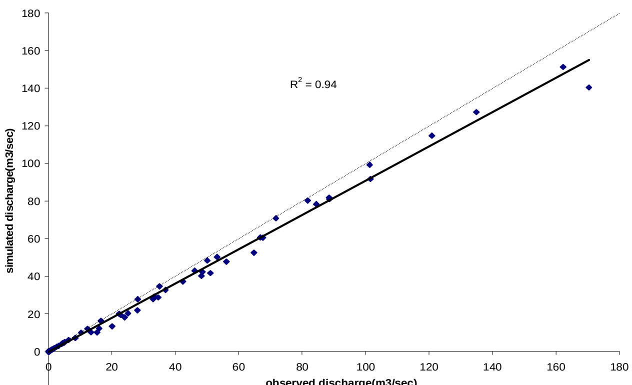

Figure 4.7 camprison between observed and simulated discharge for model calibration of Raisen

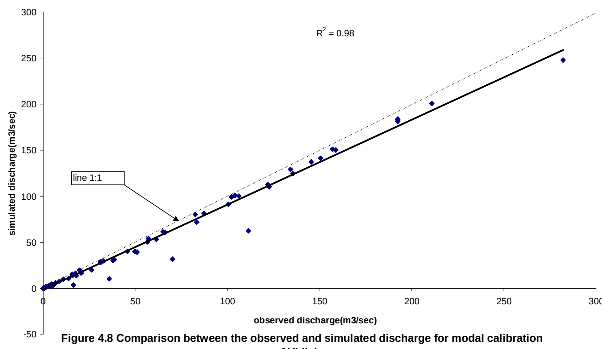

Figure 4.8 Comparison between the observed and simulated discharge for modal calibration of Vidisha.

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Table 1Descriptive statistics for calibration and validation of SWAT output Berasia

Descriptive statistics	Observed discharge (1993-1999)	Calibration (1993-1999)	Validation (2000-2002)
Mean	130.4262	122.0382	75.43508
Standard error	19.34334	17.09761	20.0536222
Median	44.825	37.77	18.62
Standard Deviation	177.2846	169.6786	120.321733
Sample Variance	31429.85	28790.81	14477.3195
Kurtosis	2.25233	2.698368	4.70844894
Skewness	1.607027	1.709843	2.18554331
Range	807.5961	782.4	512.1
Minimum	0.003909	0	0
Maximum	807.6	782.4	512.1
Sum	10955.8	10007.14	2708.646
Count	84	82	36
Confidence level (95.0%)	37.91225	36.72553	39.3043773

Table 2. Descriptive statistics for calibration and validation of SWAT output Bhopal

Descriptive statistics	Observed discharge (1993-1999)	Calibration (1993-1999)	Validation (2000-2002)
Mean	47.78737	43.95976	25.05156
Standard error	7.412808	6.889376	8.110584
Median	14.985	14.81	5.3195
Standard Deviation	67.93951	63.14218	48.6635
Sample Variance	4615.777	3986.934	2368.137
Kurtosis	3.953227	4.970611	10.95715
Skewness	1.862807	1.994506	3.094379
Range	350.8754	339.9	240.9
Minimum	0.02464	0	0
Maximum	350.9	339.9	240.9
Sum	4014.139	3692.62	897.4571
Count	84	84	36
Confidence level (95.0%)	14.52884	13.50293	15.89645

Table 3 Descriptive statistics for calibration and validation of SWAT output Raisen

Descriptive statistics	Observed discharge (1993-1999)	Calibration (1993-1999)	Validation (2000-2002)
Mean	27.18426	24.45773	18.76198
Standard error	4.250187	3.882219	4.704135
Median	5.758	5.556	3.962
Standard Deviation	38.95361	35.58113	28.22481
Sample Variance	1517.384	1266.016	796.6398
Kurtosis	3.125171	2.791744	3.288751
Skewness	1.812633	1.789016	1.893359
Range	170.3886	151.2	116.91
Minimum	0.0114	0	0
Maximum	170.4	151.2	116.91
Sum	2283.477	2054.449	675.4314
Count	84	84	36
Confidence level (95.0%)	8.330214	7.60901	9.219935

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Table 4 Descriptive statistics for calibration and validation of SWAT output Vidisha

