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CALIBRATION AND VALIDATION OF HEC-HMS MODEL FOR A RIVER BASIN IN EASTERN INDIA

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ABSTRACT

Assessment of impact of climate change on water resources in river basin requires a proper estimation of availability of water and that can only be achieved by hydrological modeling of the basin. However, hydrological modeling is a complex task and hydrologic models should be well calibrated to increase user confidence in its predictive ability which makes the application of the model effective. In this study a catchment simulation model viz., Hydrologic Modeling System, developed by the Hydrologic Engineering Center, USA (HEC-HMS) (with soil moisture accounting algorithm --SMA) has been calibrated and validated for Subarnarekha river basin in Eastern India for prediction of its hydrologic response. The analysis shows that the soil storage, tension zone storage and groundwater 1 storage coefficient to be the sensitive parameters for the simulated stream flow. The Nash - Sutcliffe model efficiency criterion, percentage error in volume, the percentage error in peak, and net difference of observed and simulated time to peak, which were used for performance evaluation, have been found to range from (0.72 to 0.84), (4.39 to 19.47%), (1.9 to 19%) and (0 to 1day) respectively, indicating a good performance of the model for simulation of stream flow and thereby quantification of available water. The study also demonstrates that the use of semi annual parameter sets that account for changing hydrologic conditions improves model performance. Thus the model may be applied to other watersheds in the Subarnarekha river basin and other hydro -meteorologically similar river basins.

Keywords: HEC-HMS model, river basin, soil moisture accounting, parameters, simulation.

INTRODUCTION

It is now widely accepted that climate change would affect the distribution of precipitation as well as the intensities and frequencies of extreme hydrological events. This would, in turn, affect all aspects of water resources worldwide. South Asia in general and India in particular, are considered particularly vulnerable to climate change and its adverse socio-economic effects because of high dependence of the majority of the population on climate-sensitive sectors like agriculture and forestry, poor infrastructure facilities and lack of financial resources. There are also vast sectoral and regional variabilities in India that affect the adaptive capacity of the country to climate change (Bhatt and Sharma, 2002).

Assessment of water resources is a prime requisite in order to frame long term sustainable management strategy for water to combat this situation. Hydrologic models which comprise integration of key hydrologic processes are appropriate tools for such studies. However, hydrological modeling which is a simplified representation of the real situation, is a challenging task particularly for regions with limited data and hydrologic models should be well calibrated and its performance be evaluated to provide reliable result for any study.

In this background, a study on the calibration and evaluation of a watershed simulation model viz., Hydrologic Modeling System, developed by the Hydrologic Engineering Center, USA (HEC-HMS -- with Soil Moisture Accounting (SMA) algorithm) (HEC 2000) has been carried out for a part of the Subarnarekha river basin in Eastern India for proper assessment and management of their water resources.

The Subarnarekha river basin, the smallest of the fourteen major river basins of India, is an inter-state river basin. The Subarnarekha river (length is 450km), having originated in Jharkhand highlands (23˚18´N, 85˚11´E, elevation 740m), drains a sizable portions of the three states of Jharkhand, Orissa and West Bengal and finally debouches into the Bay of Bengal. An optimum management of water resources of this inter-state river basin under changed climatic scenario is of utmost importance in the context of the fact that rapid urbanization, deforestation, mineral exploitation, industrialization and agricultural expansion are taking place all over the basins. It may further be noted that to the best of our knowledge, no work related to calibration and validation of (HEC-HMS - SMA) model has been carried out for the Subarnarekha River basin.

It is also worth mentioning that the HEC-HMS model has been used successfully worldwide by researchers (Beighley and Moglen (2003), Fleming and Neary (2004), Chris McColla and Graeme Aggett (2005), Yusop *et al*. (2007)).

STUDY AREA

The Subarnarekha basin extends over 19,296 km^2, covering 0.6% of geographical area of the country. Average annual rainfall in the basin is 1400 mm. The annual yield of water within the basin constitutes about 0.4% of the country's total surface water resources. The annual utilizable water resources in the basin have been estimated to be 9.66 km^3 (CWC 1988).

The basin is asymmetrical in shape - more than 75% of the total basin area is drained from the right-bank by four major tributaries; Dulung is the major tributary on

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the left-bank. The basin of the river extending from Jamshedpur upto Bhosraghat, measuring 5903 km^2 and lying between the latitudes 22º53´N and 21º58´N and longitudes 86º02´E and 87º16´E forms the study area for the present work (Figure-1).

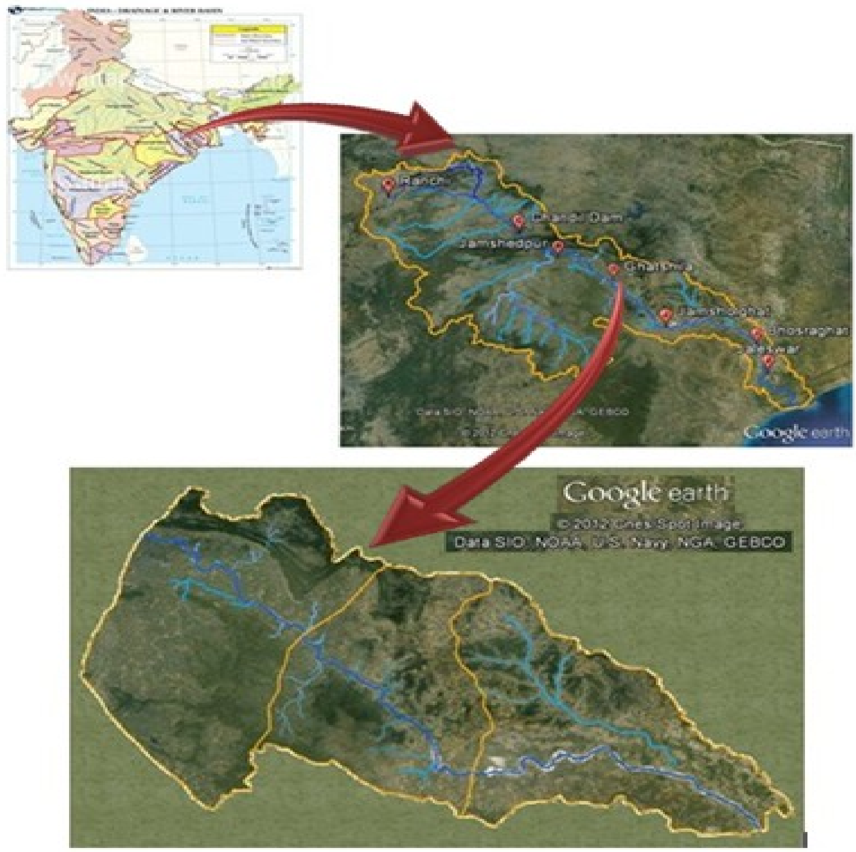

Figure-1. Location map of the study area.

