International Conference on Sustainability and management strategy (ICSMS-2014), Institute of Management and Technology, Nagpur, March 21-22, 2014.

RAINFALL RUNOFF MODELING USING CONCEPTUAL NAM MODEL

R.V. Galkate* R.K. Jaiswal, T.Thomas, T.R. Nayak

1. *R.V. Galkate, Scientist-D, National Institute of Hydrology, Regional Center, WALMI Campus, Bhopal - 462016, M.P., India, Email: rgalkate@yahoo.co.in*
2. *R.K. Jaiswal, Scientist-C, National Institute of Hydrology, Regional Center, WALMI Campus, Bhopal - 462016, M.P., India, Email: rkjaiswal_sagar@yahoo.co.in*
3. *T.Thomas, Scientist-C, National Institute of Hydrology, Regional Center, WALMI Campus, Bhopal - 462016, M.P., India, Email: thomas_nih@yahoo.com*
4. *T.R. Nayak, Scientist-D, National Institute of Hydrology, Regional Center, WALMI Campus, Bhopal - 462016, M.P., India, Email: tejramn@yahoo.com*

* *Corresponding Author*

Abstract

This paper describes the application of NAM (Nedbor Afstromnings Model), to investigate its performance, efficiency and suitability in Bina river basin of Madhya Pradesh. NAM is a deterministic, lumped and conceptual rainfall-runoff model. The model was developed, calibrated and validated using flow data at Rahatgarh site on Bina river. The model was found suitable for Bina basin in simulating hydrological response of the basin to the rainfall and predicting daily runoff with high degree of accuracy. The coefficient of determinations for the model calibration and validation were 0.796 and 0.609 respectively indicating good agreement between the observed and simulated runoff in terms of timing, rate and volume and shape of hydrograph. The model was evaluated based on Nash–Sutcliffe Efficiency Index (EI) and Sum of Square of Error (SSE). The model was found efficient with Efficiency Index 81% and found capable of predicting runoff for extended time period in Bina basin. The sensitivity analysis of the model was carried out to identify the most sensitive model parameters. Effects of the model parameters on simulated peak and low flows were analysed. Coefficient of Overland flow (C_{QOF}) was the only model parameter showing significant effects on peak and low flows both.

Key Words: Rainfall runoff modeling, MIKE11 NAM, Efficiency Index, Sensitivity analysis, Bina basin

1 Introduction

Hydrological modeling is simplified description of hydrological cycle to imitate the natural system. A rainfall-runoff model is a mathematical representation describing the rainfall-runoff relations of a catchment area, drainage basin or watershed. More precisely, it produces the surface runoff hydrograph as a response to a rainfall as input. Rainfall-runoff models are classified as deterministic, stochastic, conceptual, theoretical, black box, continuous, event, complete, routing or simplified (Linsley, 1982). Hydrologic models especially simple rainfall-runoff models are widely used in understanding and quantifying the impacts of land use changes and to provide information that can be used in land-use decision making. Many hydrologic models are available; varying in nature, complexity and purpose (Shoemaker et al., 1997). The widely known rainfall-runoff models identified are the rational method (Mcpherson, 1969), Soil Conservation Services (SCS) Curve Number method (Maidment, 1993), and Green-Ampt method (Green and Ampt, 1911).

The hydrologic response of catchment to rainfall, estimates of catchment yield, and runoff data are of vital importance for hydrological analysis for the purpose of water resources planning, flood forecasting, pollution control and many other applications (Shamsudin and Hashim 2002). Most of river catchments in India are ungauged and generally the limited discharge data are available with the concern state and central agencies. Under such circumstances rainfall-runoff model can be developed to simulate the natural hydrological processes to estimate the runoff from the catchment. Water resources development and management in the river basin can be planned by making use of appropriate hydrological model. The rainfall-runoff process is a complex activity as it is influenced by a number of implicit and explicit factors such as precipitation distribution, evaporation, transpiration, abstraction, topography and soil types. Many researchers conducted number of rainfall runoff modeling studies using different models and techniques. Nash (1958) considered watershed as a series of identical reservoirs and prepared a conceptual rainfall runoff models by routing a unit inflow through the reservoirs. Kumbhare and Rastogi (1984) tested the Nash conceptual model (1958) and found that runoff was generated in good agreement with actual runoff hydrograph. Pathak et al. (1984) developed a model to predict runoff volume from small watershed to simulate daily monthly and annual runoff volume quite accurately. Kumar and Rastogi (1989) developed a mathematical model of the instantaneous unit hydrograph based on time area histogram for a small watershed at Pantnagar. Mishra and Singh (1998) and Mishra (2000) have worked on SCS Curve Number method.

In present paper, the rainfall-runoff model has been developed in Bina river basin at Rahatgarh gauge-discharge (G/d) site using MIKE11 NAM model. It is deterministic, lumped and conceptual rainfall-runoff model that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow and base flow. The area under Bina river basin is characterized by water scarcity due to frequent drought and over exploitation of the available water resources. However, the domestic, irrigation and industrial water demands in Bina basin are increasing rapidly due to fast industrialization and urbanization in that area. Thus there is an urgent need to plan and develop water resources to meet the growing water demands in the basin.

