Eco. Env. & Cons. 27 (4) : 2021; pp. (1941-1948)
Copyright@ EM International
ISSN 0971–765X

Assessing the Feasibility of a Conceptual Rainfall Runoff Model for Different Flow Conditions over Tel River Basin, India

Brijesh Kumar[1]*, Wagari Ejigu Chali[1] and Duba Chena Dero[2]

[1]Dept. of Hydraulic & Water Resources Engineering, Bule Hora University, Ethiopia
[2]Department of Irrigation and Water Resources Engineering, Bule Hora University, Ethiopia

(Received 21 May, 2021; Accepted 30 June, 2021)

ABSTRACT

Estimation of monthly maximum and average discharge is very important for structural design and maintaining the environmental flow in the regulated rivers. In this paper an attempt has been made to apply a conceptual rainfall runoff model NAM (NedbørAffstrømnings Model) to investigate the peak and average monthly flow for flood prone Tel River basin, Odisha, India. The model was calibrated and validated based on the five years of daily data, out of which 70% of the data was used for calibration and rest 30% for validation. The model has attained very good Nash and Sutcliffe Efficiency (NSE) 0.82, Correlation Coefficient (R^2) 0.84 values during calibration and also NSE 0.76, R^2 0.80 during validation period. Calculation of flood peak is important in early warning at the downstream areas and thus its calculation should be very quick, realistic and with limited input data. The study has found that model is good enough in simulating the monthly peaks and monthly average discharge (R^2>0.0.9) with only two input forcing. Therefore, model results can be used for structural design and management of minimum environmental flow (in case of up-stream regulating reservoir) on a data deficit large catchment.

Key words : *Conceptual Rainfall, Runoff model, Tel River Basin, Ethiopia*

Introduction

Runoff estimation is very important for various water resources studies. Runoff is basically estimated based on the rainfall-runoff (R-R) analysis. To model the R-R process, there are three types of hydrological models viz. Physically based RR model, conceptual R-R model and black box RR model (Devia et al. 2015). The physically based modelsare most scientific because they considers the physical process of basin by solving physical equations of hydrological process, however these are complex to apply and requires huge input data (Kumar *et al*. 2017a; Kumar and Lakshmi, 2018). Also, error in terrain morphology and spatial aquifer properties affect the hydrological outcome from the physical model (Kumar *et al.*, 2013, 2016, 2017b; Kumar and Roy, 2019). On the other hand, black box models are just fitting the output without considering the physical process of the system and thus it has no scientific backing (Gautam *et al.*, 2000). To accomplish the benefits of black-box and physical based models, conceptual models have been developed which simplified the physical processes of the systems and furnishes output with the least input data (Darbandsari and Coulibaly, 2020).

Lumped conceptual models are developed based on the conceptual representation of hydrological processes over the watershed e.g., Tank model (Sugawara, 1995), HBV model (Bergstrom S 1995) and NAM model (DHI, 2017a; Nielsen and Hansen

1973) etc. Since, the model parameters of conceptual lumped models cannot be directly quantified from the catchment characterises and therefore model calibration is must. The model calibration can be manual (based on the trial-and-error type of parameter adjustment) or automatic. In automatic type of calibration process, the parameters are fitted as per a specified search scheme and the resulting numerical measures of the goodness-of-fit Madsen (Madsen 2000).

The NAM model is a part of MIKE 11 R-R module (DHI 2017a). This model has been used widely for runoff estimation at a catchment scale (Aredo *et al.,* 2021; Kamel 2008; Refsgaard and Knudsen 1996; Thompson *et al.,* 2004). Also, NAM model has shown its worth for the catchments with limited to no data (Aredo *et al.,* 2021; Refsgaard and Knudsen 1996). Modelling and forecasting of water resource systems, including R-R process by conceptual models have been attempted by many researchers in the past(Aredo *et al.,* 2021; Kamel, 2008; Refsgaard and Knudsen 1996; Thompson *et al.,* 2004). Among all, very few have attempted to see the feasibility of NAM on coarser time scale especially at monthly time period which are very important for water resource allocation for different purposes and to maintain the optimum environmental flow at downstream sites (Hafezparast, 2013).

In this study, an attempt has been made to showcase the R-R modelling using conceptual hydrological NAM model for a rapidly flood affected Tel River basin using limited input data. The results from the model are evaluated with different statistical indicators based on the gauged discharge data for only three years.