Data acquisition

The Survey of India toposheets (73 J/5, 73 J/6, 73J/10, 73J/11, 73 J/12, 73J/14, 73 J/16, 73 F/15) and 73 E/16 (1:50,000) and 73 E, 73 F and 73J (1: 2,50,000) were obtained from the office of The Survey of India at Kolkata. Gridded (0.5 x 0.5 degree) daily rainfall data and gridded (1 x 1 degree) daily mean temperature data for the study period of 2004-2007 and encompassing the study area were collected from National Data Centre, India Meteorological Department, Pune. Other daily meteorological data such as maximum and minimum air temperature, relative humidity, wind speed and solar radiation for Jamshedpur station for the study period have been collected from India Meteorological Department, GoI, Kolkata and those for Jhargram and Midnapore from Irrigation Division, Midnapore, Irrigation and Waterways, GOWB. The following daily discharge data for 2004-2007 were obtained from Central Water Commission, GoI, Bhubaneswar. i) For full year for Jamshedpur and Ghatsila stations. ii) For the months of July, August, and September and for first ten days of the month of October for the Jamsolaghat station. Cross section data, velocity data and daily gauge data for months of July, August, and September and for first ten days of October for 2004-2006 for the Bhosraghat station were collected from Subarnarekha Barrage Project Office, Irrigation and Waterways, GOWB. Satellite Imagery Data (IRS P6 with LISS III sensor) of January and October, 2009 were collected from National Remote Sensing Center, GoI, Hyderabad. Soil Resource Map was collected from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), GoI, Salt Lake, Kolkata.

METHODOLOGY

HEC-HMS model

The HEC-HMS model is designed to simulate the precipitation - runoff processes of dendritic watershed systems and with soil moisture accounting (SMA) algorithm, it accounts for watershed's soil moisture balance over a long-term period and is suitable for simulating daily, monthly, and seasonal stream flow. The SMA algorithm takes explicit account of all runoff components including direct runoff (surface flow) and indirect runoff (interflow and groundwater flow) (Ponce,

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1989). The model requires inputs of daily rainfall, soil condition and other hydro meteorological data.

The HMS SMA algorithm represents the watershed with five storage layers viz., canopy - interception, surface-depression, soil profile, groundwater storages (1 and 2) as shown in the Figure-2 involving twelve parameters viz., canopy interception storage, surface depression storage, maximum infiltration rate, soil storage, tension zone storage and soil zone percolation rate and groundwater 1 and 2 storage depths, storage coefficients and percolation rates. Rates of inflow to, outflow from and capacities of the layers control the volume of water lost from or gained by each of these storage layers. Current storage contents are calculated during the simulation and vary continuously both during and between storms. Besides precipitation the only other input to the SMA algorithm is the potential evapotranspiration rate (HEC 2000).

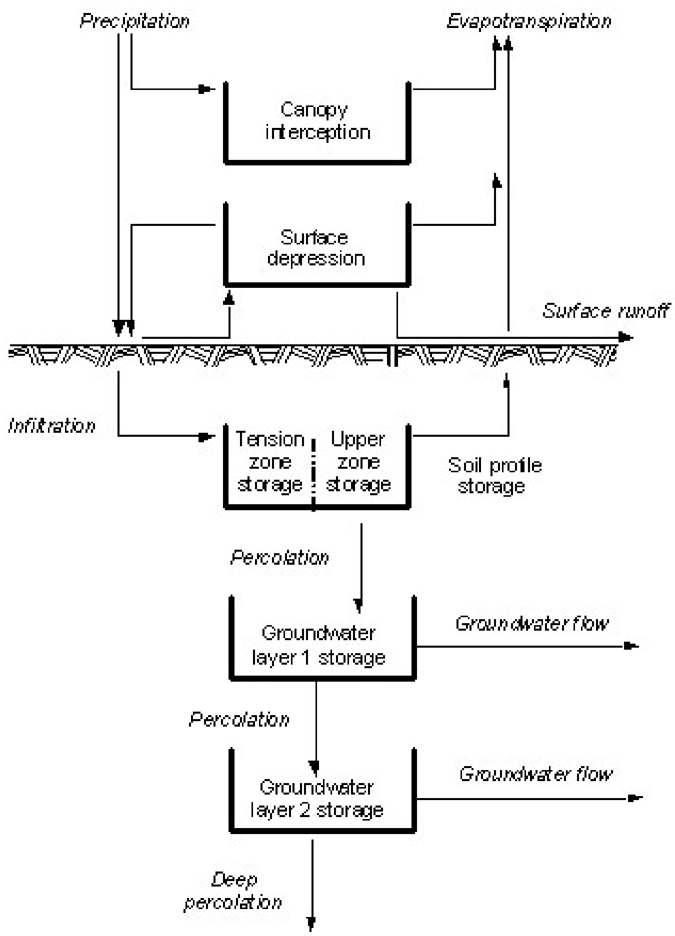

Figure-2. Schematic of soil moisture accounting algorithm (HEC 2000).

For the present study, runoff depth was computed using SMA method. Clark unit hydrograph technique with the peak and time to peak computed by Snyder's unit hydrograph method was adopted to compute stream flow hydrograph. Linear reservoir method was used to model base flow. Muskingum method of channel routing was used to generate discharge hydrograph at downstream point in channel.

Processing of meteorological data

The work involved delineation of boundary of the river basin, using elevation contours extracted from Survey of India toposheets and Goggle Earth Google 6.1.0.5001 information system (Figure-1). The study basin was divided into three subbasins (hereafter referred as, S-G, S-J and S-B) in order to account for spatial variability of precipitation and runoff response characteristics. The sub basins are gauged at their outlets (the gauging stations being Ghatsila, Jamsolaghat and Bosraghat), thus allowing model calibration and validation at interior nodes within the basin. The Thiessen-polygon method has been used to determine the daily mean rainfall and mean temperature over each sub basin using the gridded data and Penman's method has been used to calculate the potential evapotranspiration for the basin.

Estimation of parameters of the model

The parameters needed for the SMA method (canopy interception storage, surface depression storage, maximum infiltration rate, soil storage, tension zone storage and soil zone percolation rate) were estimated using land use, land cover and soil information. Satellite imageries of the basin were used to classify each sub basin into four land use and land cover classes (water body, agricultural land, grass land and forest) using Geomatica Free view 10.3 software for January and October - the data for the month of January was used for carrying out simulation study for non monsoon period while that for the month of October was used for simulation study during monsoon for the basin.

The NBSS & LUP soil database groups and maps soils that have similar properties, giving the group specific map unit names. The soil texture class extracted from the aforementioned information was used as the identifier of a soil's physical properties, such as porosity and field capacity for estimation of soil parameters of the SMA model. Groundwater 1 and 2 (hereafter referred as GW1 and GW2) storage depths and storage coefficients were estimated by stream flow recession analysis of historic stream flow observations. The soil percolation rate was based on the hydraulic conductivity of the soil profile. The groundwater 1 and 2 percolation rates were determined through model calibration.

The standard lag parameter for the Snyder Unit hydrograph technique was estimated from extracted information on basin and drainage network. The UH peaking coefficient parameter c_t was found via calibration. The storage coefficient as required by Clark's method was estimated via calibration. The storage coefficient for the GW1 and GW2 in the Linear Reservoir method (for base flow computation) was taken to be those used for calibrated SMA model. The storage-time constant K and coefficient X for Muskingum method of channel routing were estimated from observed inflow and outflow hydrographs.

A semi - annual parametrization approach considering seasonal land use pattern was adopted and thus a semiannual model was developed for the S-G subbasin only. The semi - annual model divided the year into two simulation periods where one parameter set was established for the first six months of the year and another parameter set for the last six months of the year. However, the S-J and S-B basins were modeled for the wet months.

