Rainfall runoff modeling using MIKE 11 NAM of the Jhelum river in Kashmir Valley, India

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सार – यह शोध झेलम नदी बेसिन में श्रीनगर के राम मुंशीबाग गेजिंग स्टेशन में एनएएम (नेडबोरएफस्ट्रॉमिंग्स मॉडल) के निष्पादन, दक्षता और प्रयोज्यता की जांच करता है। एनएएम एक वर्षा–अपवाह मॉडल है जो निर्धारणात्मक, एकमुश्त और संकल्पनात्मक है। वर्ष 2006-2013 के लिए झेलम नदी के राम मुंशीबाग के गेजिंग स्टेशन के लिए मॉडल का मूल्यांकन किया गया था ताकि वर्षा के लिए बेसिन की जल विज्ञान संबंधी प्रतिक्रिया को पुनः प्रस्तुत किया जा सके, और दैनिक अपवाह का सटीक पूर्वानुमान लगाया जा सके। मॉडल को वर्ष 2006-2009 के लिए अंशांकित किया गया और वर्ष 2010-2013 के लिए मान्य किया गया। अनुकरण अवधि के दौरान अधिकतम विसर्जन 746.745 m³/s पाया गया। MIKE 11 सांख्यिकीय विश्लेषण का उपयोग करते हुए, नैश–सटक्लिफ दक्षता (NSE) 0.907, निर्धारण गुणांक (R^2) 0.954, और अंशांकन अवधि के लिए आयतन अंतर (Dv%) 17.8 था। 2010-2013 के सत्यापन वर्ष के लिए, प्राप्त एनएसई 0.963, R^2 (0.892) और (डीवी%) 13 था। झेलम नदी के अपवाह पूर्वानुमान के लिए मॉडल की प्रयोज्यता का प्रदर्शन किया गया, जिसे बेसिन–पैमाने पर एकीकृत जल संसाधन प्रबंधन और उत्पादन के लिएअनुप्रयुक्त किया जा सकता है। परिणामस्वरूप, जल संसाधनों की प्रभावी योजना और प्रबंधन करने के लिए शीतोष्ण जलग्रहण क्षेत्रों में जल विज्ञान संबंधी अनुकरण के लिए मॉडल का सफलतापूर्वक उपयोग किया जा सकता है।

ABSTRACT. This research examines the performance, efficiency and applicability of the NAM (Nedbor Afstromnings Model) in the Ram Munshi Bagh gauging station of Srinagar in Jhelum river basin. NAM is a rainfall-runoff model that is deterministic, lumped and conceptual. The model was evaluated for the year 2006-2013 for the gauging station of Ram Munshi Bagh of Jhelum river in terms of reproducing the basin's the hydrological response to the rainfall and accurately predicting daily runoff. The model was calibrated for the years 2006-2009 and validated for the year 2010-2013. The maximum discharge during the simulation period was found to be 746.745 m³/s. The Nash-Sutcliffe Efficiency (NSE) was 0.907, the Coefficient of Determination (R^2) was 0.954 and the volume difference (Dv%) was 17.8 for the calibration period, using MIKE 11 statistical analysis. For the validation year of 2010-2013, the obtained NSE was 0.963, the R^2 obtained was 0.892 and Dv (%) obtained was 13. The applicability of the model for runoff prediction for the Jhelum river was demonstrated, which may be applied to basin-scale integrated water resource management and production. As a result, the model can be successfully utilized for the hydrological simulations in temperate catchments in order to plan and manage water resources effectively.

Key words – Rainfall, Runoff, MIKE 11, NAM, Srinagar, Kashmir.

