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Rainfall Runoff Modeling using Mike 11 Nam Model

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Abstract
River basin planning and management is primarily based on the accurate assessment and prediction of catchment runoff. A continuous effort has been made by the various researchers to accurately assess the runoff generated from precipitation by developing various models. In this paper conceptual hydrological MIKE 11 NAM approach has been used for developing a runoff simulation model for Arpa sub-basin of Seonath river basin in Chhattisgarh, India. NAM model has been calibrated and validated using discharge data at Kota gauging site on Arpa basin. The calibration and validation results shows that this model is capable to define the rainfall runoff process of the basin and thus predicting daily runoff. The ability of the NAM model in rainfall runoff modeling of Arpa basin was assessed using Nash–Sutcliffe Efficiency Index (EI), coefficient of determination (R^2) and Root Mean Square Error (RMSE). This study demonstrate the usefulness of developed model for the runoff predication in the Arpa basin which act as a useful input for the integrated water resources development and management at basin scale.

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Keywords

Arpa basin;
MIKE 11 NAM Model;
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Root Mean Square Error;
simulation.

Introduction

While modeling rainfall runoff process of a basin it is to be noted that this process is highly nonlinear and time-varying. Such properties of this hydrological process indicates that it is always challenging task to describe it by simple models. In reality, response of a catchment show high temporal variability throughout the year and this variability depends on rainfall pattern (both temporal and spatial), evaporation, catchment characteristics and many other hydrological parameters. A number of hydrological models were demonstrated by various investigators for addressing such modeling issues.[1] Artificial Neural Networks are increasingly used in modelling various hydrological processes and flood forecasting.[2] A number of attempts have also been made to apply fuzzy models in flood forecasting[3,4,5,6] stage discharge relationship[7,8,9] which provides an important input for rainfall runoff modelling. Furthermore, inherent nonlinearity of the hydrological

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processes can be modelled by the Fuzzy rule based systems as demonstrated by the researchers through monthly reservoir inflow forecasting[10] and flood forecasting.[11,12,13] Conceptual and physical based models are being successfully applied for runoff simulation. Most of the models which are commonly used for the simulation of catchment runoff are lumped conceptual models. Simulation models have a vital role in integrated water resource development management and related decision making. Various available rainfall runoff models considers different model structures. Some of the most common models are: Green and Ampt[14]; Rational[15]; SCS-CN,[16] and for ungauged basins geomorphological unit hydrograph (GIUH).[18,19,20,21] A number of conceptual models represent the physical processes lumped over the entire catchment. Such model are the HBV,[22] Sacramento,[23] the Tank,[24] HEC[25,26,27] and the NAM MIKE 11.[28,29] Selection of a hydrological model is generally based on available hydro-metrological data, hydrological problem and accuracy criteria. In general, the parameters of hydrological models can't be acquired directly from the basin features therefore the model calibration is required to finalise the parameter values.

In this paper rainfall runoff process for Arpa basin up to Kota has been modelled using MIKE 11 NAM software. In the Arpa basin available water resources is over exploited and therefore immediate steps are required to develop water resources in the basin so as to fulfill the growing demands of water. Using the rainfall and evaporation daily series of the study basin the runoff was simulated. The model