Model evaluation

The model evaluation procedure included sensitivity analysis, calibration and validation. The sensitivity analysis of the model was performed to determine the important parameters which needed to be precisely estimated to make accurate prediction of basin yield. Thus, at first the model was run with the model input values (the base data file), estimated by methods presented above and base output was collected. This was followed by varying each input parameter within prescribed range keeping the others constant and running the model. The output values were analyzed to determine their variations with respect to the base output set and this is a measure of the sensitivity. The model was calibrated for the identified sensitive parameters to improve the agreement between the simulated and observed data. Again, the automated calibration procedure in HEC-HMS uses an iterative method to minimize an objective function, such as sum of the absolute residuals, sum of the squared residuals, peak-weighted root mean square error etc. (HEC 2000). Thus, both manual and automated calibration methods were used for this study. The criteria for model evaluation adopted for this study involves the following:

- Percentage error in simulated volume (PEV)
- Percentage error in simulated peak (PEP), and
- Net difference of observed and simulated time to peak (NDTP), as given below

$$PEV = \frac{(Vol_o - Vol_c)}{Vol_o} \times 100 \tag{1}$$

$$PEP = \frac{(Q_{po} - Q_{pc})}{Q_{po}} \times 100 \tag{2}$$

$$NDTP = \frac{(T_{po} - T_{pc})}{T_{po}} \times 100 \tag{3}$$

Vol_o is the observed runoff volume (m^3); Vol_c is the computed runoff volume (m^3); Q_{po} is the observed peak discharge (m^3/s); Q_{pc} is the computed peak discharge (m^3/s); T_{po} is the time to peak of observed discharge (h); and T_{pc} is the time to peak of computed discharge (h).

The PEV value measures the deviation between the simulated and the observed volume of stream flow. The NDTP and the PEP values measure the average absolute time lag and the percent deviation between the simulated and observed peak flows, respectively. The prediction of overall performance of the model was assessed using Nash - Sutcliffe model efficiency (EFF) criterion (Nash and Sutcliffe, 1970), recommended by ASCE Task Committee (1993) where Q_{oi} is ith ordinate of the observed discharge (m^3/s); $\overline{Q_o}$ is the mean of the ordinates of observed discharge (m^3/s); Q_{ci} is ith ordinate of the computed discharge (m^3/s).

$$EFF = \frac{\sum_{i=1}^{n}(Q_{oi} - \overline{Q}_o)^2 - \sum_{i=1}^{n}(Q_{oi} - Q_{ci})^2}{\sum_{i=1}^{n}(Q_{oi} - \overline{Q}_o)^2} \tag{4}$$

The EFF values can vary from 0 to 1, with 1 indicating a perfect fit of the data. According to common practice, simulation results are considered to be good for values of EFF greater than or equal to 0.75, while for values of EFF between 0.75 and 0.36 the simulation

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results are considered to be satisfactory (Motovilov *et al*., 1999).

RESULTS AND DISCUSSIONS

Sensitivity analysis

Soil storage was found to be the most sensitive parameter for the simulated stream flow for all the three sub basins followed by tension zone storage for sub basin S-G and sub basin S-B. Additionally, land imperviousness and soil percolation also caused the most variation in simulated stream flow for sub basin S-J. Parameters viz., soil storage, land imperviousness, soil percolation were found to be sensitive for sub basin S-G during non-monsoon; GW1 coefficient was found to be sensitive for sub basin S-G during both non-monsoon and monsoon. Thus, in the present study the model was calibrated for the three sub basins for respective identified parameters.

It may be noted that soil storage was identified to be a sensitive parameter by Fleming and Neary (2004) (for Dale Hollow watershed located within the Cumberland River basin in USA), Bashar and Zaki (for the catchment of main stream of the Blue Nile at the border between Sudan and Ethiopia) and Ayka, A. (2008) (for Kulfo and Bilate catchments in Abaya-Chamo sub-basin, the sub-basin of the Rift valley lakes in Ethiopia). Additionally, tension zone storage was found to be the sensitive parameters by Fleming and Neary (2004); soil percolation rate and groundwater components were found to be the sensitive parameters by Ayka, A. (2008) and Bashar and Zaki.

Calibration analysis

The model was calibrated for the S-G sub basin for the full year of 2004 and 2007; However due to non-availability of data, the model was calibrated for wet months only (as stated earlier) of 2004 and 2007 for sub basin S-J and for wet months of 2004 only for sub basin S-B. The data sets for 2004 and 2007 were chosen for calibration because the weather conditions in these years were less extreme than in other years. The Groundwater 1 and 2 storage depths and storage coefficients, as obtained from stream flow recession analysis (Table-1) for the three sub basins, were found to depict wide variation.

Table-1. GW1, GW2 storage coefficient and storage depth values for different sub basins.

Sub-basin	Time	GW1		GW2	
		Coefficient (hr)	**Storage** (mm)	**Coefficient** (hr)	**Storage** (mm)
Ghatsila	June 2004	141.2	13.9	266.7	8.3
	Aug 2004	32.9	204.8	85.7	88.7
	Sept 2004	200	189.9	266.7	170.8
	Oct 2004	68.6	106.8	400	172.1
	July 2005	48	40.9	200	34.3
	June 2006	96	172	343	315.5
	Sept 2008	77.4	121	300	167.7
Jamsholaghat	June 2004	80	12	120	26.8
	June 2005	120	55	380	153
	Oct 2005	144	43	270	108
	June 2007	160	247	310	369
	Sept 2007	110	26	202	57
Bhosraghat	Aug 2004	102	16.5	138	22
	Sept 2004	98	8.9	152	18.3
	July 2005	78	6.7	120	12.4
	June 2006	119	22	196	37
	Oct 2007	126	9.6	208	17.4
	Sep 2007	112	14	238	25.2

An initial estimate of GW1 and GW2 were made from among those stated above on the basis of the value which yielded closest agreement between estimated and observed stream flow. This was further calibrated to have a final estimate of the parameters.

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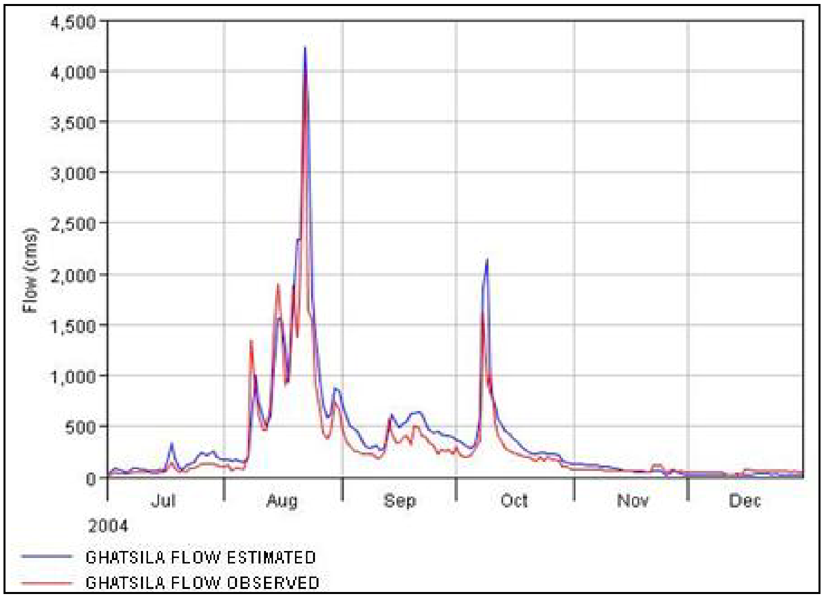

Figure-3(a). Observed and calibrated hydrographs for 2004 (S-G).