2 Study Area

Bina river is an important tributary of Betwa river and traverses though Sagar, Vidisha and Raisen districts of Madhya Pradesh. The sub-basin area up to the Rahatgarh G/d site located at the latitude of $23^{0}47^{'}57^{''}$ N and longitude of $78^{0}23^{'}50^{''}$ E has been selected to develop the rainfall runoff model. Total catchment area of Bina river up to Rahatgarh G/d site is 1180 Km^2 having average annual rainfall 1196 mm. The Index map of Bina basin up to Rahatgarh G/d site is shown in Figure 1. The topography in the basin is generally observed rolling and undulating. The major part of the area is covered by black cotton soil. However clay loam soil and sandy clay loam soil falls in the southern and northern part of study area. The important rocks found in the area are sand stone, Quartzite sand stone, Lime stone and Basalt. The main types of land use and land cover are agriculture, forests, settlements, barren land, etc. and main crops grown in the Kharif season is soybean and in Rabi season is wheat. The mean minimum and mean maximum temperature (May and June) of the region is 11.5^{0}C and 40.7^{0}C respectively. At present, the domestic water demands of Rahatgarh, Khurai and Bina towns; Bina Railway Junction and industrial water demands of Bina Refinery and JP Power Project are being met from the Bina river. Beside that a major irrigation scheme has been proposed on Bina river, thus the limited water availability and large demands will create a wide gap demanding augmentation of water resources development in the basin.

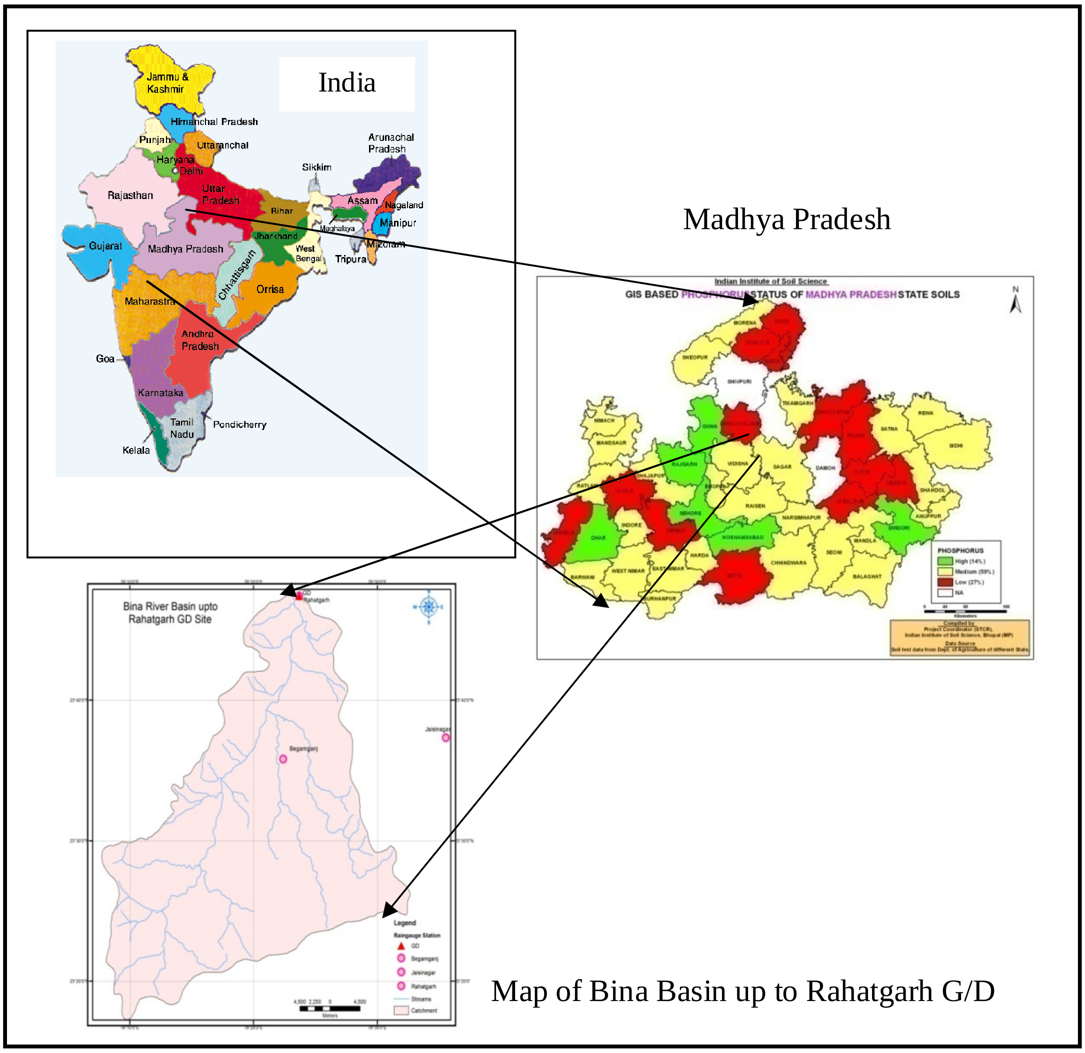

Figure 1: Index Map of Bina River Basin up to Rahatgarh Gauge Discharge (G/D) Site

3 Methodology

3.1 MIKE11 NAM Model

MIKE11 NAM is a rainfall-runoff model that is part of the MIKE 11 module developed by Danish Hydraulic Institute (DHI), Denmark. MIKE 11 software is meant for simulation of flows, water quality and sediment transport in river, irrigation systems, channels and other water bodies. The NAM (Nedbor Afstromnings Model) is deterministic, lumped and conceptual rainfall-runoff model that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow and base flow (DHI 2003). The physical processes involved for runoff simulation in the model are shown in Figure 2. It treats each sub-catchment as one unit, therefore the parameters and variables are considered for representing average values for the entire sub-catchments. The result is a continuous time series of the runoff from the catchment throughout the modeling period. Thus, the MIKE11 NAM model provides both peak and base flow conditions that accounts for antecedent soil moisture conditions over the modelled time period. The NAM model has been applied to a number of catchments around the world, representing many different hydrological regimes and climatic conditions. Fleming (1975); Kjelstrom and Moffat (1981); Kjelstrom (1998), Arcelus (2001), Shamsudin and Hashim (2002) and many other researchers carried out rainfall runoff modeling using MIKE 11 NAM model.