Study Area and Data Set

The Tel River Basin is a sub-catchment of Mahanadi River basin which originates from the plane lands of Koraput district of Orissa, about 32 km to the west of Jorigam. The main tributaries of the Tel River are Udanti, Lant, Sutkel, Indra, Rail, Ret, Hatti, Uttei and Khadago. The Tel basin is approximately rectangular in shape having maximum length of 230 km

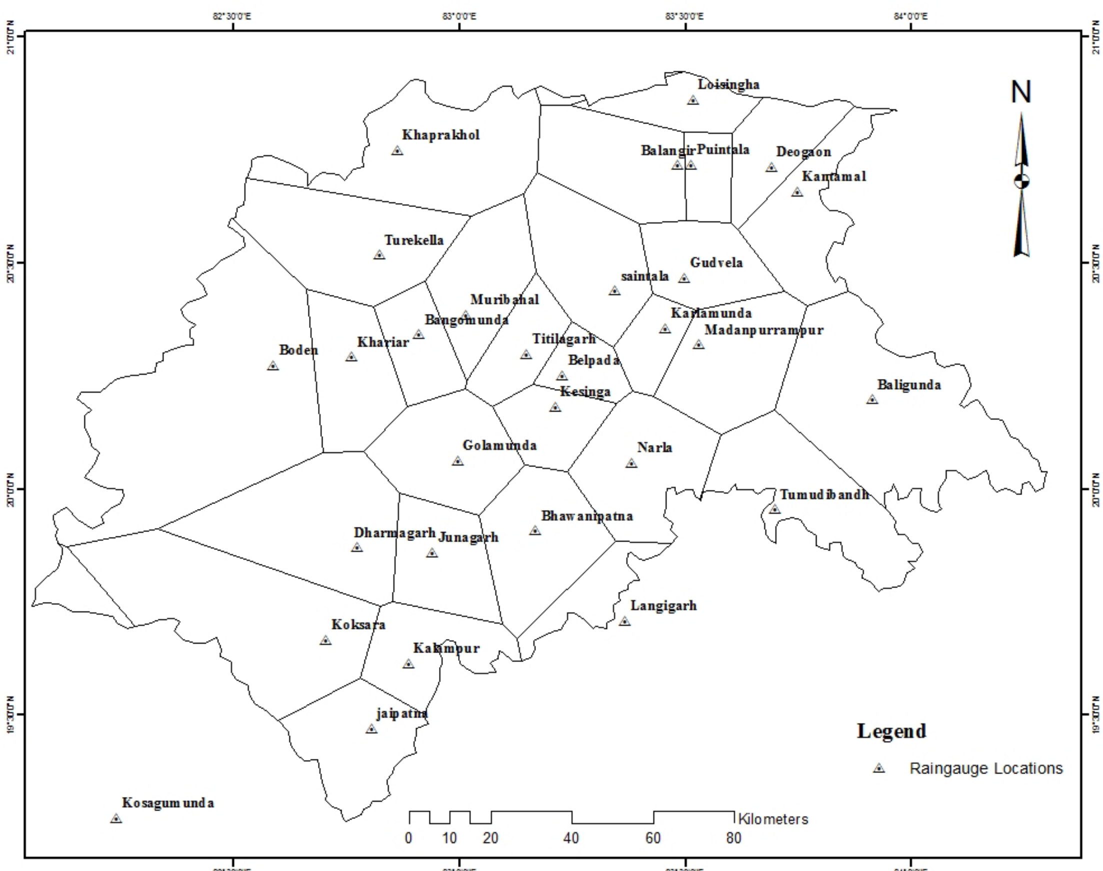

Fig. 1. Location map of the study area and contributing Theisen areas for corresponding gauge stations

towards east-west and a width of 182km in the north-south direction. It has total area of around 22,818 km^2 which is bounded between the geographical position's north latitudes of 19° 15′ and 20°55′ and east longitudes of 82° 03′ and 84°17′ (Fig. 1). The Tel Rivertravels a total length of 296 km and then joins the Mahanadi River on the right bank, 1.6 km below Sonepur and brings huge unregulated flow which use to flood the downstream flat coastal areas.

The NAM model uses rainfall and evapotranspiration as input data. For the present study, the rainfall data for five years and 28 stations (Figure 1)were collected from the Orissa Rainfall Monitoring System (https://rainfall.nic.in/login.asp)and evapotranspiration for one station (Golamunda) from Krishi Vigyan Kendra, Orissa Agriculture University. For the NAM model the area representation for each rain-gauge station was assigned based on the Theisen polygon analysis.

Methodology

Description of the Model

The NAM (NedbørAffstrømnings Model) was developed by Technical University of Denmark (Nielsen and Hansen 1973)as a lumped conceptual R-R model for European snow dominated catchments. In this model, "the hydrological cycle is the basis of the quantitativesimulation of water storage and flows in the watershed and itsparameters represent an average value for the whole watershed". The model has four different but mutually related storages and their respective flow as shown in the Figure 2.

