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Rainfall-Runoff Modeling Using MIKE 11 NAM Model for Vinayakpur Intercepted Catchment, Chhattisgarh

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ABSTRACT: Rainfall-runoff estimation for a catchment is of vital importance in most of the hydrologic analysis for water resources planning. This study envisages the rainfall-runoff modeling using MIKE 11 NAM model in Vinayakpur intercepted catchment in Chhattisgarh state. The model was calibrated using measured stream flow data for the period 2001 to 2004 and then validated from period 2005 to 2007. The calibration and validation procedures were carried out to provide a satisfactory estimation. The simulated runoff occurred maximum in August (1681.63 cumecs) and minimum in April (84.14 cumecs). The outputs of the calibrated model were used in water resources management model *viz.,* MIKE basin as they normally work based on monthly flows with a large time horizon. The optimum values of nine NAM model parameters obtained during calibration procedure were used for simulation. The reliability of MIKE 11 NAM was evaluated based on Nash-Sutcliffe coefficient, correlation coefficient (r^2) and root mean square error (RMSE). The R^2 value of model calibration and validation were observed to be 0.79 and 0.75, respectively.

Key words: Rainfall-runoff, NAM, Vinayakpur intercepted catchment, MIKE basin

Rainfall-runoff estimation plays a very important role for purposes of water resources planning; flood forecasting, pollution control, inter-basin water transport, decision-making and policy formulations, etc. Precipitation distribution, evaporation, transpiration, abstraction, watershed topography, and soil types are implicit and explicit factors which affect rainfall-runoff process in modeling (Dawson *et al.,* 2000). The runoff discharge and flow rate at a river site varies greatly throughout the course of time, depending on seasonal rainfall, watershed characteristics and many other parameters. Several models have been developed to simulate hydrological processes such as rainfall-runoff process, which can be divided into three categories *viz.,* “physical”, “conceptual” and “black box” models. Lumped conceptual models require significant amounts of calibration data and also experience of user is necessary. Physical distribution based models become unsuitable as they need a large amount of data about topology, soil, vegetation and geological characteristics of catchment area. The quality of observed data also plays important role in accuracy of empirical black box models and they are useful operational tools in cases where enough meteorological data are not available (Bojkow, 2001). Because of non-linear and multi-dimensional nature, rainfall-runoff modeling is extremely complicated (Lipiwattanakarn *et al.,* 2004). The widely known rainfall-runoff models identified are of rational method (Mc Pherson, 1969), Soil Conservation Service-Curve Number Method (Maidment, 1993) and Green Ampt Method (Green and Ampt, 1911). The hydrological model of NAM 11 is an integrated and conceptual model of rainfall-runoff which is able to simulate surface flow, subsurface and base flow; this model was developed by Danish Hydraulic Institute (DHI) in 1972 (DHI, 1999). Shamsudin and Hashim (2002) applied NAM model for predicting the runoff rate in Liang River located in northern part of Malaysia and they obtained satisfactory results and found that the predicted values by the NAM model were in accordance with the historical data appropriately. Lipiwattanakarn *et al.* (2004) compared the performance of ANN and MIKE 11 NAM models. They found that ANN model was more efficient in simulating the discharge peak while MIKE 11 NAM was more capable in simulating the base flow or discharge. Liu *et al.* (2007) suggested a novel sensitive analysis scheme for MIKE 11 NAM rainfall-runoff model which indicated the sensitivity analysis problem in a general multi-objective framework. Model calibration is needed because the parameters of such models cannot be obtained directly from measurable quantities of catchment characteristics. A trial and error parameter adjustment is made in the process of manual calibration. In such cases, comparing the simulated and the observed hydrographs based on a visual judgment is used as a basis for the calibration process. In auto-calibration, modeling parameters are automatically adjusted according to a specified search scheme and the resulting numerical measures of the goodness of fit (Madsen, 2003). MIKE 11 NAM is a rainfall-runoff model which is a part of the MIKE 11 RR module. MIKE 11 NAM, MIKE SHE and WATBAL models were validated on three catchments in Zimbabwe for water resources decision-making (Refsgaard and Knudsen, 1996), where at least one year’s data were available for calibration. The runoff hydrographs for the un-gauged Nzhelele river were simulated using MIKE 11 NAM model and the Australian Water Balance Model (AWBM) by Makungo *et al.* (2010). The simulated runoff hydrographs can be used in water resources planning and management, and water resources systems operation. The rainfall-runoff relationship in the Strymonas river catchment was studied by Doulgeris *et al.* (2012) using the MIKE 11 NAM model. MIKE 11 NAM was used for the simulation of rainfall-runoff process in the Strymonas river and Lake Kerkini by Doulgeris *et al.* (2008) for water resources management aspects. In this paper, lumped conceptual rainfall-runoff model is used for long term daily and monthly discharge calculation for the Vinayakpur intercepted catchment based on the available rainfall and evaporation data.