Descriptive statistics	Observed discharge (1993-1999)	Calibration (1993-1999)	Validation (2000-2002)
Mean	46.10967	41.13943	23.38136
Standard error	6.650194	6.183206	5.589526
Median	16.95	13.82	8.037
Standard Deviation	60.95003	56.67002	33.53716
Sample Variance	3714.907	3211.491	1124.741
Kurtosis	2.238998	2.002332	2.493966
Skewness	1.576933	1.598138	1.760162
Range	281.9819	247.9	130.5
Minimum	0.01806	0	0
Maximum	282	247.9	130.5
Sum	3873.212	3455.712	841.7291
Count	84	84	36
Confidence level (95.0%)	13.03414	12.11886	10.95527

Table 5 Result of the calibration and validation of the SWAT model

Sr. No.	Period	Evaluation Statistics											
		Berasia			Bhopal			Raisen			Vidisha		
		R^2	NSE	RE	R^2	NSE	RE	R^2	NSE	RE	R^2	NSE	RE
1.	Calibration (1993-1999)	0.97	0.98	6.68	0.96	0.97	8.00	0.94	0.99	10.17	0.98	0.93	15.97
2.	Validation (2000-2002)	0.98	0.99	6.77	0.97	0.99	10.61	0.95	0.95	7.91	0.76	0.99	10.56

Validation of the SWAT model

The SWAT model was validation with the observed discharge measured at the upper Betwa basin outlet for the years 2000-2002. The result is presented in figure 5 to 8.For the model validation the coefficient of determination (R^2), Relative error (RE%) and Nash-sutcliffe coefficient (E) were obtained as table 5. The high value of Nash Sutcliffe

model efficiency of Berasia, Bhopal, Raisen and Vidisha is 0.99, 0.99, 0.95 and 0.98 indicates that the model performance is very good. The observed and simulated monthly runoff values of upper betwa basin for the validation period (2000-2002) along with 1:1 line are shown in figure 5 to 8.

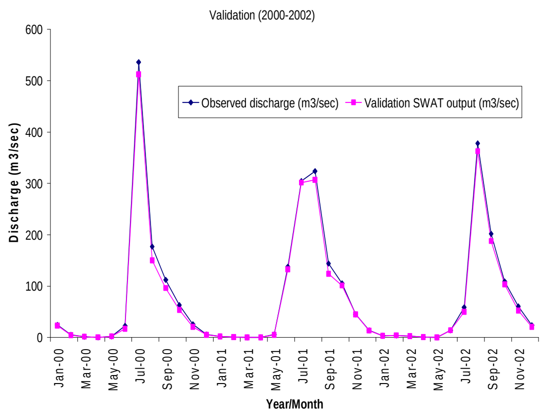

Fig. 4.9 Observed monthly discharge (2000-2002) simulation result for validation period of Berasia

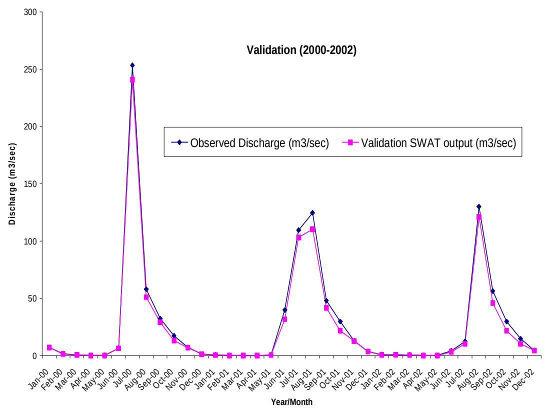

Fig. 4.10 Observed monthly discharge (2000-2002) simulation result for validation period of Bhopal

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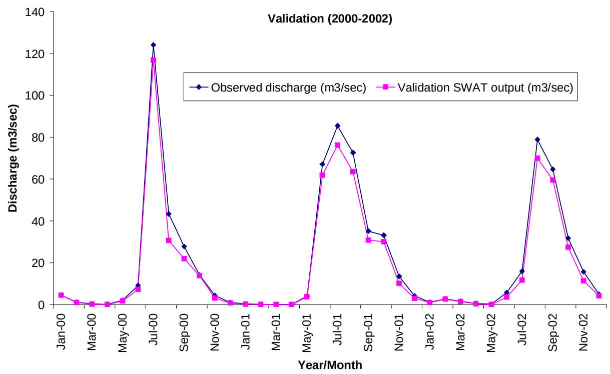

Fig. 4.11 Observed monthly discharge (2000-2002) simulation result for validation period of Raisen