The four storage layers are namely snow storage, surface storage, lower zone storage and underground storage. Also, three flow systems are flow (QOF), interflow (QIF) andunderground flow (QBF). Mainly, rainfall,potential evapotranspiration and temperature are main input data required, however the output of the model is time dependent discharge at the watershed outlet (DHI 2017b).

Auto-calibration

The final model parameters for the NAM model are calibrated by the observed discharge at the basin outlet. This calibration process can be done either manually or automatically. The auto-calibration use to be done to optimize the two objective functions

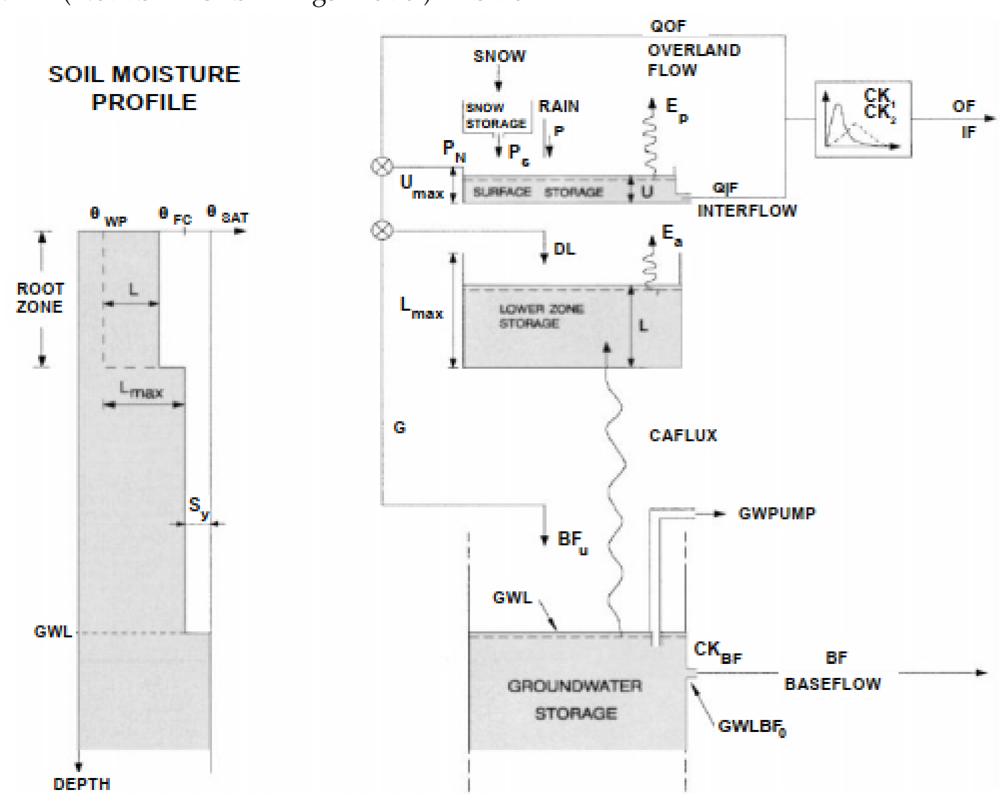

Figure 2: NAM Model Structure(DHI 2017a)

viz."(a) minimizing the percentage bias (%PBIAS) tostablish an agreement observed and simulated runoff (b) maximizing theNash and Sutcliffe Efficiency (NSE) for whole time span so that an agreement between the shape of observed and simulated hydrograph can be established(Madsen 2000, 2003)".

The Auto-calibration is done by assigning equal weight for each objective and the optimum parameterization isachieved by shuffled complexevolution algorithm (SUFI)(Madsen 2000, 2003).In thispaper, the calibration scheme includes "the overall volume error andthe improvement in the NSE(DHI 2017b; Madsen 2000, 2003). Calibration of the NAM R-R model is achieved by adjusting nine parameters (related to surface, root zone and ground water) anddefining the initial conditions to achieve set optimal objective functions value (PBIAS and NSE).Then the parameters are estimatedwith a calibration procedure that was based on available discharge data.Apart from that, two groundwater parameters (recharge to lower reservoirsand a time constant for routing lower base flow) were also included in order to simulatea slower base flow in catchments so that the model performance can be improved.All these parameters were fitted with the auto-calibration procedure.