For this purpose, the MIKE 11 NAM model was adopted in order to do better calibration of NAM parameters. The calibration and validation procedures of the model were carried out to provide a satisfactory estimation.

Material and Methods

Study area

The study area is the Vinayakpur intercepted basin which falls under the Durg district of Chhattisgarh. The basin extends between 20°35′10″ to 20°85′11″ N latitude and 81°23′05″ to 81°7′30″ E longitude. The total area of the basin is 1019.17 km^2. The Durg district is located at 317 m above mean sea level. It is bounded by Bemetara district in the North, Rajnandgaon district in the West, Balod district in the South and Raipur district in the East. The annual average rainfall is 1052 mm. The study area can be located on the Survey of India (SOI) toposheet no. 64 G/4, 64 G/8, 64 D/13, 64 H/1, 64 H/5, 64 D/13 64 H/2 and 64 H/6 on 1:50,000 scale. The toposheets were used to delineate the study area for preparing the drainage network map. The Tandula river is the main river with a total length of 51.01 km and stream order is five. There is only one gauging site in the study area which is located at Tandula Vinayakpur (owned by Water Resource Department, Chhattisgarh). The distribution of the study area as in Table 1 is comprised of six blocks namely-Balod, Dondilohara, Gunderdehi, Gurur, Durg and Doundi.

Table 1 : Distribution of study area under different blocks of Durg district

Blocks	Area of block falling under basin (km^2)	Percentage area of basin
Balod	250.49	24.57
Dondilohara	238.41	23.39
Durg	19.06	1.87
Gunderdehi	473.24	46.43
Gurur	31.12	3.05
Doundi	1.17	0.11

Table 2 : Input data requirement by the model

Variable	Type	Unit	TS Type
Daily Rainfall	Rainfall	mm	Step accumulated
Daily potential evapotranspiration	Evaporation	mm	Step accumulated
Daily discharge	Discharge	m^3/s	Instantaneous

Rainfall-runoff modeling (MIKE 11 NAM model)

NAM is a part of rainfall-runoff module of MIKE 11 river modeling system which simulates rainfall-runoff process occurring at the catchment scale. This can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to a river network. In this manner, it is possible to treat a single catchment or a large river basin containing numerous catchments and a complex network of rivers and channels within the same modeling framework.

Structure of the NAM model

The model structure is an imitation of the land phase of the hydrological cycle. NAM simulates the rainfall-runoff process by continuously accounting for water content in four different and mutually interrelated storages that represent different physical elements of a catchment as shown in Figure 1.

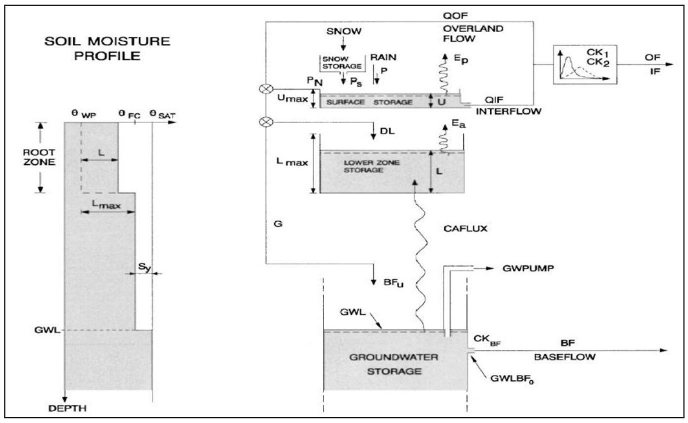

Fig. 1 : Structure of NAM model for rainfall-runoff simulation

These mutually interrelated storages include snow storage, surface storage, lower or root zone storage and groundwater storage. In addition, NAM allows treatment of man-made interventions in hydrological cycle such as irrigation and groundwater pumping.