1. Introduction

Runoff modeling aids in the comprehension of hydrologic processes and how changes affect the hydrological cycle (Xu, 2002). Runoff models show what happens in water systems as a result of changes in pervious surfaces, vegetation and weather. A runoff model, according to Devi *et al.* (2015), is a series of

equations that aid in estimating the quantity of the rainfall that converts into runoff as a function of several characteristics used to represent the watershed. Surface runoff modeling is challenging since the calculation is complex and contains many interconnected variables. Inputs, governing equations, boundary conditions or parameters, model processes and outputs are all common components of a model (Singh, 1995). Surface runoff modeling is used to predict catchment yields and responses, assess water availability and understand catchment yields and reactions (Vaze, 2012). Calibration to the individual catchment is essential for the rainfall-runoff models to effectively simulate runoff in a catchment. For improved output, calibrated parameters are changed to fit observed data (Beven, 2012; Kumar et al., 2019). A rainfall-runoff model can be calibrated in a variety of ways. The manual trial-and-error method adjusts each model parameter based on observed historical data and the parameters are then visually compared to see if another trial should be run (Singh, 1995). Manual calibration is time-consuming and successful calibration requires experience (Xu, 2002); another flaw is the inability to tell when the "optimal" fit has been achieved (Singh, 1995). Algorithms for automatic optimization are computer-based methods for reducing calibration time. These techniques quickly calibrate the rainfall-runoff models, using confidence intervals to reduce the gap between modeled and observed data (Xu, 2002). To put a value on correctness, goodness-of-fit calibration approaches generate a numerical link between observed and simulated output. Methods such as least squares and maximum likelihood are examples of goodness-of-fit strategies (Pechlivanidis *et al.*, 2011). Obtaining the most trustworthy runoff data necessitates the use of a calibration process. Manual or automatic algorithms might be used to calibrate the model. Model parameters are often modified through trial-and-error and subjective judgment in manual calibration.

For the management of water supplies in different basins, the MIKE 11 model has become increasingly popular. The MIKE 11 NAM is a rainfall-runoff model created by the Danish Hydraulic Institute (DHI) as part of the MIKE 11 module. MIKE 11 is a programme that simulates flows, water quality and sediment movement in rivers, irrigation systems, channels and other bodies of water. Madsen (2000) applied MIKE 11 NAM model following automatic calibration strategy. He used an automated method of optimization based on a shuffled algorithm of complex evolution. The scheme optimizes four separate calibration targets for numerical performance measures : overall water balance, hydrograph overall shape, peak flows and low flows. An automated optimization process can therefore be implemented to solve the problems of multi-objective calibration.

Shamsudin and Hashim (2002) substantiated MIKE 11 NAM model for rainfall-runoff simulation in Layang River in Malaysia. With approximate values of 20.94 m^3/s and 18.93 m^3/s sequentially, the simulated peak flow occurred in 1992 and 1995. Optimum values were presented for the model parameters obtained during the calibration process. On the Efficiency Index (EI) and Root Mean Square Error (RMSE), the reliability of MIKE11 NAM was assessed. The EI and RMSE obtained during this research are respectively 0.75 and 0.08. Arpit *et al.* (2019) tested MIKE 11 NAM rainfall runoff model to develop R-R relationship. The model was developed in the Belkhedi, Narmada basin, Madhya Pradesh, India, using discharge data observed for 7 years. The coefficient of model calibration and validity determination was found to be 0.859 and 0.83, respectively. The Performance Index was found to be 73.7 percent and 67.5 percent respectively during calibration and validation, which is a good deal.

Thus, in this paper the rainfall runoff process for Ram Munshi Bagh Catchment has been modeled using MIKE 11 NAM software. Available water resources in the Ram Munshi Bagh Catchment are over-used, necessitating quick action to develop water resources in the basin in order to meet the expanding demands for water. The runoff was simulated using the study basin's daily rainfall and evaporation series. The model parameters are chosen in such a way that the model accurately simulates the runoff from the Ram Munshi Bagh of Jhelum catchment.

2. Materials and method

2.1. *Study area*

Kashmir Valley forms a part of the Jhelum basin and has a well-developed drainage system. The Jhelum Basin lies between 32°58'42" to 35°08'02" N latitude and 73°23'32" to 75°35'57" E latiitude and is mostly confined within the Kashmir Valley. The approximate width of the Jhelum river is 350 feet at Sangam, 250 feet at Ram Munshi Bagh and 692 feet at Asham. Jhelum basin includes 24 catchments with the left bank tributaries draining the slopes of the Pir Panjal range, while the right bank tributaries come from the Himalayan slopes.