Calibration of the NAM 11 RR model was then done for three year of time span(1st January 2008 to 31st December 2010) using discharge for one outlet station named Kantamal (Figure 1). The first phase the NAM model was applied for the R-R calibration process and to determine the optimumvalues of the model parameters. The second phase is the discharge simulation and the prediction based on the estimated model parameters during the calibration process. The study has evaluated the performance of the model during simulation period using three statistical indicators listed in the below equations.

$$R^2 = \left(\frac{\sum_{i=1}^{n}(o-\bar{o})(s-\bar{s})}{\left[\sum_{i=1}^{n}(o-\bar{o})^2 \sum_{i=1}^{n}(s-\bar{s})^2\right]^{0.5}}\right)^2 \quad .. (1)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(o-s)^2}{\sum_{i=1}^{n}(o-\bar{o})^2} \quad .. (2)$$

$$PBIAS = \frac{\sum_{i=1}^{n}|o-s|}{\sum_{i=1}^{n} o} \times 100 \quad .. (3)$$

Results and Discussion

In this study, conceptual model MIKE 11-NAM model was used to predict the daily runoff for Tel River sub-catchment. The model calibration was done for three years (1st January 2008 to 31st December 2010) and validation for two years (1st January 2011 to 31st December 2012), following the rule of 70% input data for calibration and 30% data for validation. Following the model auto-calibration and validation procedure, the fitted parameters were used to simulate the discharge for the entire time span of five years.

It is evident from the model structure that the fitted NAM parameters are representative of catchment's hydrology in the pre-classified range (upper and lower bound) during the auto-calibration process. For this study, NAM parameters estimated for the Tel River catchment are presented in Table 1.

Figure 3 & 4 are showing the graphical representation and evaluation of NAM model's result during the calibration and validation period respectively. During calibration period, model has achieved the

Table 1. Fitted NAM parameters for Tel Sub-basin

Parameters	Description	Upper Bound	Lower Bound	Final Value
Umax (mm)	Maximum water content in surface storage*	5	35	16.8
Lmax (mm)	Maximum water content in root zone storage	50	350	220
CQOF (-)	Overland flow runoff coefficient	0	1	0.22
CKIF (hr)	Time constant for routing interflow	500	1000	680
CK1,2 (hr)	Time constant for routing overland flow	3	80	76
TOF (-)	Root zone threshold value for overland flow	0	0.99	0.86
TIF (-)	Root zone threshold value for interflow	0	0.99	0.00012
TG (-)	Root zone threshold value for GW recharge	0	0.99	0.52
CKBF (hr)	Time constant for routing base flow Lower	500	6000	5951
Cqlow (-)	base flow/recharge to lower reservoir Time	0	100	67
Cklow (hr)	constant for routing lower base flow	1000	30000	1915

NSE 0.82 and R^2 0.84 while during validation period NSE 0.76 and R^2 0.80. The model has performed well to depict the flow pattern especially the peak flow, however it had weak performance during non-monsoon seasons compared to monsoon season. For the entire simulation period of five years (January 2008 to December 2012),the statistical indicator for the observed VS simulated discharge are very good in terms of NSE 0.78, R^2 0.82 and PBIAS<16.42%.

Also, the runoff peaks are quite well depicted by NAM model and as it is reflected in figure 3 for 13th August 2008, 17th July 2009 and 10th August 2010. However, during low flow the PBIAS is very high which is seen (Fig. 3) in terms of mis-match of the hydrograph between observed and simulated runoff during non-monsoon season. The interest of this research is (a) predict the runoff peaks and dates and (b) mean monthly runoff in quick time with limited hydrological data for the Tel River Basin so that the downstream flood and water management problems can be solve. The NAM model has performed optimally for the given objectives and constrains during the simulation period (1st January 2008 to 31st December 2009).

Figure 5 is the cumulative density plot of observed vs simulated runoff and the Kantamal gauging site. This shows that the simulated flow is below the observed for flow <3000m³/s, which means the flow observations are not properly being simulated by NAM model. However, simulated and observed graph are almost overlapping to each other for flow >3000m/s, which means that the NAM model is very good in depicting the high flow or peak flow.

The scatter plot of monthly minimum, maximum,

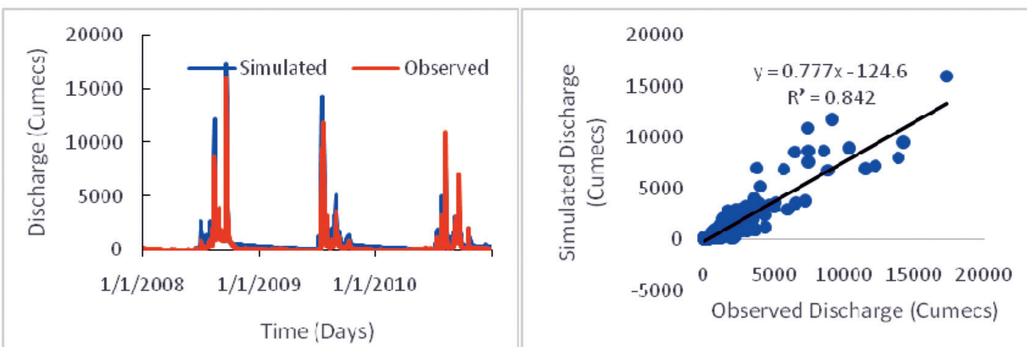

Fig. 3. Time series and scatter plot for calibration period (2008-2010)