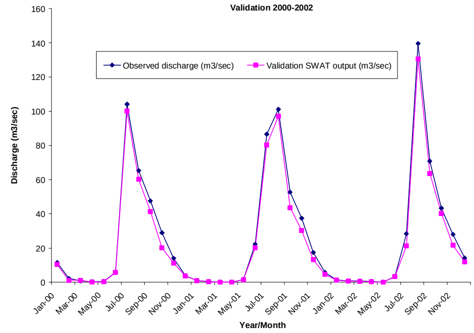

Fig. 4.12 Observed monthly discharge (2000-2002) simulation result for validation period of Vidisha

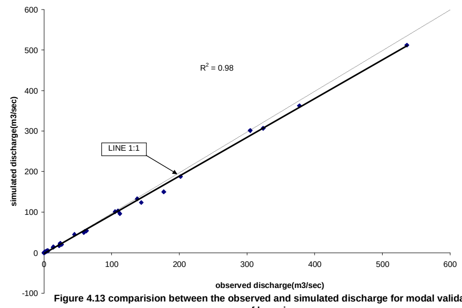

Figure 4.13 comparision between the observed and simulated discharge for modal validation of berasia

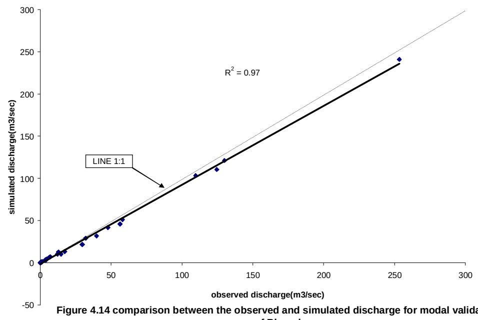

Figure 4.14 comparison between the observed and simulated discharge for modal validation of Bhopal

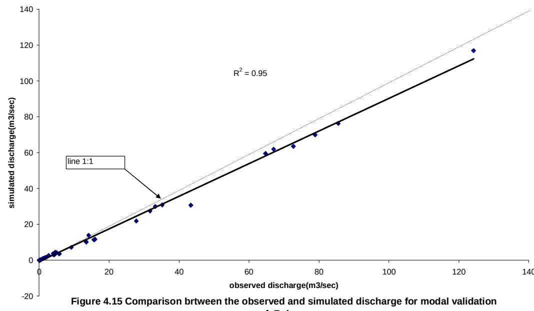

Figure 4.15 Comparison brtween the observed and simulated discharge for modal validation of Raisen.

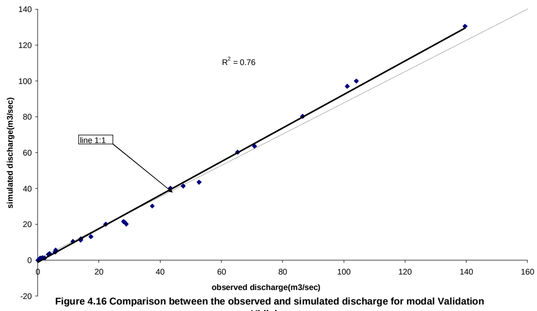

Figure 4.16 Comparison between the observed and simulated discharge for modal Validation Vidisha.

It is observed from figure that the simulated runoff values are distributed uniformly about the 1:1 line for both the lower and higher values of the observed discharge. Higher value of the coefficient of determination (0.98,0.97,0.99,0.76) indicates a close relationship between the measured and simulated runoff for the validation period from validation graph shown in figure17 to 20, by adjustment of the parameters, the amount of water infiltrated into the soil becomes sub-surface water so that the stream runoff increases. After some iterations, the stream runoff increases and the predicted graph becomes closer to the observed graph but not 100% similar because some assumptions and adjustment about land and soil characteristic that was used in modeling may not be the some as the real conditions in field. Final result of the swat model show that the relative error is 10.17% and 15.97% (>10%) of raisen and vidisha respectively. It indicates that the model does not represent the actual condition of stream flow. In case there is human error in the input data, it may have effect on the result of the program. Thus, it is important to carefully review precipitation and flow data for the particular duration to make sure that the input data were correct.

IV. CONCLUSION

The calibration of model for Betwa basin good agreement between observed and simulated inflow. The model simulated monthly surface runoff was in close agreement with observed values for Berasia and Vidisha. Where as reasonable agreement found for Bhopal and Raisen. The model predicted surface runoff were very high for the month of September may be due to inappropriate representation of real situation in the model. Sediment yield also followed some trend as it entirely depends on amount of the runoff. In Bhopal and Raisen the trend is greatly deviate due to temporal variation.

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