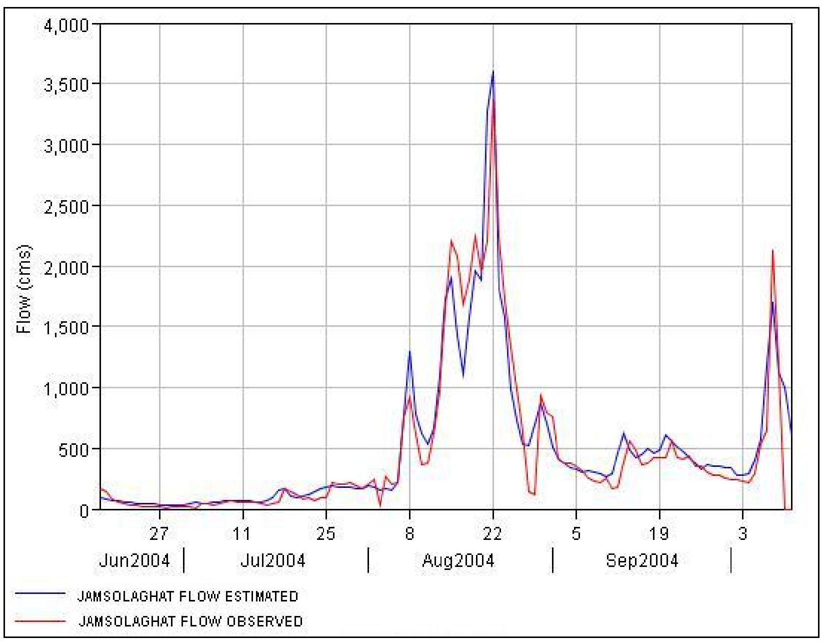

Figure-3(b). Observed and calibrated hydrographs for 2004 (S-J).

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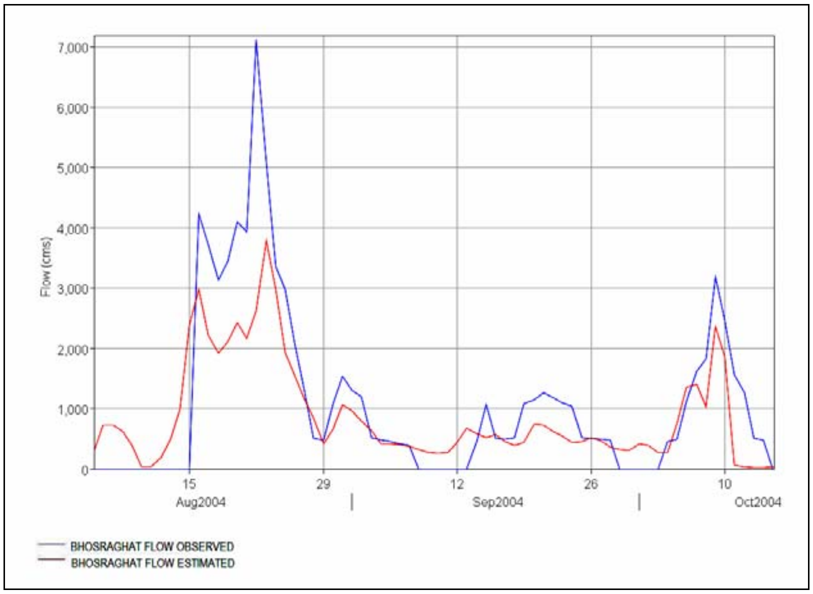

Figure-3(c). Observed and calibrated hydrographs for 2004 (S-B).

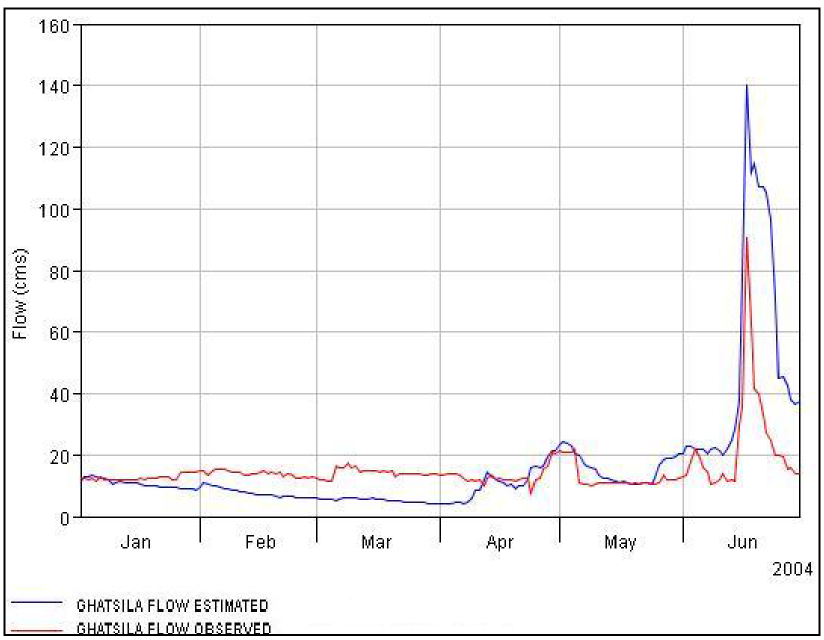

Figure-3(d). Observed and calibrated hydrographs for 2004 non-monsoon (S-G).

Figures 3(a), 3(b), 3(c) and 3(d) show a time-series comparison of simulated and observed stream flows for the sub basins for the calibration period of 2004. The peak values of the simulated flow match well with the peak values of measured flow. However, the model slightly over-predicts the peak flows for S-G and S-J sub basins and under-predicts peak values of flow for S-B sub basin. The performance measures of the model for the calibration years for the sub basins are shown in the Table-2.

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Table-2. Performance measures of the model for the calibration years for the sub basins.

Sub basin	Performance measures	Calibration 2004			Calibration 2007		
Ghatsila	PEV	-26.14			-2.46		
	PEP	-5	17	-12	-0.95	28	0.45
	NDTP	0 day	1 day	0 day	0 day	1 day	0 day
	EFF	0.78			0.91		
	R^2	0.86			0.90		
Jamsolaghat	PEV	- 15.6			- 8		
	PEP	4.6	- 7	19	- 13.9	9.5	21.9
	NDTP	0 day	0 day	0 day	0 day	0 day	0 day
	EFF	0.87			0.77		
	R^2	0.88			0.83		
Bhosraghat	PEV	-1.22			Not Applicable		
	PEP	29.16	46.8	22.76			
	NDTP	0 day	0 day	0 day			
	EFF	0.74					
	R^2	0.7					
Ghatsila (Non-Monsoon)	PEV	- 11.5			- 14.9		
	PEP	- 49	+ 9.9	+ 13.6	+ 11.15		
	NDTP	0	1	0	0 day		
	EFF	0.73			0.81		

It is seen from Table-2 that PEV values vary between (1.22 and 15.6%) for all the sub basins. The PEP values vary between (0.45 to 22%) for sub basins S-G and S-J. The NDTP values have always been found to be 0 for all the sub basins excepting for the second highest peak for the S-G sub basin. It may also be noted that the PEV value of 26.14% for S-G sub basin for 2004 and PEP value of 28% for the second highest peak for S-G sub basin for 2007 have been found to be slightly higher than the acceptable levels of accuracy (±20%) for hydrologic simulations (Bingner *et al*. 1989). The high value of the Nash-Sutcliffe model efficiency (EFF) (between 0. 74 and 0.91) for all the sub basins indicate close agreement between observed and simulated runoff. It may further be noted that PEV, PEP and NDTP values for S-G sub basin during non-monsoon part of calibration years lie within the range stated above, however the Nash-Sutcliffe model efficiency (EFF) values of 0.73 and 0.81 were found to be slightly low for the calibration years of 2004 and 2007. Figure-3(c) for sub basin S-B shows the difficulty in simulation of peak flows, specially the largest one.