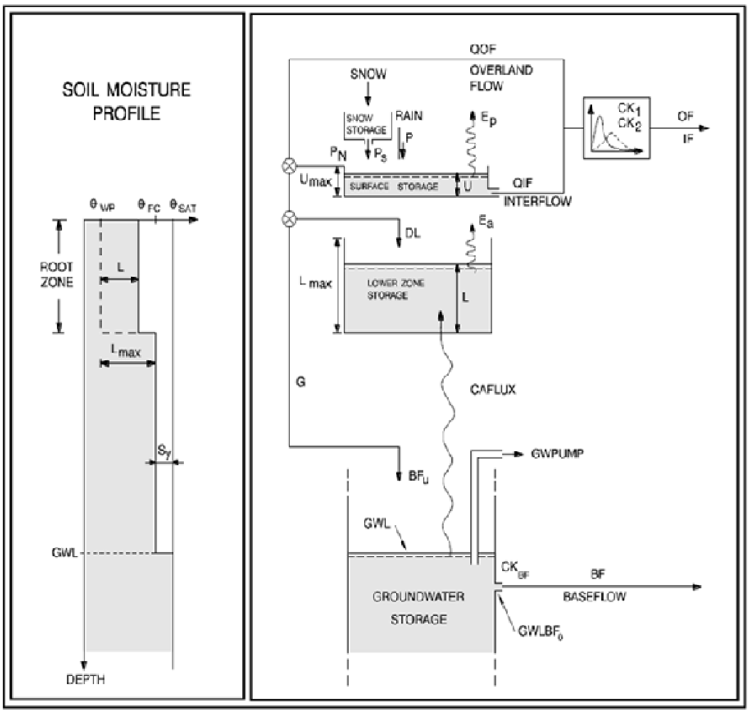

Figure 2: Processes of NAM Model

NAM is prepared with 9 parameters, representing surface zone, root zone and ground water storage. U_{max} denotes the upper limit of the amount of water in the surface storage. The soil moisture in the root zone, a soil layer below the surface from which the vegetation can draw water for transpiration, is represented as lower zone storage, *L*. L_{max} denotes the upper limit of the amount of water in this storage. Evapotranspiration demands are first met at the potential rate from the surface storage. When the surface storage, *U* spills, i.e. when $U > U_{max}$, the excess water P_N give rise to overland flow as well as to infiltration. Q_{OF} denotes the part of P_N that contributes to overland flow. The interflow contribution, Q_{IF}, is assumed to be proportional to *U* and to vary linearly with the relative moisture content of the lower zone storage. The interflow is routed through two linear reservoirs in series with the same time constant C_{K1K2}. The overland flow routing is also based on the linear reservoir concept but with a variable time constant. The amount of infiltrating water, *G* recharging the groundwater storage depends on the soil moisture content in the root zone. The base flow, *BF* from the groundwater storage is calculated as the outflow from a linear reservoir with time constant C_{KBF}. Description of the parameters and their effects is presented in Table 1.

Table 1: Different parameters of the NAM model

Parameter	Unit	Description	Effects
U_{max}	Mm	Maximum water content in surface storage	Overland flow, infiltration, evapotranspiration, interflow
L_{max}	Mm	Maximum water content in lower zone/root storage	Overland flow, infiltration, evapotranspiration, base flow
C_{QOF}		Overland flow coefficient	Volume of overland flow and infiltration
C_{KIF}	Hrs	Interflow drainage constant	Drainage of surface storage as interflow
T_{OF}		Overland flow threshold	Soil moisture demand that must be satisfied for overland flow to occur
T_{IF}		Interflow threshold	Soil moisture demand that must be satisfied for interflow to occur
TG		Groundwater recharge threshold	Soil moisture demand that must be satisfied for groundwater recharge to occur
C_{K1}	Hrs	Timing constant for overland flow	Routing overland flow along catchment slopes and channels
C_{K2}	Hrs	Timing constant for interflow	Routing interflow along catchment slopes
C_{KBF}	Hrs	Timing constant for base flow	Routing recharge through linear groundwater recharge

3.2 Input Data

The basic input data requirements for the MIKE11 NAM model are meteorological data and discharge data for model calibration, definition of the catchment parameters, and definition of initial conditions. The basic meteorological data requirements are precipitation time series, potential evapotranspiration time series and temperature time series. On this basis, the model produces a time series of catchment runoff, a time series of subsurface flow contributions to the channel, and information about other elements of the land phase of the hydrological cycle, such as soil moisture content and groundwater recharge.

3.2.1 Rainfall

The daily rainfall data of four rain-gauge stations namely Begamganj, Gairatganj, Rahatgarh, and Jaisinagar for the period of five years i.e. from 1990 to 1994 was used for the modeling. The areal precipitation of the area was computed from point precipitation by using Thiessen Polygon Method (1911) with the help of Arc Map 10 software.

3.2.2 Runoff

The Gauge-discharge data of Rahatgarh site on Bina river for the period of five years i.e. from 1990 to 1994 was used for the rainfall runoff modeling. Before using the rainfall and runoff data for the development of model, the rainfall and runoff records were checked for their consistency by estimating the correlation coefficient between two time series and runoff coefficients for annual runoff.