The present study was conducted at Ram Munshi Bagh catchment of Jhelum basin, located in Srinagar city, which is centrally located in the Kashmir region. It is located between 34°0' N to 34°15' N latitude and 74°45' E to 75°0' E longitude. It has a catchment area of 5490 km^2. The present study area is given in Fig. 1.

2.2. *Description of NAM model*

The MIKE11 NAM is a rainfall-runoff model created by the Danish Hydraulic Institute (DHI) as part of
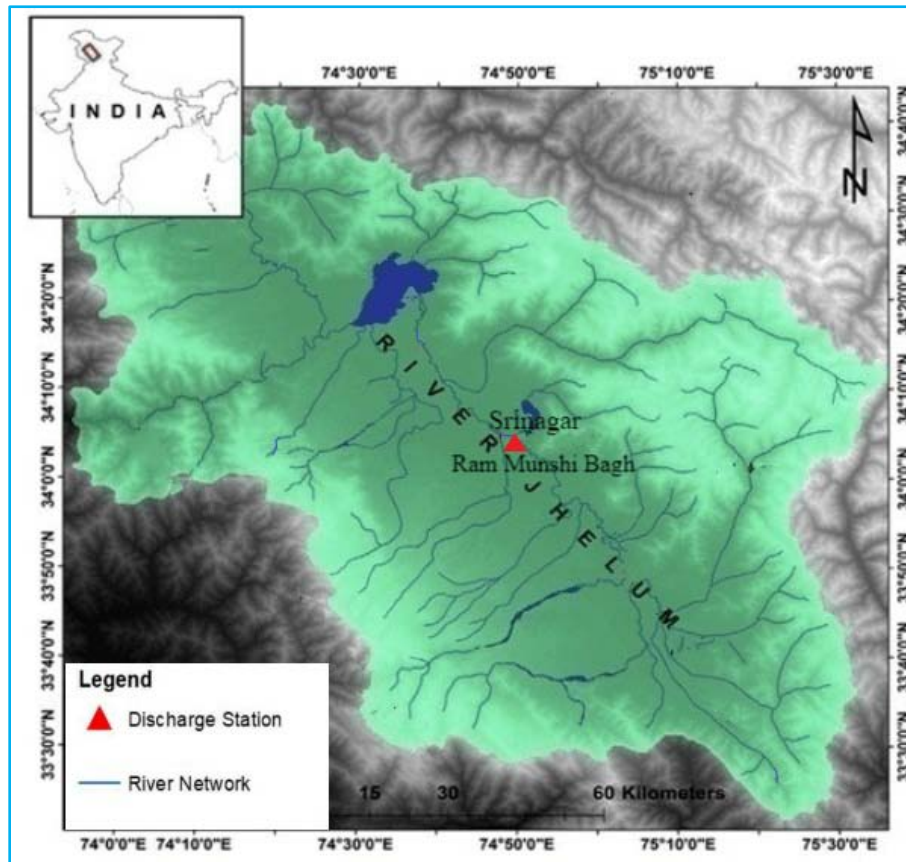
Fig. 1. Map of Kashmir valley showing the location of study area

the MIKE 11 module. MIKE 11 is a programme that simulates flows, water quality and sediment movement in rivers, irrigation systems, channels and other bodies of water. The Nedbor Afstromnings Model (NAM) is a deterministic, lumped and conceptual the rainfall-runoff model that works by continually compensating for moisture content in three separate and directly interconnected storages that depict overland flow, interflow and base flow (DHI, 2008). It considers the parameters and variables to represent average values for the entire sub-catchment since it regards each sub-catchment as a single unit. The end result is a continuous time series of catchment runoff across the simulation period. As a result, the MIKE11 NAM model generates both peak and base flow conditions, taking into consideration antecedent soil moisture conditions across the modeled time period. The NAM model has been used to simulate a variety of the hydrological regimes and climatic circumstances in a number of catchments across the world. Many additional researchers used the MIKE 11 NAM model to model the rainfall runoff, including Fleming (1975); Kjelstrom and Moffat (1981); Kjelstrom (1998); Arcelus (2001); Shamsudin and Hashim (2002) and many others.