In order to ascertain whether the inadequacy of the SMA algorithm resulted in underestimation of peak flows, specially the largest one (Table-2) for sub basin S-B, the sub basin response was simulated with all rainfall converted into direct runoff (i.e., assuming basin loss to be zero). Though the PEP values were reduced from 46.81% to 32.21%, for 2004 the observed peaks could not be properly simulated. This nullifies the SMA algorithm to be the source of uncertainty. The possible source of discrepancy may be in estimating discharge from the measured cross sectional area and flow velocity when used for extreme flood events. The observed and simulated daily stream flow for 2004 along with 1:1 line are shown in Figures 4(a), 4(b), 4(c) and 4(d).

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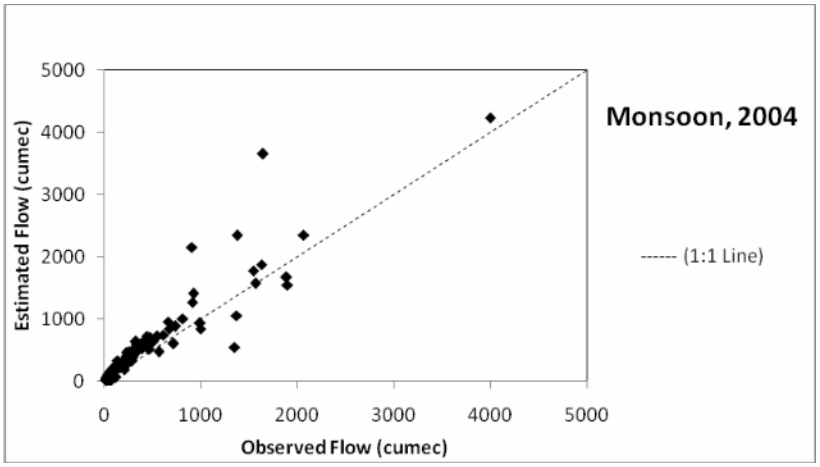

Figure- 4(a). Comparison between the observed and simulated stream flow for the year 2004 (S-G).

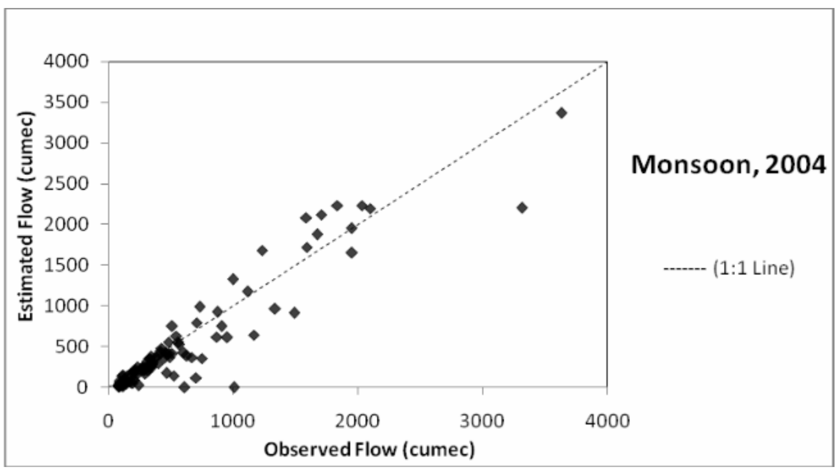

Figure-4(b). Comparison between the observed and simulated stream flow for the year 2004 (S-J).

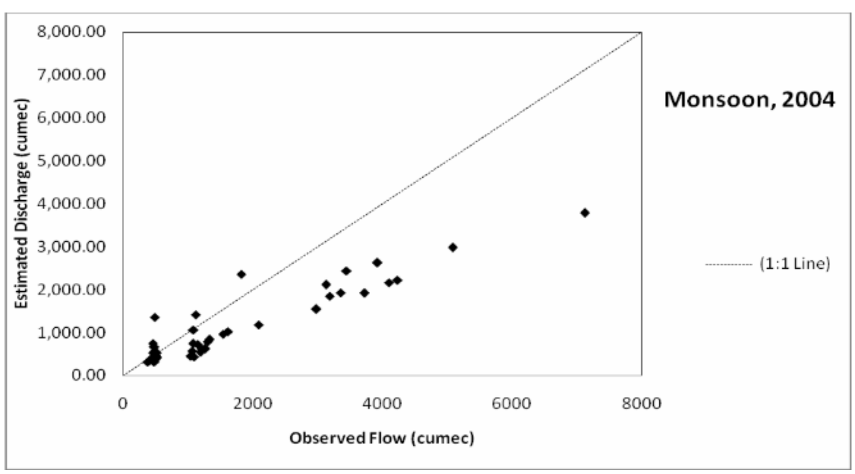

Figure-4(c). Comparison between the observed and simulated stream flow for the year 2004 (S-B).

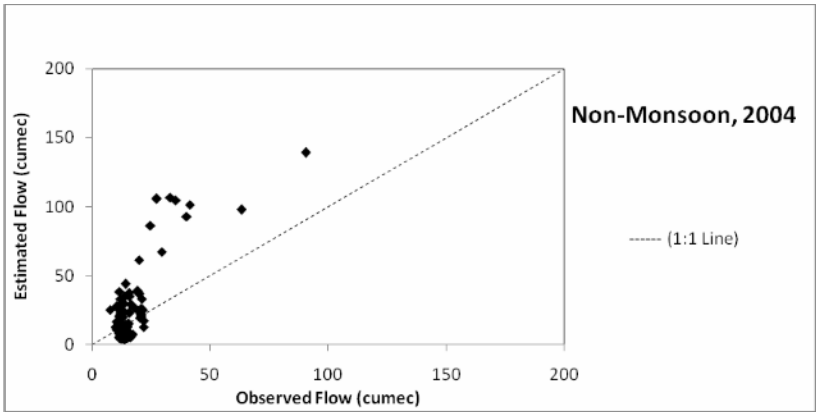

Figure-4(d). Comparison between the observed and simulated stream flow for the year 2004 Non-Monsoon (S-G).