3.2.3 Potential evapotranspiration

Potential Evapotranspiration (*ETo*) is one of the important input in development of MIKE 11 NAM model due to its high effect on runoff in the form of evaporation from the surface. The CROPWAT 8.0 software which is based on Penman Monteith Method (1965) was used for estimation of *ETo*. The climatological data of nearest Sagar climatological observatory of Indian Meteorological Department was used to estimate *ETo* using the meteorological data like temperature, wind speed, humidity, and sunshine hours.

3.3 MIKE 11 NAM Model Setup

MIKE 11 NAM model was setup to carry out rainfall-runoff modeling in Bina river basin at Rahatgarh G/d site having catchment area 1180 km^2 and average annual rainfall 1182 mm. The input information of daily rainfall, runoff and potential evapotranspiration for the period of five years from 1990 to 1994 was converted to *dfso* format using MIKE ZERO software which was then used for the model development.

3.4 Model Calibration

Calibration is a process of standardizing predicted values, using deviations from observed values for a particular area to derive correction factors that can be applied to generate predicted values that are consistent with the observed values. Once the MIKE 11 NAM model was set up with the input information, the model was calibrated for three years period from 1990 to 1992. During calibration, the default model parameters were kept same and model was run in auto-calibration mode. The model output simulation results during calibration were checked for coefficient of determination (R^2) value and graphically analysed for degree of agreement between simulated and observed runoff. The model parameters were again adjusted one by one using trial and error method to obtain the set of best fit model parameters which could simulate runoff with high degree of agreement with observed runoff in term of timings, peaks and total volume.

3.5 Model Validation

Model validation means judging the performance of the calibrated model over the portion of historical records which have not been used for the calibration. The MIKE 11 NAM model thus calibrated was then validated for the remaining period of two years from 1993 to 1994. During validation the set of model parameters obtained during the calibration was used and model was run without auto-calibration mode to simulate runoff. The statistics of the simulated results were analysed and output of the model were checked to compare the simulated and observed runoff to verify the capability of calibrated model to simulate the runoff.

3.6 Accuracy Criteria

Accuracy of the model can be examined on the basis of coefficient of determination (R^2), Efficiency Index (*EI*) and Sum of Square of Error (*SSE*). The use of the coefficient of determination is to test the goodness of fit of the model and to assess how well a model explains and predicts future outcomes. It is expressed as a value between zero and one. The coefficient of determination (R^2) of the MIKE 11 NAM model was calculated by using the following equation:

$$R^2 = \frac{\sum_{i=1}^{n}(q_o - \bar{q}_o)(q_s - \bar{q}_s)}{\sqrt{[\sum_{i=1}^{n}(q_o - \bar{q}_o)^2][\sum_{i=1}^{n}(q_s - \bar{q}_s)^2]}}$$

Where, q_o= observed flow, $\overline{q}_o$= mean value of observed flow, q_s= simulated flow and n = number of data points.

The reliability of the model was evaluated on the basis of Efficiency Index (*EI*) as described by the Nash and Sutcliffe [20]. *EI* depends upon the error present in the model like missing data or inconsistency in the data and it is directly proportional to errors present in the input information of the model. The efficiency index was calculated by using the following relationship:

$$EI = \frac{[\sum_{i=1}^{n}(q_o - \bar{q}_o)^2 - \sum_{i=1}^{n}(q_o - q_s)^2]}{\sum_{i=1}^{n}(q_o - \bar{q}_o)^2}$$

Where, q_o= observed flow, $\overline{q}_o$= mean value of observed flow, q_s= simulated flow and n = number of data points. The value of efficiency index lies between 0 to 1. The efficiency index equal to 1 indicates the best performance of the model.

While analysing the accuracy of the model, the objective function was to minimize the Sum of Square of Error (*SSE)* between the observed and simulated runoff. It was calculated by using the simulated and observed runoff time series as given by the equation below.

$$SSE = \sum_{i=1}^{n}(q_o - q_s)^2$$

Where, q_o=observed discharge and q_s=simulated discharge

3.7 Sensitivity Analysis

The MIKE11 NAM model thus developed was run by selecting one parameter as a variable and keeping other parameters constant to identify the most sensitive model parameters. The model parameters were selected one by one and were increased and decreased by 20% to both side from their values obtained during calibration of the model. As the sensitivity of the each parameter is dependent on how and to what extent it affects the *EI* and *SSE* of the model, thus the *EI* and *SSE* were estimated for each model run. The output results were analyzed by plotting selected parameter values against the *EI* and *SSE* and the most influencing and sensitive model parameters were identified.

3.8 Effect of Model Parameters on Runoff

Effect of each model parameters on peak flows and low flows were analyzed by running the model by increasing the model parameters one by one. The simulated runoff was critically analysed for its peaks and low flow values during the flow regime.

4 Results and Discussion

MIKE 11 NAM model was developed to carry out rainfall-runoff modeling in Bina river basin at Rahatgarh G/d site having catchment area 1180 Km^2 using daily rainfall data of four rain-gauge stations Begamganj, Gairatganj, Rahatgarh and Jaisinagar. The Thiessen polygon map of the study area is shown in Figure 3. Among four raingauge stations, Begamganj and Gairatganj are the most influencing station covering maximum area. The weights of raingauge stations with proportion to their representative areas are given in Table 2. The monthly rainfall distribution is shown in Figurer 4 and statistical analysis of annual and seasonal rainfall is given in Table 3.