The NAM model is a deterministic, lumped and conceptual the rainfall-runoff model that takes into account the water absorption of up to four separate storages. NAM can be produced in a variety of ways, depending on the situation. The surface zone, root zone and ground water storage are all represented by 9 parameters in NAM. The upper limit of the amount of water in the surface storage is known as Umax. Lower zone storage, L, represents the soil moisture in the root zone, a soil layer below the surface from which the vegetation can take water for transpiration. The upper limit of the amount of water in this storage is denoted by Lmax. The potential rate of evapotranspiration is met initially by surface storage. The extra water PN causes overland flow as well as infiltration when the surface storage, U, overflows, *i.e*., when U > Umax. The part of PN that contributes to overland flow is referred to as QOF. The interflow contribution, QIF, is considered to be proportional to U and to fluctuate linearly with the lower zone storage's relative moisture content. With the same time constant CK1K2, the interflow is routed through two linear reservoirs in series. Overland flow routing is based on the linear reservoir principle as well, but with a variable time constant. The amount of infiltrating water,

TABLE 1

Different parameters of NAM Model

Parameter	Description	Effect
U_{max}	Maximum amount of water in surface storage	Overland flow, infiltration, evapotranspiration, interflow
L_{max}	Lower zone maximum water content/root storage	Overland flow, infiltration, evapotranspiration, base flow
C_{QOF}	Coefficient of overland flow	Infiltration and overland flow volume
C_{KIF}	Constant interflow drainage	Interflow drainage of surface storage
T_{OF}	Threshold of overland flow	For overland flow to occur, the soil moisture demand must be met.
T_{IF}	Threshold interflow	For interflow to occur, the soil moisture demand must be met.
T_G	Threshold of groundwater recharge threshold	For groundwater recharge to occur, the soil moisture requirement must be met.
C_{KBF}	Base flow timing constant	Linear groundwater recharge is used to route recharging.

G, refilling the groundwater store is determined by the root zone soil moisture content. The outflow from a linear reservoir with time constant CKBF is used to compute the base flow, BF, from the groundwater storage. Table 1 gives a description of the parameters and their impacts.

2.3. *Input data*

The Meteorological data and discharge data (for Ram Munshi Bagh station) are required for model calibration, specification of catchment parameters and definition of beginning conditions in the MIKE11 NAM model. Precipitation time series, potential evapotranspiration time series and temperature time series are the most fundamental Meteorological data requirements. The model generates a time series of catchment runoff, a time series of subsurface flow contributions to the channel and information about other aspects of the land phase of the hydrological cycle, such as soil moisture content and groundwater levels, based on this information.

2.3.1. *Rainfall*

The daily precipitation data was collected from the Meteorological Department, Srinagar for 8 years, *i.e*., from 2006-2013. This knowledge was needed for the model calibration and the validation. Data for the hydrological year 2006-2009 was used for calibration of the model and the data while the data for the hydrological years 2010-2013 were used for the validation of the model.

2.3.2. *Runoff*

The daily discharge data for the year 2006-2013 was collected from the Irrigation and Flood Control Department, Srinagar for Ram Munshi Bagh station. This

knowledge was needed for the model calibration and the validation. Data for the hydrological year 2006-2009 was used for calibration of the model and the data while the data for the hydrological years 2010-2013 were used for the validation of the model.

2.3.3. *Potential evapotranspiration*

Because of its large impact on runoff in the form of evaporation from the surface, potential evapotranspiration is a key input in the creation of the MIKE 11 NAM model. The Meteorological Department in Srinagar provided the potential evapotranspiration statistics for the years 2006 to 2013.