Based on the meteorological input data, NAM produces catchment runoff as well as information about other elements of the land phase of the hydrological cycle, such as the temporal variation of the evapotranspiration, soil moisture content, groundwater recharge and groundwater levels. The resulting catchment runoff is divided conceptually into overland flow, inter flow and base flow.

The application of MIKE 11 model for rainfall-runoff estimation can be divided into two stages. The first stage is calibration process to determine an optimum value of model parameters. The second stage is stream flow simulation using estimated model parameter during calibration process.

NAM module (MIKE 11) model setup for Vinayakpur intercepted catchment

NAM module of MIKE 11 was used to estimate all the basin water balance components, i.e. runoff, actual evapotranspiration, and groundwater recharge. For this purpose, seven years (2001 to 2007) data of rainfall, evaporation and runoff were used. The rainfall of Admabad, Anda, Balod and Gondly stations was used. The observed runoff data of Vinayakpur gauging site was used for comparison of results. The catchment area of 1019.17 sq. km was assigned to the model. The total data period of 07 years was divided into two parts; i.e. 2001 to 2004 for the calibration and 2005 to 2007 for validation purpose.

NAM calibration

During calibration, the catchment parameters were adjusted until a satisfactory fit between simulated flow contributions, (overland flow, inter flow and base flow) and observed stream flow was attained. The following objectives were usually considered during model calibration:

i. A good agreement between the average simulated and average observed catchment runoff.

ii. A good overall agreement of the shape of the hydrograph.

iii. A good agreement of the peak flows with respect to timing, rate and volume.

iv. A good agreement for base flows.

In calibration process, different calibration objectives mentioned above should be taken into account. If objectives are of equal importance, one should seek to balance all objectives, whereas in case of priority to a certain objective, that objective should be favoured.

For a general evaluation of calibrated model, simulated runoff is compared with observed runoff measurements. Both graphical and numerical performance measures should be applied in calibration process. The graphical evaluation includes comparison of simulated and observed hydrograph, and comparison of simulated and observed accumulated runoff. The numerical performance measures include overall water balance error (i.e., difference between average simulated and observed runoff), and a measure of overall shape of hydrograph based on coefficient of determination and Nash-Sutcliffe coefficient.

The model was calibrated for the period 2001 to 2004 using auto-calibration. In auto-calibration, model fixes surface and root zone parameters and groundwater parameters automatically.

Input data requirements

The data requirements for NAM MIKE 11 RR model are meteorological data, stream flow data for model calibration and verification, definition of catchment parameters, and definition of initial conditions. The basic meteorological data requirements are precipitation time-series, potential evapotranspiration time-series, temperature and radiation time-series if snow accumulation and melt is to be modelled. Table 3 describes the required input data and the format.

There are six rain gauge stations in basin namely Admabad, Anda, Balod, Gondali, Kharkhara and Matia. The rainfall data at these stations is collected by Water Resources Department, Govt. of Chhattisgarh. The rainfall of these stations was analyzed station-wise. These rainfall data were used in rainfall-runoff modeling and estimation of water availability in the Vinayakpur intercepted basin.

Results and Discussion

Rainfall-runoff modeling (MIKE 11 NAM model)

The simulated minimum and maximum runoff for a seven year period (2001-2007) show that the annual runoff varies between 68.6 mm to 611.6 mm. The runoff at the gauging site was simulated with the help of NAM model. The simulated runoff was maximum for the month of August (1681.63 m^3/s) and minimum for the month of April (84.14 m^3/s).