Figure 3: Thiessen polygon of the study area

Table 2: Thiessen weights for raingauge stations

Station	Raingauge Station	Weights
1	Begamganj	0.67
2	Gairatganj	0.22
3	Rahatgarh	0.09
4	Jaisinagar	0.02

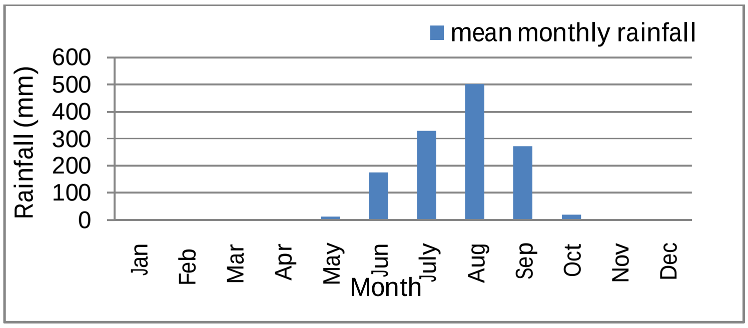

Figure 4: Mean monthly rainfall of study area.

Table 3: Statistical analysis of annual and seasonal rainfall

Station	Annual rainfall			Seasonal rainfall		
	Mean (mm)	Standard deviation (mm)	Coefficient of variance	Mean (mm)	Standard deviation (mm)	Coefficient of variance
Begamganj	1208	359	29.80	1195	305	25.52
Gairatganj	1139	295	20.90	1076	371	29.88
Rahatgarh	1155	338	29.32	1115	328	29.48
Jaisinagar	1226	402	32.82	1177	388	32.98
Average	1182	348.5	28.21	1141	348	29.465

From the analysis of monthly rainfall distribution as shown in Figure 4, it was observed that the total annual rainfall in the area is mainly due to the southwest monsoon and receives about 97% of annual rainfall during monsoon season. From the Statistical analysis of annual and seasonal rainfall as shown in Table 3, it was observed that the average annual and seasonal rainfall in the study area was 1182 and 1141mm respectively. Coefficient of variance of annual rainfall varying between 20.9 to 32.82 at Gairatganj to Jaisinagar and trend was found almost same for the seasonal rainfall, which found varying from 25.52 to 32.98 showing moderate variation of the rainfall in study area. The standard deviation of annual rainfall of all four stations was found ranging from 295 to 402 mm.

4.1 Model Calibration

Before starting the model development, the reliability of rainfall data was tested by plotting the annual rainfall against the annual runoff as shown in Figure 5. The correlation coefficient was obtained as 0.9816, showing good correlation between rainfall and observed runoff. A straight line graph thus obtained, shown the linear relation between rainfall and observed runoff and concluded that the data was consistent to be used further in rainfall-runoff modeling. Runoff coefficients, the ratio between runoff and rainfall were calculated using annual rainfall and observed annual runoff and given in the Table 4. The values of runoff coefficients were observed varying from 0.45 to 0.61. The total annual potential evapotranspiration (*ETo*) was estimated 1669 mm whereas *ETo* was observed highest in the month of April (195.3 mm) and May (240.87 mm) and lowest in the month of November (93.6 mm) and December (78.43 mm).

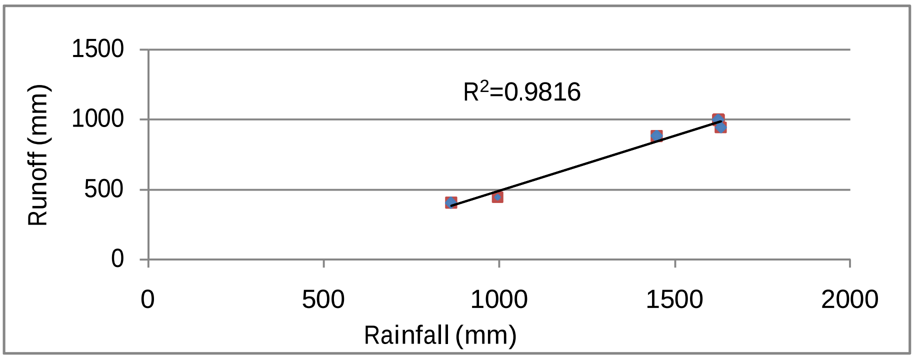

Figure 5: Graph showing linear relation between rainfall and runoff

Table 4: Representing runoff coefficient

Year	Annual Rainfall (mm)	Annual Runoff (mm)	Runoff coefficient
1990	1632.3	999.0	0.61
1991	995.2	442.9	0.45
1992	863.0	403.7	0.47
1993	1448.5	881.5	0.61
1994	1631.2	934.5	0.58

The MIKE11 NAM model was setup for the Rahatgarh G/d site of Bina river with all input information and calibrated for the period of three years from 1990 to 1992 to obtain the set of best fit model parameters which could simulate runoff with high degree of agreement with observed runoff. The set of model parameters were obtained during the model calibration were found within their specified range as shown in Table 5.