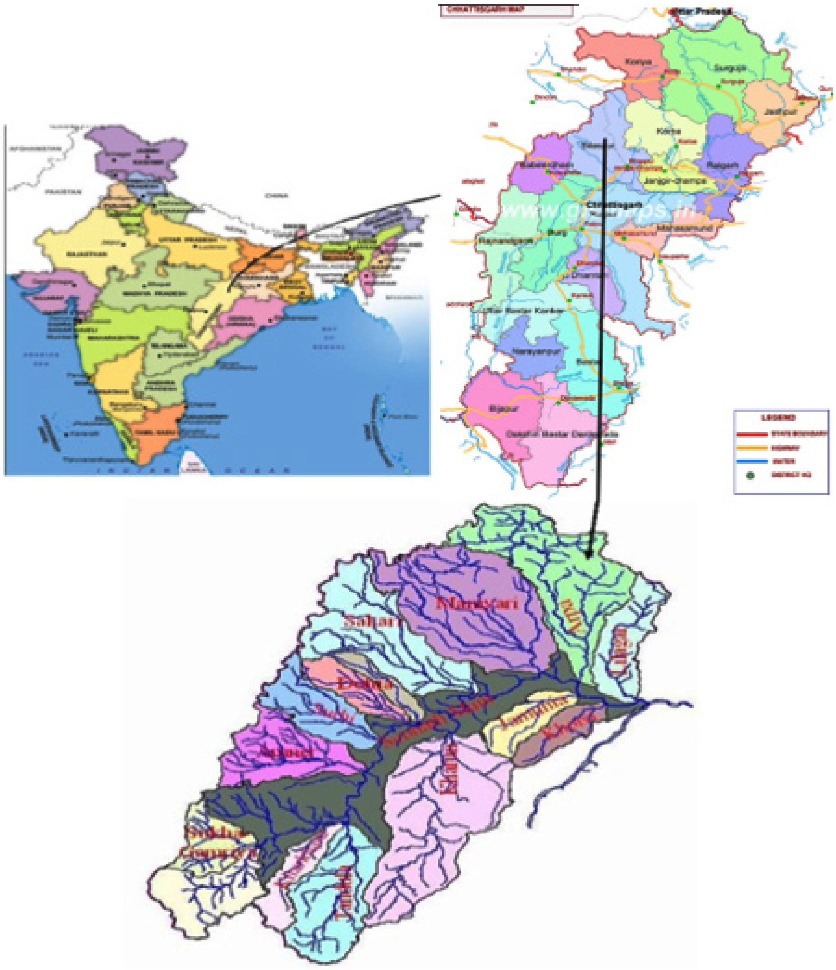

Fig. 1: Index map of Arpa basin

parameters are considered in such a way so that the model simulates the runoff from the Arpa basin with a desired accuracy. The model calibration may be carried out manually or automatic algorithms. In manual calibration model parameter are generally adjusted by trial-and error and visual judgment.

Study Area

The origin of the river Mahanadi is near village Pharsiya in Raipur, Chhattisgarh. Seonath river is a tributary of Mahanadi while the Seonath river's tributary is Arpa river. The Arpa Basin is located at latitude 2208'N and Longitude 82005'E. The Arpa river having a catchment area as 1681.8 km^2 and it originates from Bilaspur, Chhattisgarh, India. River Arpa is very wide from Belghan to Bilapur. Bed of the Arpa river is sandy with exposed rocks at certain places. The major portion of the Arpa river basin is having red yellow and laterite soils. In the basin about 60 to 62% area is having red yellow soil and 35 to 45% area is having laterite soils. Rest 5 to 10% area of the basin have other soils like red alluvial, red sandy, black and peat soils.[30] Rainfall and temperature in the study area indicates significant variations from month to month indicating lowest temperature as 11.62 °C and highest as 46.35 °C. The average rainfall of the Arpa basin is 135 cm and forest area of the basin falls under tropical forest.[30] The Arpa basin (study area) which is located on Seonanath river is shown in Fig. 1.

Description of Nam Model

The NAM model[28] has been used in present study for modeling of rainfall runoff process. NAM model is based on the hydrological cycle and different parameters used in the model are taken as average value of whole watershed. NAM model structure is presented in Figure 2. NAM model has four storage layers e.g. (i) snow (ii) surface (iii) lower zone and (iv) underground ad three flows e.g. (i) overland flow (QOF), interflow (QIF) and underground flow (QBF). The NAM model can either be applied independently in a catchment or in a network form by dividing large basin in small sub-basins. Thus the model gives an opportunity to consider a single sub-basin or a large river basin divided in number of sub-basins with complex river. This model also has capability to model most common man-made hydrological