It is observed from the figures that the simulated stream flow values are either lying on 1:1 line or are distributed uniformly about the 1:1 line for lower values of observed stream flow for all the sub basins. The simulated values are distributed uniformly about the 1:1 line also for higher values of observed stream flow. Higher values of the coefficient of determination (range being 0.83 to 0.91) for the sub basins indicate a close relationship between the observed and simulated stream flow (Table-2). Thus the results indicate that overall estimation of stream flow by the model during the calibration period is satisfactory and therefore may be accepted for further analysis. Sub-watershed wise input soil parameters used in the model are presented in Table-3.

Table-3. Input soil parameters used in the model for sub basins.

Season	SMA parameter	Sub Basins		
		Ghatsila	Jamsolaghat	Bhosraghat
Monsoon	Canopy storage (mm)	3.2	2.3	3.2
	Surface storage (mm)	12.7	12.8	12.7
	Max rate of infiltration (mm/hr)	2.0	6.3	4.5
	Impervious (%)	2.7	7.4	4.2
	Soil storage (mm)	384.9	417.4	388.8
	Tension storage (mm)	140.8	106.5	135.9
	Soil percolation (mm/hr)	0.3	0.4	0.2
	Groundwater 1 storage (mm)	121	26	9.6
	Groundwater 1 percolation (mm/hr)	0.3	0.3	0.2
	Groundwater 1 coefficient (hr)	77.4	110	126
	Groundwater 2 storage (mm)	176	57	17.4
	Groundwater 2 percolation (mm/hr)	0.3	0.2	0.2
	Groundwater 2 coefficient (hr)	300	202	208

Model validation

The calibrated model was then used to estimate daily stream flow from the sub basins for the years 2005 and 2006 using semiannual model for S-G sub basin and for wet months for other two sub basins. The observed and simulated hydrographs for sub basins for 2005 have been shown in Figures 5(a), 5(b), 5(c) and 5(d). The model over-predicts the peak flows for all the sub basins. The performance measures for the sub basins are shown in the Table-4.

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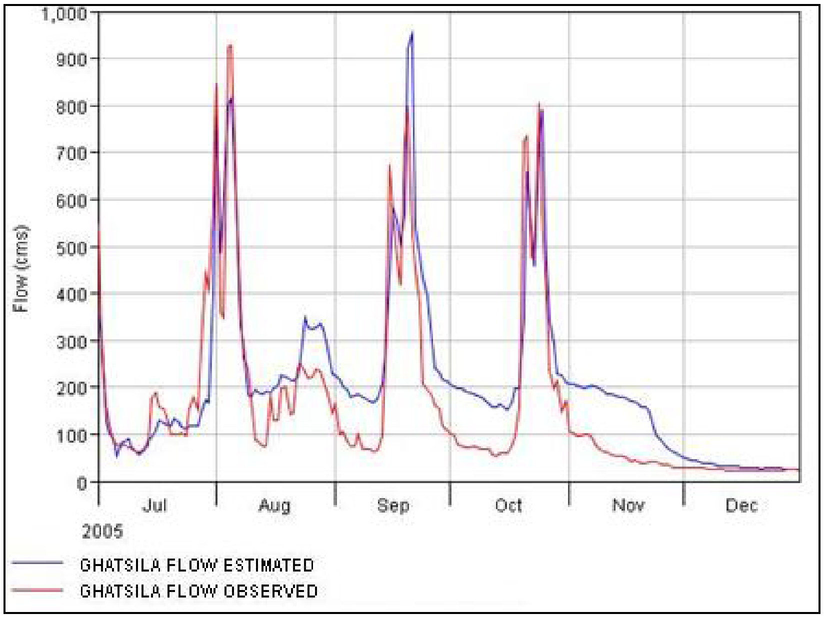

Figure-5(a). Observed and calibrated hydrographs for 2005 (S-G).

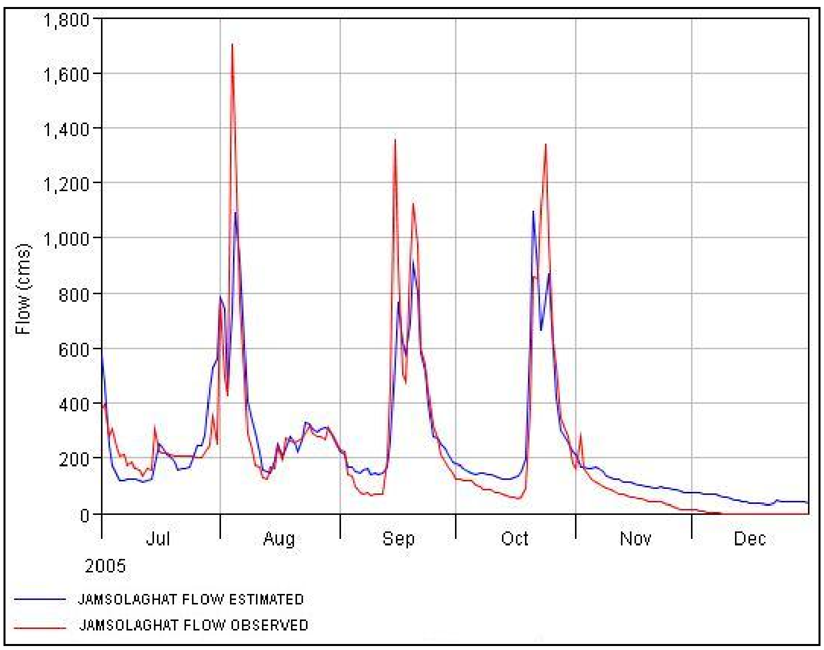

Figure-5(b). Observed and calibrated hydrographs for 2005 (S-J).

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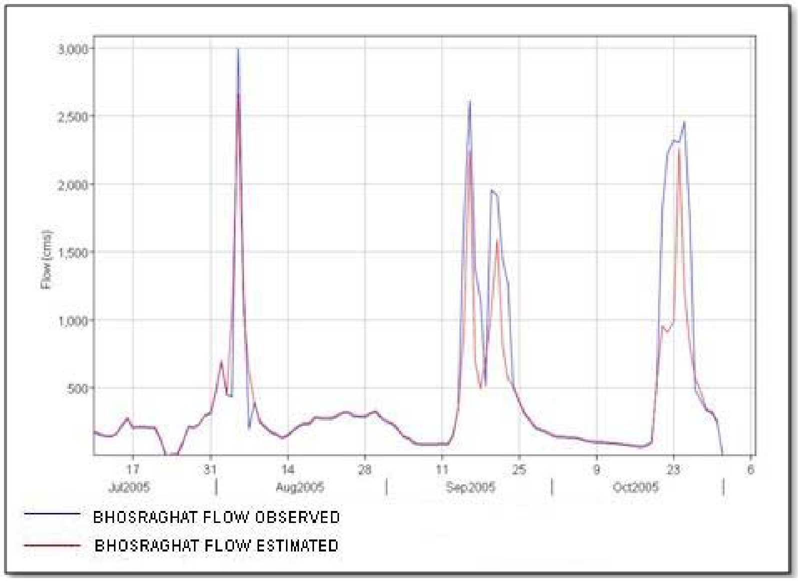

Figure-5(c). Observed and calibrated hydrographs for 2005 (S-B).