Table 5: Model parameter values of model calibration and their range

Sr. No.	Parameter	Unit	Model Parameter Final Values	Parameter Range
1	U_{max}	*mm*	14.400	5.76 – 20
2	L_{max}	*mm*	129.000	100 – 300
3	C_{QOF}		0.750	0.1- 1
4	C_{KIF}	*hrs*	531.100	200 – 1000
5	C_{K1K2}	*hrs*	10.000	10 – 15
6	T_{OF}		0.349	0 - 0.99
7	T_{IF}		0.606	0 - 0.99
8	T_{G}		0.122	0 - 0.99
9	C_{KBF}	*hrs*	1041.000	500 – 1000

The statistics of various components of hydrological cycle, like runoff, actual evapotranspiration, ground water recharge, overland flow, inter flow and base flow simulated during model calibration are given in Table 6 in the form of water balance. The coefficient of determination (R^2) for the model calibration was observed 0.796 which indicated the good agreement between the observed and simulated runoff in terms of timing, rate and volume. The difference in the total observed and simulated flows was 0.3% which was reasonable indicating good match between observed and simulated runoff. From the analysis of simulation results, it could be seen that, during the calibration period of three years, out of total rainfall of 3490.5 mm, the simulated discharge was 1840 mm, overland flow formed was 1043.1 mm, the water contributed as inter flow and base flow were 76 and 721.6 mm respectively and remaining 728.2 mm of water was contributed to the ground water recharge.

Table 6: Model calibration result (all values are in mm)

Year	Q-Obs	Q-Sim	% Diff	RF	PET	AET	GWR	OF	IF	BF
1990	999.0	945.8	5.3	1632.3	1668.8	649.2	358.5	570.9	32.9	342.0
1991	442.9	482.7	-9.0	995.2	1668.8	536.8	201.9	249.9	20.8	212.0
1992	403.7	412.3	-2.1	863.0	1668.8	448.3	167.7	222.3	22.3	167.7
Total	1845.6	1840.8	0.3	3490.5	5006.3	1634.2	728.2	1043.1	76.0	721.6
Coefficient of determination (R^2) =0.796										

(Q=Runoff, RF=Rainfall, PET=Potential Evapotranspiration, AET=Actual Evapotranspiration, GWR=Ground Water Recharge, OF=Overland Flow, IF=Inter Flow and BF=Base Flow)

The comparison of observed and simulated monthly runoff volume is shown in Figure 6. From the figure it was observed that the monthly observed and simulated runoffs were almost matching in terms of runoff volume. From the analysis of Figure 7, showing runoff hydrographs of different events during calibration period, it was observed that the shapes of the hydrographs of observed and simulated runoff were matching well for almost all the runoff events. These graphs indicated the good match between the observed and simulated runoff. It can also be seen that the time of beginning and termination of observed and simulated runoff events were matching well whereas the amplification in peak values of runoff events were matching with moderate accuracy.

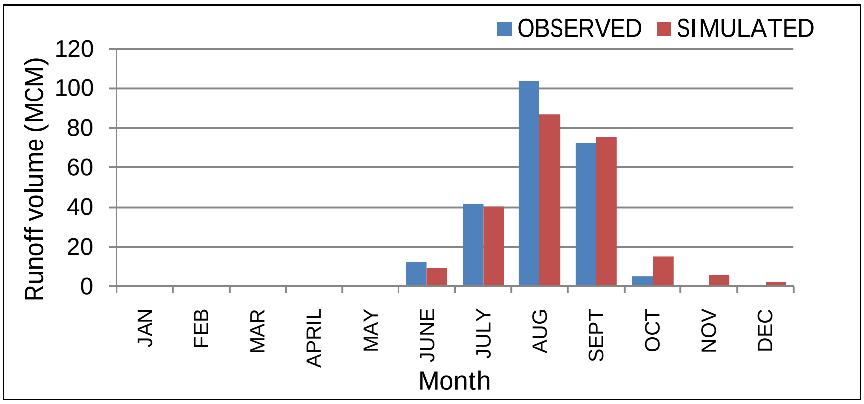

Figure 6: Observed and simulated monthly runoff volume during model calibration

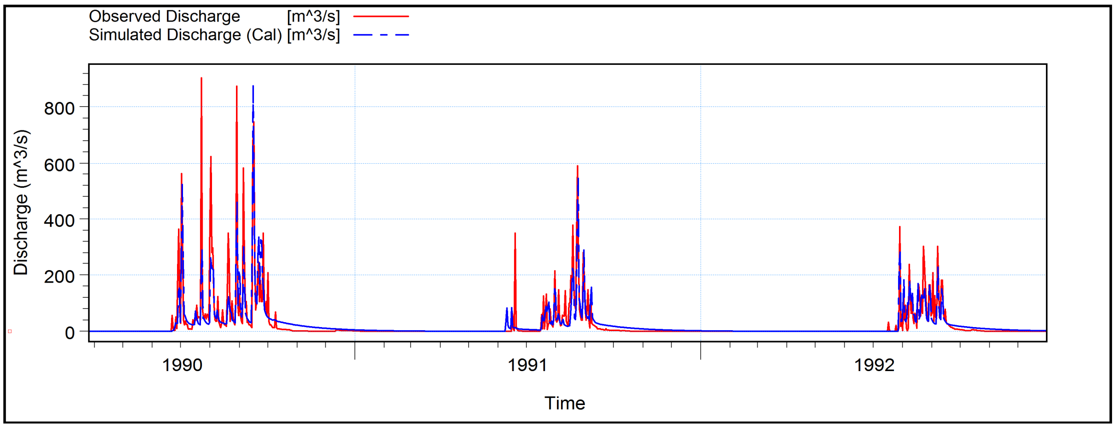

Figure 7: Observed and simulated runoff hydrograph during model calibration

4.2 Model Validation

The MIKE 11 NAM model was then validated for the remaining period of two years from 1993 to 1994 by using the same set of model parameters obtained during the model calibration. The statistics of simulated hydrological components during model validation are given in Table 7. The coefficient of determination for the validation period of the model was 0.609 indicated that the model developed was performing well to simulate runoff in good agreement with observed runoff in terms of timing, rate and volume. The difference between total observed and simulated runoff was observed as 1.2% which could be acceptable for the model.