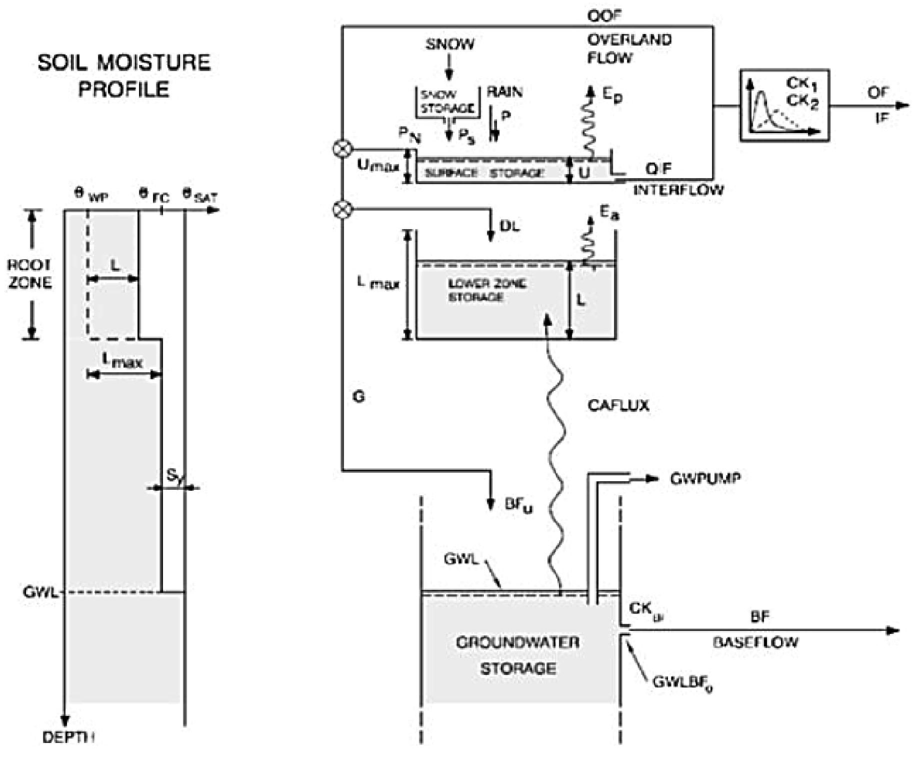

Fig. 2: Basic Structure of the NAM Model

interventions e.g. irrigation and groundwater pumping. In NAM model inputs are precipitation, potential evaporation and temperature and the output is runoff. The model parameters can be decided on the basis of catchment characteristics, however the final values of the model parameter is decided after model calibration. In this paper parameters have been estimated using combination of auto calibration and manual calibration.

The NAM model has optimization module for the multi-objective parameter calibration. It uses shuffled complex evolution algorithm. Multi-objective optimization method considers following 4 objective functions:

Overall Volume error which provides good agreement between observed and simulated runoff as given by:

$$F_1(\theta) = \left| \frac{\sum_{i=1}^{N} w_i\left[Q_{obs,i} - Q_{sim,i}(\theta)\right]}{\sum_{i=1}^{N} w_i} \right| \quad ...(1)$$

Overall root mean square error (RMSE) which gives overall agreement of hydrograph shape:

$$F_2(\theta) = \left[\frac{\sum_{i=1}^{N} w_i^2\left[Q_{obs,i} - Q_{sim,i}(\theta)\right]^2}{\sum_{i=1}^{N} w_i^2} \right]^{1/2} \quad ...(2)$$

Average RMSE of Peak Flow events for good agreement respect to peak flow timing, rate and volume

$$F_3(\theta) = \frac{1}{M_p} \sum_{j=1}^{M_p} \left[\frac{\sum_{i=1}^{n_j} w_i^2\left[Q_{obs,i} - Q_{sim,i}(\theta)\right]^2}{\sum_{i=1}^{n_j} w_i^2} \right]^{1/2} \quad ...(3)$$

Average RMSE of low flow events

$$F_4(\theta) = \frac{1}{M_l} \sum_{j=1}^{M_l} \left[\frac{\sum_{i=1}^{n_j} w_i^2\left[Q_{obs,i} - Q_{sim,i}(\theta)\right]^2}{\sum_{i=1}^{n_j} w_i^2} \right]^{1/2} \quad ...(4)$$

Where,
$Q_{obs,j}$ = Observed discharge at time i
$Q_{sim,j}$ = Simulated discharge at time i
N = Total number of time steps
M_p = Number of peak flow events
M_l = Number of low flow events
N_j = Number of time steps in peak/low flow event no. j
Θ = set of model parameters
W_i = Weighting function

Depending upon the application of the rainfall-runoff model, one can decide specific combinations of the above mentioned objective functions.