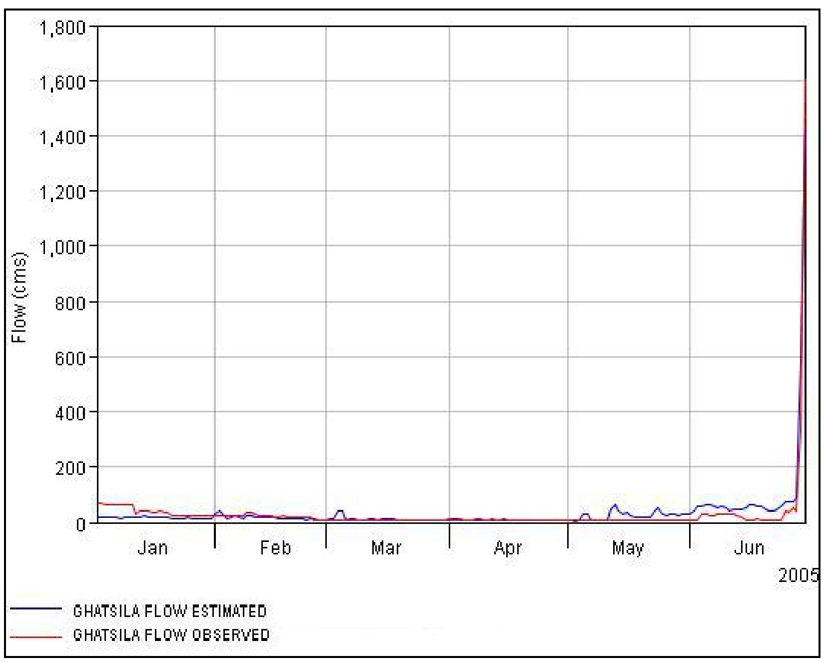

Figure-5(d). Observed and calibrated hydrographs for 2005 non-monsoon (S-G).

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Table-4. Performance measures of the model for the validation years for the sub basins.

Sub basin	Performance measures	Validation 2005			Validation 2006		
Ghatsila	PEV	-12.2			-8.55		
	PEP	12	-19	-1.99	-51	4.7	-3.98
	NDTP	0 day	1 day	1 day	1 day	0 day	1 day
	EFF	0.77			0.72		
	R^2	0.78			0.63		
Jamsolaghat	PEV	- 5.9			- 5.6		
	PEP	35	43	19	- 27		
	NDTP	1 day	1 day	0 day	0 day		
	EFF	0.79			0.81		
	R^2	0.78			0.85		
Bhosraghat	PEV	- 4.39			Not applicable		
	PEP	10.21	11.34	4.72			
	NDTP	0 day	0 day	0 day			
	EFF	0.84					
	R^2	0.67					
Ghatsila (non-monsoon)	PEV	- 13.8			- 7		
	PEP	10			- 36.35		
	NDTP	0			0		
	EFF	0.91			0.68		

It is observed from Table-4 that PEV, PEP and NDTP values vary from (4.39 to 19.47%), (1.9 to 19%) and (0 to 1day), respectively; the PEP values of 27% and 35% for sub basins for S-J for validation years are close to acceptable levels (±20 %) of accuracy for simulations models. However, a high PEP value of 51% was noted for the sub basin S-G for 2006. The reasonably high (0.72-0.84) values of the Nash-Sutcliffe model efficiency (EFF) for the sub basins show satisfactory performance of the model. The scatter diagrams for comparison of the simulated stream flow with the measured stream flow for 2005 along with 1:1 line are presented in Figures 6(a), 6(b), 6(c) and 6(d).

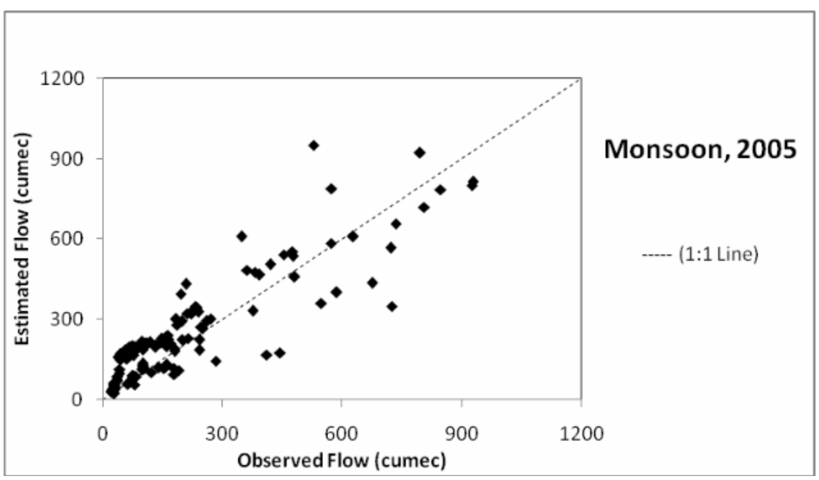

Figure-6(a). Comparison between the observed and simulated stream flow for the year 2005 (S-G).

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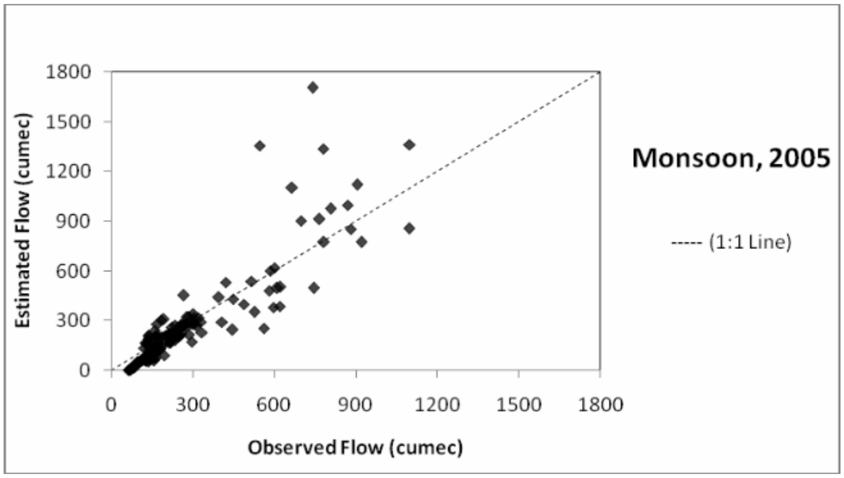

Figure-6(b). Comparison between the observed and simulated stream flow for the year 2005 (S-J).

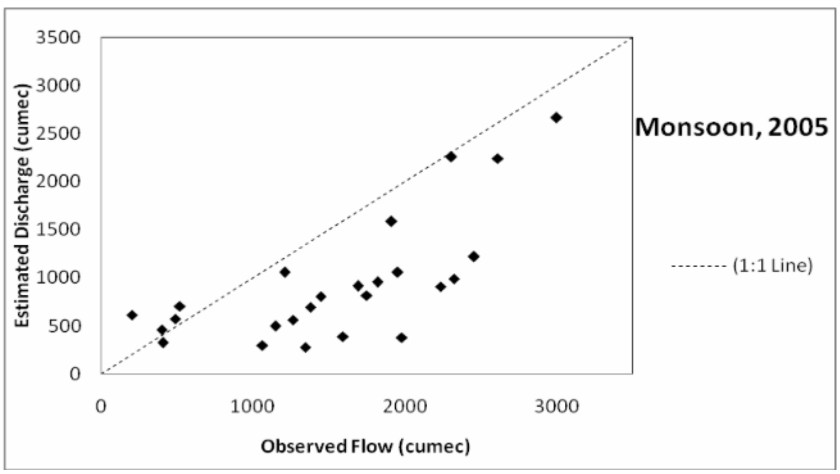

Figure-6(c). Comparison between the observed and simulated stream flow for the year 2005 (S-B).