Table 7: Model validation result (all values are in mm)

Year	Q-Obs	Q-Sim	% Diff	RF	PET	AET	GWR	OF	IF	BF
1993	881.5	818.6	7.1	1448.5	1668.8	598.3	296.3	506.9	30.6	281.1
1994	934.5	976.3	-4.5	1631.2	1250.2	358.3	385.7	725.0	28.7	222.6
Total	1816.0	1794.9	1.2	3079.7	2919.0	956.5	682.0	1231.9	59.4	503.7
Coefficient of determination (R^2) = 0.609										

(Q=Runoff, RF=Rainfall, PET=Potential Evapotranspiration, AET=actual evapotranspiration, GWR=Ground Water Recharge, OF=Overland Flow, IF=Inter Flow and BF=Base Flow)

From the analysis of Fig 8 showing good match between observed and simulated monthly runoff volume during validation period, it could be concluded that the model thus developed was working well during the extended period also. The Figure 9 is showing good match between hydrographs of different events of observed and simulated runoff during the validation period, indicated that the model parameters obtained during calibration were simulating runoff with the accuracy. The analysis of model validation results indicated that the NAM model developed was performing well and seems to be capable of generating or predicting runoff time series for the extended time period with reasonable accuracy in Bina basin. The Efficiency Index (*EI*) obtained during the calibration was 81% which shows that NAM model developed was efficient and capable of predicting runoff with accuracy. It could also be concluded that the NAM model thus developed in Bina sub basin at Rahatgarh can be used to simulate the runoff in other sub basins of similar characteristics.

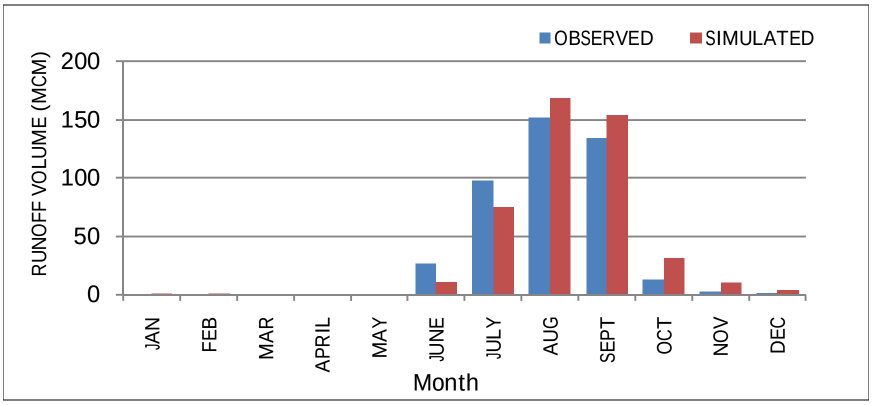

Figure 8: Observed and simulated monthly runoff volume during model validation

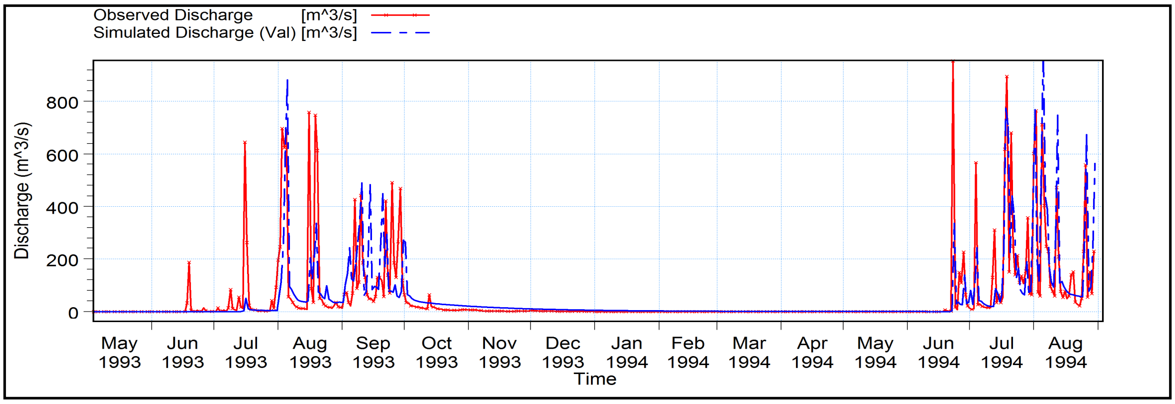

Figure 9: Observed and simulated runoff during model validation

4.3 Sensitivity Analysis

The sensitivity analysis of the MIKE11 NAM model was carried out by running the model by selecting model parameters one by one as a variable and keeping other parameters constant to identify the most sensitive model parameters. For each simulated runoff time series, EI and *SSE* were calculated using equation 2 and 3 respectively. The output results were analyzed by plotting *EI* and *SSE* against the respective model parameters. The model parameters C_{QOF}, L_{max} and C_{K1K2} were found as the most influencing and sensitive as shown in Fig 10 whereas remaining parameters were found non-sensitive as shown in Fig 11.