Input Data

As mentioned in the previous section, in NAM model meteorological data, stream flow data are the inputs. Therefore, ten years daily rainfall of Kota, Khtghat and Maniyari i.e. from 2000 to 2009 ware used for the modeling. It has observed that there is no missing data in the available time series. Usefulness of HYMOS software in processing of metrological and hydrological has been demonstrated by various researchers.[32,33,34,35,36] The computation of the average rainfall has been performed using HYMOS software using the layers of base map (basin boundary) and rain gauge location map. The Thiessen weights for each rain gauge station have been computed as a ratio of the influencing area of each station divided by the total basin area. Discharge data of Kota site on Arpa basin from 2000 to 2009 was used for the rainfall runoff modeling. Before using these data for the development of model, the rainfall and runoff records were checked for their consistency and corrected using the HYMOS software. Daily ET (evapotranspiration) data of the basin was collected from the water resource department, Chhattisgarh and used for the analysis.

Mike 11 Nam Model Setup

In order to simulate runoff from Arpa basin NAM model inputs were prepared. The input data of daily rainfall, runoff and potential evapotranspiration at Kota gauge discharge site of Arpa basin for the period of ten years from 2000 to 2009 were used in the model. During the calibration of NAM model,

Table 1: Thiessen weights for rain gauge stations

S. No.	Rain gauge Stations	Weights
1.	Kota	0.4
2.	Khtghat	0.3
3.	Maniyari	0.3

fine-tuning of the model parameters was carried out so as to obtain an acceptable matching of simulated and observed stream flow data. Rainfall-runoff data from 2000 to 2003 have been applied for the model calibration. During calibration, adjustment of model parameters have been carried out using automatic calibration option of the NAM model. The optimum parameters values obtained using auto calibration option and finally verified using trial & error are considered for determining the runoff from the Arpa basin. After the calibration, model was then tested for selected period i.e from 2004 to 2009. Further, the model statistics of the calibration and validation results were used to verify the model usefulness in runoff prediction.

Accuracy Criteria

The capability of rainfall runoff model was assessed using coefficient of determination (R^2), Nash–Sutcliffe Efficiency Index (EI) and Root Mean Square Error (RMSE). EI was developed to evaluate goodness between simulated and observed runoff. When EI value is 1 it indicates the perfect model. The coefficient of determination (R^2) of NAM model was calculated by using the following equation:

$$R^2 = \frac{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})(Q_{sim}-\bar{Q}_{sim})}{\sqrt{[\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})^2][\sum_{i=1}^{n}(Q_{sim}-\bar{Q}_{sim})^2]}} \quad ...(5)$$

Nash and Suticliffe efficiency index[37] is given as:

$$EI = \frac{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})^2-\sum_{i=1}^{n}(Q_{sim}-\bar{Q}_{sim})^2}{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})^2} \quad ...(6)$$

RMSE method[38] was also applied for evaluating MIKE 11 NAM. This method measures error between

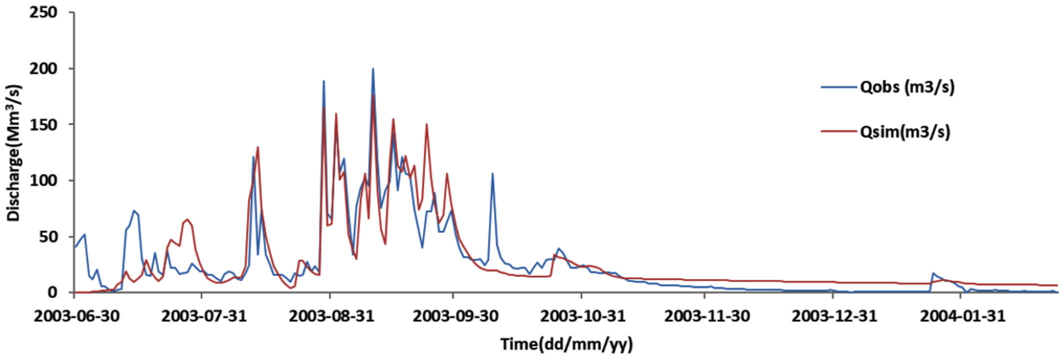

Fig. 3: Simulated and observed runoff for the period 2003-04 (calibration results)