Table 3 : Model parameter values and their range

Parameter	Unit	Description	Model parameter values	Parameter range	Change	Effects
U_{max}	mm	Maximum water content in surface storage	19.2	5.76–20	Increase	Peak runoff decreased Runoff volume reduced
L_{max}	mm	Maximum water content in root zone storage	292	100–300	Increase	Peak runoff decreased Runoff volume reduced
C_{QOF}		Overland flow runoff coefficient	0.263	0.1-1	Increase	Peak runoff decreased Runoff volume increased
C_{KIF}	hrs	Time constant for routing interflow	534.4	200–1000	Increase	-
C_{K1K2}	hrs	Time constant for routing overland flow	29.6	10–50	Increase	Peak runoff decreased The triangular shape expand horizontally
T_{OF}		Root zone threshold value for overland flow	0.0144	0-0.99	Increase	Peak runoff decreased Runoff volume reduced
T_{IF}		Root zone threshold value for interflow	0.000784	0-0.99	Increase	-
T_G		Root zone threshold value for GW recharge	0.813	0-0.99	Increase	-
C_{KBF}	hrs	Time constant for routing base flow Lower base flow/recharge to lower reservoir	3707	500-10000	Increase	Base flow decreased

Model calibration

The calibrated results of observed and simulated runoff are shown in Figure 2. The correlation coefficient during the calibration is 0.79 and Nash-Sutcliffe coefficient is 0.63 which indicates a good match. The total water balance error during calibration is 6.1% which is within acceptable limits.

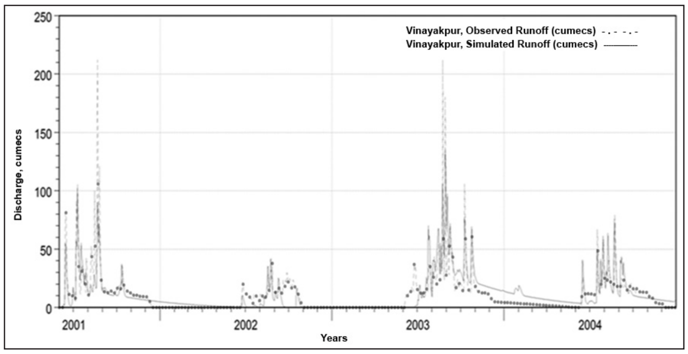

Fig. 2 : Comparison of observed and simulated runoff during model calibration (coefficient of determination = 0.63)

Model validation

The model was validated for the period 2005 to 2007 using the model calibrated parameters. The validated results of observed and simulated runoff are shown in Figure 3. The correlation coefficient during validation was calculated as 0.75 and Nash-Sutcliffe coefficient was 0.56 which indicates a good match. The total water balance error during the validation was 4.7% which is again within acceptable limits.

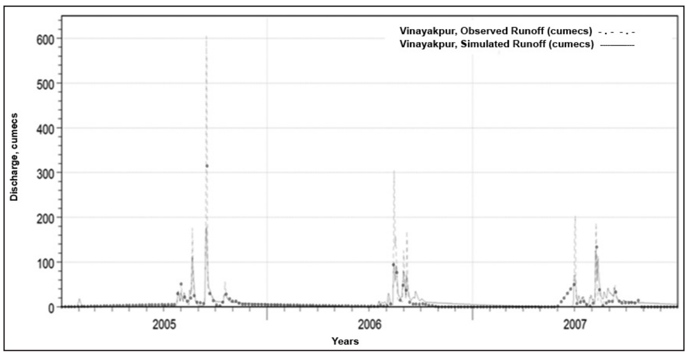

Fig. 3 : Comparison of observed and simulated runoff during model validation (coefficient of determination = 0.56)

The difference between total accumulated observed and simulated runoff during calibration and validation was observed to be 6.1% and 4.7%, respectively. This indicates that difference between total accumulated observed and simulated runoff is well within acceptable limits. The coefficient of determination for calibration and validation period of model was 0.63 and 0.56, respectively which indicates that the developed model is performing well to simulate the runoff. The auto-calibration procedure for the NAM model parameters, a set of NAM model parameters was calculated and then the simulated discharge was compared with observations. The final values of NAM parameters that have been adjusted in the calibration process are illustrated in Table 3. It shows that the final calculated values of model parameters represented hydrologically the catchment's characteristics in the range of predefined bandwidth during the auto-calibration procedure.

Conclusions

The results of NAM model for calculation of daily discharge from catchment rainfall is acceptable to use monthly discharges in water management models like MIKE basin. The rainfall-runoff models *viz.,* MIKE 11 NAM is lumped conceptual type of model and need not require lot of data to calculate daily and monthly discharges. Thus these are useful tools for use in water management on the large scale modeling with medium and long term simulation periods.

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