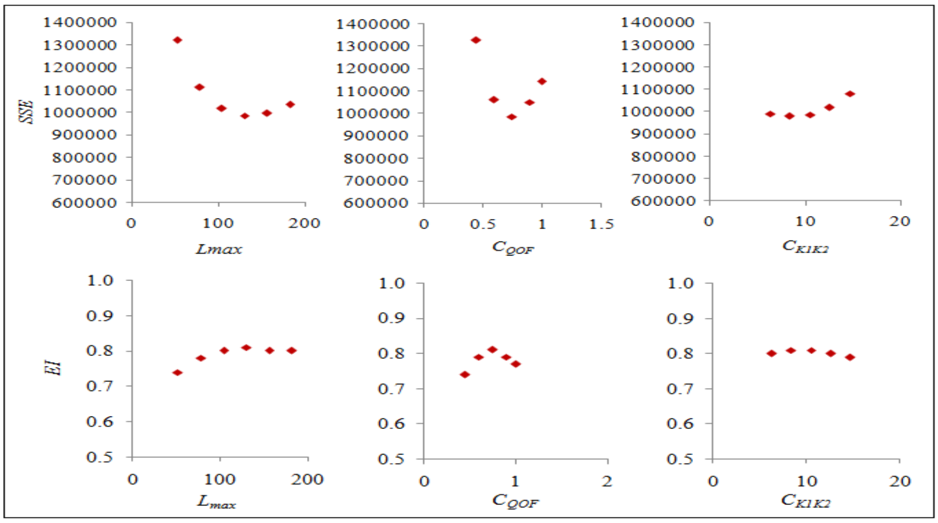

Figure 10: Graph between EI and SSE against the sensitive model parameters

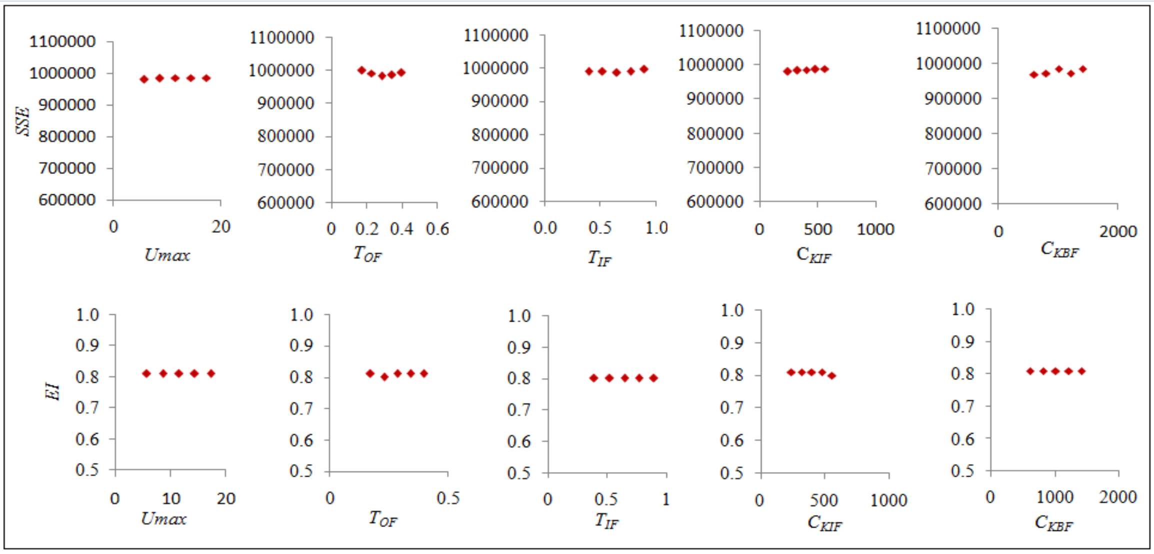

Figure 11: Graph between EI and SSE against the non-sensitive model parameters

4.4 Effect of Model Parameters on Runoff

Effects of the model parameters on simulated peak and low flows were analysed by running the model by increasing model parameter values one by one and results are shown in Table 8. From the analysis, it was observed that C_{QOF} was the only parameter which has shown significant effects on peak and low flows both. When C_{QOF} was increased, the peak flows were observed increasing and low flows were observed decreasing. The peak flows were found decreasing with increase in L_{max}, C_{K1K2}, T_{OF} and C_{KBF} and there was no effect on low flows. Whereas the parameters like U_{max}, C_{KIF} and T_{IF} did not show any effect on peak as well as low flows.

Table 8**:** Effect of increase of model parameters on peak flows and low flows

Sr. No.	Model Parameter	Effect on Peak flows	Effect on Low flows
1	U_{max}	No effect	No effect
2	L_{max}	Decreases	No effect
3	C_{QOF}	Increases	Decreases
4	C_{KIF}	No effect	No effect
5	C_{K1K2}	Decreases	No effect
6	T_{OF}	Decreases	No effect
7	T_{IF}	No effect	No effect
8	C_{KBF}	Decreases	No effect

5 Conclusions

The MIKE11 NAM rainfall runoff model was found suitable for Bina basin in simulating hydrological response of the basin to the rainfall and predicting daily runoff with high degree of accuracy. The model was seen performing well to simulate runoff in good agreement with observed runoff in terms of timing, rate, volume and shape of hydrograph. The rainfall runoff model thus developed seems to be capable of predicting runoff for extended time period in Bina basin and other sub basin of similar characteristics. The model was found efficient in generating runoff using rainfall data and it could be the important tool in water resources management and planning of the Bina basin. The MIKE 11 NAM model was found sensible to parameters like, C_{QOF}, L_{max} *and* C_{K1K2}. The coefficient of overland flow (C_{QOF}) was found as the important parameter in modeling as it was seen significantly affecting peaks and low flows both.

Acknowledgment

The authors are thankful to National Institute of Hydrology, Regional Centre, Bhopal for providing support and facilities for conducting study. The authors are also thankful to State Water Data Centre, Water Resources Department, Govt. of Madhya Pradesh, Bhopal for providing rainfall and discharge data of Bina river basin.

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