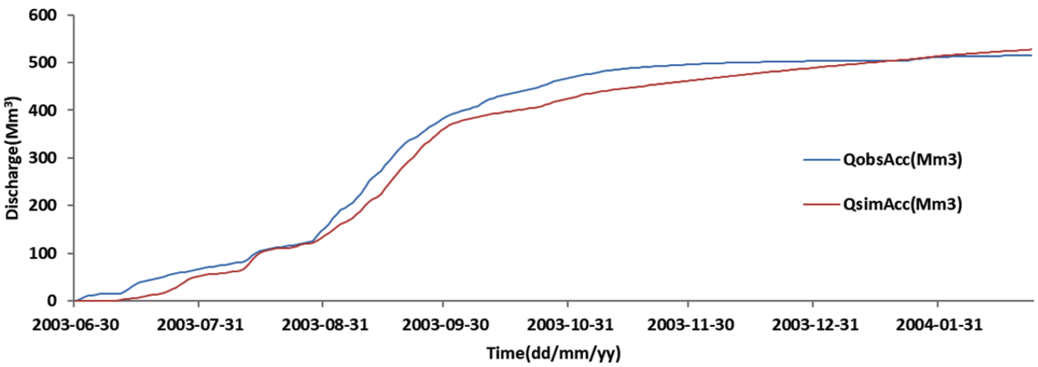

Fig. 4: Accumulated simulated and observed runoff for the period 2003-04 (calibration results)

the computed and observed values. RMSE values equal to zero indicate the computed and observed values are matching perfectly. RMSE is given as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2} \quad ...(7)$$

Where,

Q_{obs} = observed flow at time i number of data points

$\bar{Q}_{obs}$ = mean value of observed flow = $\frac{1}{n}\sum_{i=1}^{n} q_o$

Q_{sim} = simulated flow at time *i*

$\bar{Q}_{sim}$ = mean value of simulated flow

n = number of data point

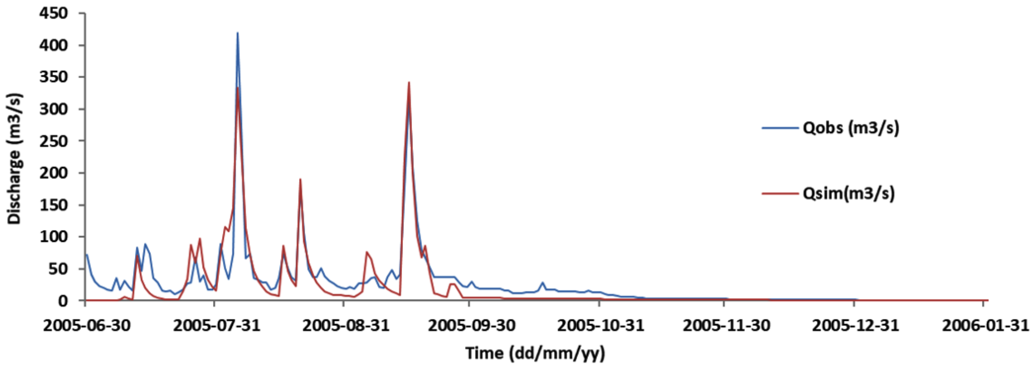

Fig. 5: Simulated and observed runoff for the period 2005-06 (validation results)

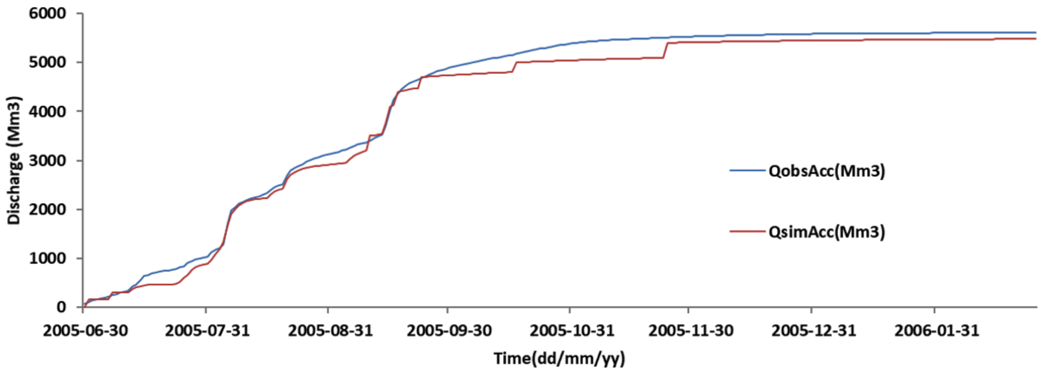

Fig. 6: Accumulated simulated and observed runoff for the period 2005-06 (validation results)