2.4. *MIKE 11 NAM Model Set-up*

The MIKE 11 NAM model was used to model the rainfall and runoff in the Ram Munshi Bagh watershed. The daily rainfall, runoff and potential evapotranspiration input data was converted in format using MIKE ZERO software and then used for model development over an eight-year period from 2006 to 2013.

2.4.1. *Model calibration*

Calibration is the process of normalizing expected values by computing input parameters based on deviations from observed values for a specific area. These correction factors may then be used to generate predicted values that are compatible with the observed values. The MIKE 11 NAM model was calibrated over a four-year period from 2006 to 2009 once it was built up with the input data. The default model settings were kept the same during calibration and the model was run in auto-calibration mode. During calibration, the coefficient of determination value (R^2) of the model output simulation data was verified. The model parameters were

tweaked one by one using the trial and error method to find the set of best fit model parameters that could accurately replicate runoff in terms of timings, peaks and total volume.

2.4.2. *Model validation*

Model validation refers to evaluating the calibrated model's performance over the fraction of historical records that were not used in the calibration. The MIKE 11 NAM model was subsequently calibrated and validated for the remaining four years, from 2010 to 2013. The set of model parameters obtained during calibration were used for the validation and the model was run without auto-calibration mode to simulate runoff. To test the calibrated model's capacity to simulate runoff, the statistics of the simulated results were examined and the model's outcome was evaluated to correlate the simulated and observed runoff.

2.5. *Accuracy criteria*

Accuracy of the model can be examined on the basis of coefficient of determination (R^2), efficiency Index (*EI*) and percent volume difference (D_v). 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 accuracy criteria of the MIKE 11 NAM model were calculated by using the following equation:

2.5.1. *Nash Sutcliffe Efficiency coefficient*

The Nash-Sutcliffe Efficiency (NSE) is a standardized statistical measure that specifies the relative extent of the residual variance compared to the data variance measured (Nash and Sutcliffe, 1970). Nash-Sutcliffe efficiency demonstrates how well the 1:1 line suits the plot of observed versus simulated results. NSE = 1, refers to the model's perfect fit to the data observed. NSE = 0, means that the predictions for the model are as precise as the mean of the data observed. The NSE is determined as follows :

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Obs_i - Sim_i)^2}{\sum_{i=1}^{n} (Obs_i - \overline{Obs})^2} \qquad (2)$$

where,

Obs_i is the observation value

Sim_i is the forecast value

$\overline{Obs}$ is the average of observation values

2.5.2. *Coefficient of determination (R^2)*

The correlation of R^2 determines how well the regression model fits the results. The coefficient of determination, R^2, is identical to the coefficient of correlation, R. The formula of the correlation coefficient will tell you how effective a linear relationship is between two variables. R^2 is the square of the coefficient of correlation. You need to calculate the Pearson correlation and then square it in order to calculate R^2. In equation, the coefficient of determination is computed as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Obs_i - Sim_i)^2}{\sum_{i=1}^{n} (Obs_i - \overline{Obs})^2} \qquad (3)$$

where,

Obs_i is the observation value

Sim_i is the forecast value

$\overline{Obs}$ is the average of observation values

2.5.3. *Percent Volume Difference (D_v)*

Perhaps the simplest goodness-fit criterion is the variance of runoff volumes Dv, also known as the percentage bias. WMO (1986) gives the deviation of the runoff volumes. The variance of runoff volumes is equal to zero for a perfect model. The smaller the value of variance runoff volumes, the better the model's efficiency. The percent volume difference can be computed as follows:

$$D_v\% = \frac{\sum_{i=1}^{n} (S_i - O_i)}{\sum_{i=1}^{n} O_i} \times 100 \qquad (4)$$

where,

O_i is the observed value.