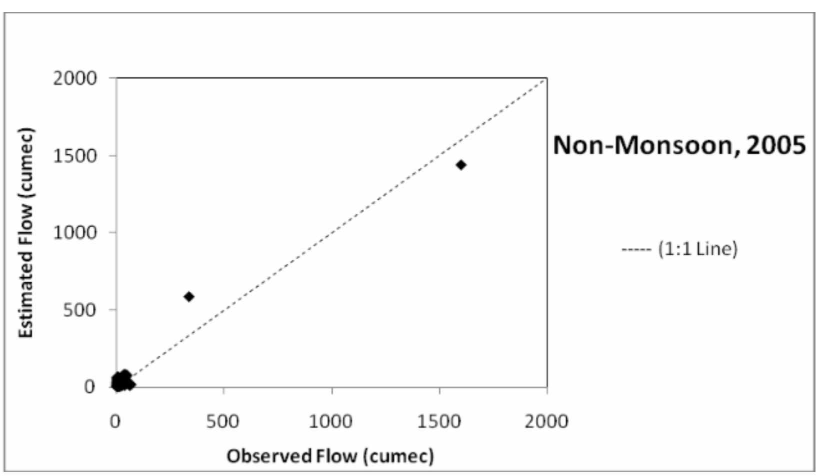

Figure-6(d). Comparison between the observed and simulated stream flow for the year 2005 (S-G).

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It is seen from the figures that the points are almost evenly distributed about the 1:1 line for the two validation years, for sub basins of S-G and S-J excepting for high discharge values (located above the 1:1 line) for the validation year of 2005 for S-J. The values of the coefficient of determination (range being 0.78 to 0.85) for the sub basins S-G and S-J indicate a close relationship between the observed and simulated stream flow (Table-4). However, the values of the coefficient of determination were found to be slightly low (0.63) for 2006 for sub basin SG and (0.70) for 2005 for S-B and indicate a satisfactory performance. Thus, the results indicate that the model could predict the stream flow for the study basin with marginal deviation as discussed above for the study years. Figures 7(a) and 7(b) show a time series comparison between the simulated stream flows from semiannual and annual models and the observed stream flows for 2005 and 2006 for the S-G sub basin. In contrast to the plots for the semiannual model, these plots indicate that the annual model, which was calibrated for wet conditions, over predicted stream flows.

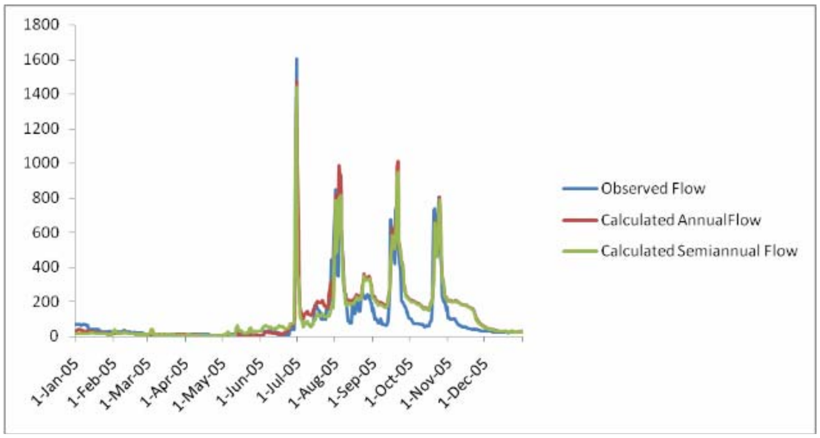

Figure-7(a). Observed and calibrated hydrographs for 2005 (S-G).

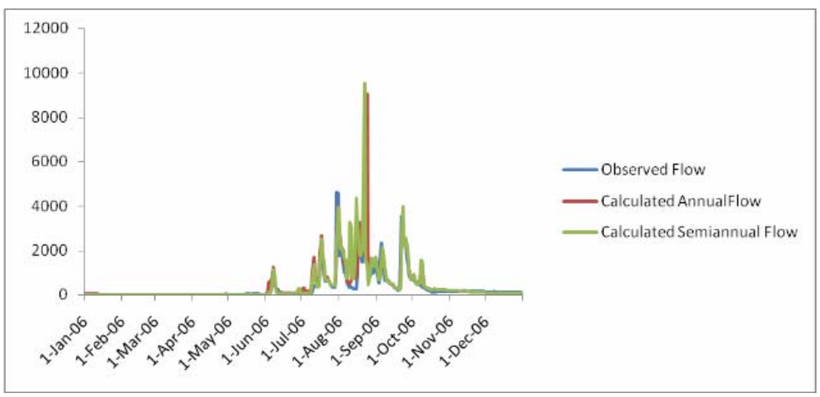

Figure-7(b). Observed and calibrated hydrographs for 2006 (S-G).

Table-5 lists the performance measures calculated for S-G sub basin during the validation years. It is seen from the Table that the semiannual model produces the best results for 2005 and 2006. These results illustrate that using models calibrated for both wet and dry hydrologic conditions, as opposed to only one hydrologic condition, reduces the errors caused by the model structure.

Table-5. Non-monsoonal performance measures for S-G sub basin using monsoonal model input.

Performance measures	2004	2007	2005	2006
PEV	- 28.44	- 16.80	- 16.99	- 31.30
PEP	- 52.76	- 20.17	- 7.90	- 50.33
NDTP	0 (day)	0 (day)	0 (day)	0 (day)
EFF	0.86	0.87	0.89	0.44

It may be noted that in course of their study in the Dale Hollow watershed (located within the Cumberland River basin, USA) Fleming and Neary (2004) concluded that the use of seasonal parameterization approach improves model performance. These results also show that two different parameter sets that account for changing hydrologic conditions produce simulation results that are more accurate than a single parameter set applied to an entire year.

CONCLUSIONS

The HEC-HMS catchment simulation model (with soil moisture accounting algorithm -- SMA) has been calibrated and validated for Subarnarekha river basin, extending from Ghatsila upto Bhosraghat, in Eastern India for prediction of its hydrologic response.

The analysis shows that the soil storage, tension zone storage and groundwater 1 storage coefficient to be the sensitive parameter for the simulation of stream flow. The Nash-Sutcliffe model efficiency (EFF), percentage error in volume, the percentage error in peak, and net difference of observed and simulated time to peak which were used for performance evaluation, have been found to range from (0.72 to 0.84), (4.39 to 19.47%), (1.9 to 19%) and (0 to 1day), respectively, indicating a good performance of the model for simulation of stream flow. The high coefficient of determination (0.70 to 0.85) indicates a positive relationship between the measured and simulated stream flow for validation years of study.

The results also show that two different parameter sets that account for changing hydrologic conditions produce simulation results that are more accurate than a single parameter set applied to an entire year.

Thus the study shows that the calibrated model performs well in simulating stream flow and the model may be applied to other watersheds in the Subarnarekha river basin and other hydro meteorologically similar river basins.

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