Table 2: Performance of MIKE 11 NAM Model

Model Performance Indices	NAM Model Calibration	NAM Model Validation
Coefficient of determination	0.76	0.73
Root Mean Square Error	22.74	27.13
NS Efficiency Index	0.63	0.61
Water balance	2.23	-7.14

Results and Discussion

NAM model was used for rainfall runoff modeling in Arpa basin at Kota gauge discharge (G/d) site which has 1681.8 km^2 catchment area. In this basin rainfall data of three rain-gauge stations namely Kota, Khtghat and Maniyari is available. Using the information of the available raingauges, Thiessen polygon map has been prepared. Among three rain gauge stations, Kota is the most influencing station covering maximum area. The weights of rain gauge stations with proportion to their representative areas are given in Table 1.

Model Calibration

The objective of the calibration we have chosen to be water balance. The purpose of making water balance first priority of the calibration is because the water availability of the Arpa basin is considered for integrated water resources development and management.

During calibration, optimum model parameters have been estimated by automatic calibration option of the NAM model and manually fine-tuned. The final values of parameters were used in the NAM model to estimate runoff from Arpa basin. Model was calibrated using daily time series data from 2000 to 2004. In order to clearly illustrate the model results during calibration only one year data has been plotted. Figure 3 indicates that the simulated and observed runoff show a good match during calibration for the period 2003-04. Figure 4 presents the accumulated observed and simulated runoff and indicates a very good match during calibration. The nature of rainfall generally indicates spatial variability of rainfall distribution within the catchment and it has a direct impact on rainfall runoff model calibration.

Model Validation

Validation of the model means that the developed model can be applied appropriately not only in calibration data period but also in another time periods. In this study, the effective model parameters are obtained from the calibration processes.

Daily time series data from 2005 to 2009 have been used for model checking i.e. for the model validation. The daily runoff was simulated using rainfall from 2005 to 2009. Figure 5 presents the computed daily runoff of Arpa basin during 2005–2006. The observed and simulated accumulated runoff plot (Figure 6) indicates that the developed model is able to define the runoff generation process of the selected basin.

Accuracy Criteria

The accuracy of the developed MIKE 11 NAM model has been evaluated by coefficient of determination and EI. The Efficiency Index (EI) obtained during this study was 0.63 in calibration and 0.61 in validation (Table 2). Coefficient of determination is obtained as 0.76 during calibration and 0.73 in validation. The Root Mean Square Error (RMSE) is computed for determining the accuracy of MIKE 11 NAM model which defines absolute error between the observed and computed runoffs. In this study, the RMSE value was obtained as 22.74 in calibration and 27.13 in validation. The values of NS Efficiency Index, RMSE and coefficient of determination suggested that the observed and simulated runoff are in good agreement. Model is able to capture most of the peek flows particularly during validation, however during calibration some of the peak flows are not properly captured by the developed model. Uncertainty in data input may be one of the reason for this. It has been observed that the model is capable to capture flow hydrograph more accurately for the period mid June to mid September (monsoon season) while pre monsoon and post monsoon simulations showing difference from observed flows. However, the model gives good matching of accumulated observed and simulated runoff which provides very good estimate of total water availability in the basin.

Conclusions

The runoff estimation for the Arpa basin of Seonath river is hoped to contribute in hydrological analysis, water resources development and management and it also solve the water sharing problems. In this study, the rainfall runoff was successfully modeled using MIKE 11 NAM. Acceptable results were obtained during calibration and validation as confirmed from R^2, EI, RMSE and water balance values. This study demonstrates the usefulness of NAM MIKE 11 for the daily runoff simulation. Furthermore, the developed model can also be used to generate runoff series for future scenarios and thus for developing decision support system for management of water resources.

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Conflict of Interest

The Author(s) declare jo conflict of interest.

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