3. Results and discussion

The MIKE 11 NAM model was developed to carry out the rainfall-runoff modeling at Ram Munshi Baghgauging station using daily rainfall data, daily discharge data and daily potential evapotranspiration data.
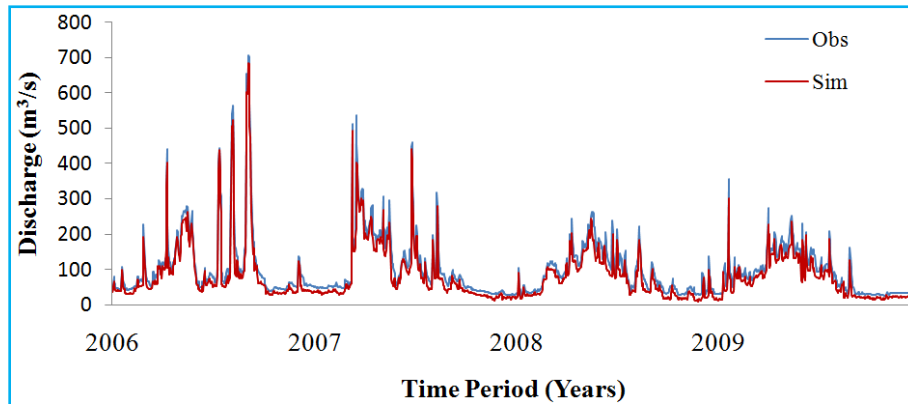
Fig. 2. Model simulated and observed discharge for the year 2006-2009
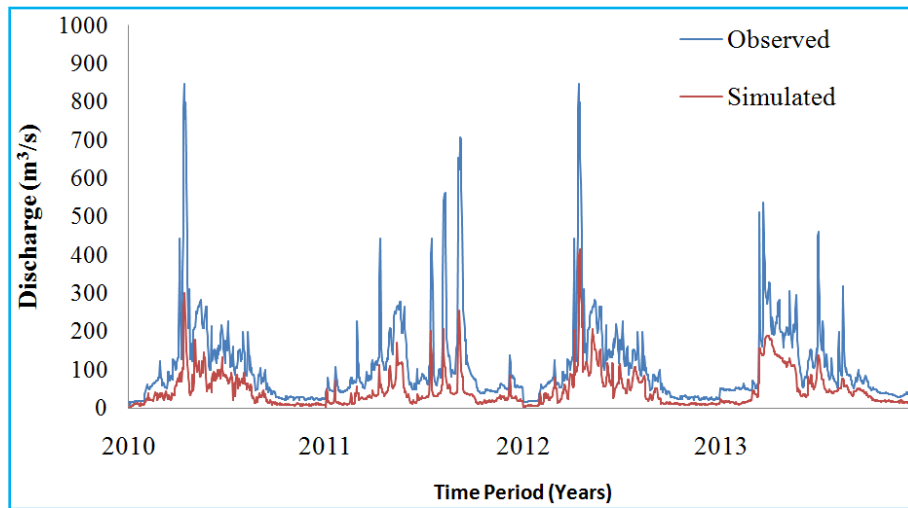

Fig. 3. Model simulated and observed discharge for the year 2010-2013

3.1. *Model calibration*

The MIKE11 NAM model was built up with all input data and calibrated during a four-year period from 2006 to 2009 to find the best set of model characteristics for simulating runoff with a high-level of agreement with observed runoff. As indicated in Table 2, the set of model parameters collected during model calibration were found to be within their particular limit.

Fig. 2 provides a comparison of observed and simulated monthly runoff volume. In terms of runoff volume, the monthly observed and simulated runoffs were practically identical, as seen in the Fig. 2. It is clear from Fig. 2 that the runoff hydrographs of several events over the calibration period and it was shown that the morphologies of observed and simulated runoff hydrographs were almost identical for almost all of the

TABLE 2

Model parameter values of model calibration and their range

Parameter	Unit	Model parameters final value	Parameter range
U_{max}	mm	15.4	5.76-20
L_{max}	mm	138	100-300
C_{QOF}		0.85	0.1-1
C_{KIF}	hrs	654.9	200-1000
T_{OF}	hrs	0.45	0-0.99
T_{IF}		0.35	0-0.99
T_G		0.65	0-0.99
C_{KBF}	hrs	989.5	500-1000

runoff occurrences. The observed and predicted runoffs were found to be very similar in these graphs. It can also

TABLE 3

Model Calibration Results

Year	Observed discharge	Simulated discharge	RF	PET	AET	GWR	OF	IF	BF
2006	706.483	684.215	992	1435.6	543.2	332.1	597.6	20.9	324.5
2007	537.7	484.128	865	1432.2	433.4	234.5	298.7	15.4	245.3
2008	263.19	244.93	435	1321.5	334	123.78	199.3	10.9	130.9
2009	355.83	300.184	567	1412.3	443	198.7	265.4	13.2	250.3

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

TABLE 4

Model validation results

Year	Observed discharge	Simulated discharge	RF	PET	AET	GWR	OF	IF	BF
2010	736.23	598.993	985	1435	532	324.5	578.9	23.43	332.7
2011	706.483	554.698	975.21	1425	512.5	303.2	546.3	20.19	321.5
2012	746.745	514.778	995.43	1448	556	356.98	598.76	26.78	350.98
2013	537.7	489.189	843.25	1405	432.1	234.5	303.42	14.32	257.8

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

TABLE 5

Model Accuracy Criteria

Model Accuracy Criteria	Nash-Sutcliffe Efficiency (N_{SE})	Coefficient of Determination (R^2)	Deviation Volume (Dv %)
Calibration Period (2006-2009)	0.907	0.954	17.8
Validation Period (2010-2013)	0.963	0.892	13.2

be shown that the start and end times of actual and simulated runoff episodes were very similar, whereas the escalation in peak values of runoff events was only moderately accurate. The results of model calibration is also shown in Table 3.

The statistics of essential aspects of the hydrological cycle simulated during model calibration, such as runoff, actual evapotranspiration, ground water recharge, overland flow, interflow and base flow. The coefficient of determination (R^2) for the model calibration was 0.954, indicating that the observed and simulated runoffs were in excellent accordance in terms of time, pace and volume (Table 5). The N_{SE} value was found 0.90 and D_v (%) 17.8.

3.2. *Model validation*

The MIKE 11 NAM model was subsequently verified for the remaining four years from 2010 to 2013 using the same set of model parameters obtained during model calibration (Fig. 3). The results of model validation is summarized in Table 4. Table 5 shows the statistics of simulated the hydrological components during model the validation. The coefficient of determination for the validation period of the model was 0.892, indicating that the constructed model was performing well in simulating runoff in terms of time, rate and volume in good agreement with observed runoff.

3.3. *Model accuracy criteria*

The MIKE 11 statistical results between observed and simulated discharge for the calibration period showed Nash-Sutcliffe Efficiency (N_{SE}) equal to 0.907, the Coefficient of Determination (R^2) equal to 0.954 and Volume Difference ($D_v\%$) equal to 17.8%. For the validation year of 2010-2013, the obtained N_{SE} was 0.963, the R^2 obtained was 0.892 and Dv% obtained was 13.2% as shown in Table 5.

4. Conclusions

The applicability of the constructed model for runoff prediction in Srinagar is demonstrated in this study, which may be applied to basin-scale integrated water resource management and production. The MIKE 11 NAM the rainfall runoff model was found to be acceptable for the Ram Munshi Baghgauging station of Jhelum Catchment in terms of simulating the hydrological response of the basin to the rainfall and accurately predicting daily runoff. In terms of time, rate, volume and hydrograph shape, the model was seen to perform well in simulating runoff in good agreement with observed runoff. Thus, the rainfall runoff model built far appears to be capable of predicting runoff in the Ram Munshi Bagh of Jhelum river catchment over a long length of time. The model was found to be effective in generating runoff using the rainfall data and it might be a significant tool in the Jhelum catchment's water resource management and planning.

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Disclaimer : The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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