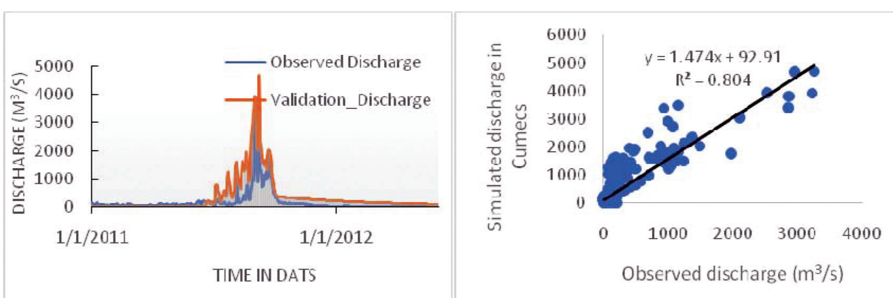

Fig. 4. Time series and scatter plot for calibration period (2011-2012)

Table 2. Yearly statistics of Observed VS Simulated discharge for the Tel Basin

Year	Observed (m^3/s)				Simulated (m^3/s)			
	Mean	Min	Max	Sum	Mean	Min	Max	Sum
2008	537.696	35.411	2505.076	6452.356	712.798	0.426	2986.343	8553.577
2009	362.222	30.665	2227.941	4346.666	741.253	118.536	3490.052	8895.037
2010	322.668	37.581	1208.055	3872.019	594.352	103.078	1647.165	7132.223
2011	412.324	36.523	2326.921	4352.668	672.534	106.352	3592.022	8792.237
2012	362.868	38.461	2228.056	4172.289	794.285	102.678	2649.865	8232.323

average and accumulated simulated vs observed flow are presented in the Figure 6. The monthly maximum value for observed and simulated flow has R^2>0.91 which is very good and it indicates the monthly maximum values are predicted well by the model. Therefore, the model can be applied for the cases such as irrigation water distribution where knowledge of peak monthly water availability is desired. Also, since the maximum peak values are responsible for flood, and therefore monthly flood frequency analysis based on the NAM simulated flow may provide a basis when observed data is not available at the desired river reach. The monthly accumulated and monthly average simulated vs observed scatter plot have R^2 values >0.9 which indicate that the model is very good to do the monthly water balance studies and related application such as water supply and integrated water resources management at the catchment scale. The R^2 for monthly minimum simulated vs observed flow is <0.6 which is not good at this time scale, therefore NAM model needs to be improved for low flow simulations. Also, since it is not able to predict the flow properly, therefore the simulated NAM discharge may not be useful for drought related studies where accuracy of low flow simulation is must.

By comparing the output of NAM model, it is evident that the results are useful at monthly maximum, monthly average, and monthly accumulated scale since it has R^2>0.9 for monthly maximum, monthly average, and monthly accumulated. However, during monthly minimum scale the results are showing poor agreement between the observed and simulated flow. It means that model results are use-

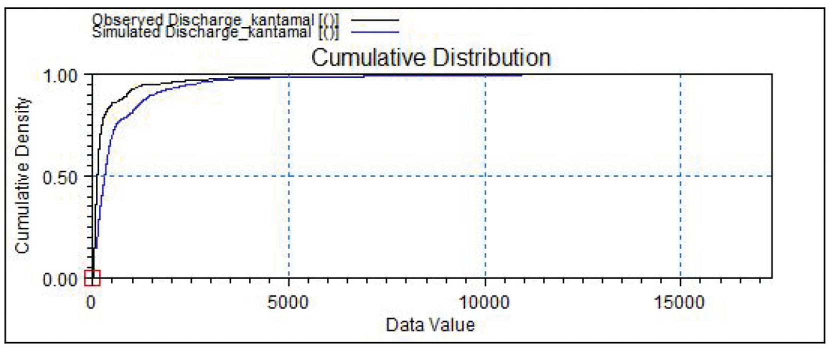

Fig. 5. Cumulative density plot between observed VS Simulated records

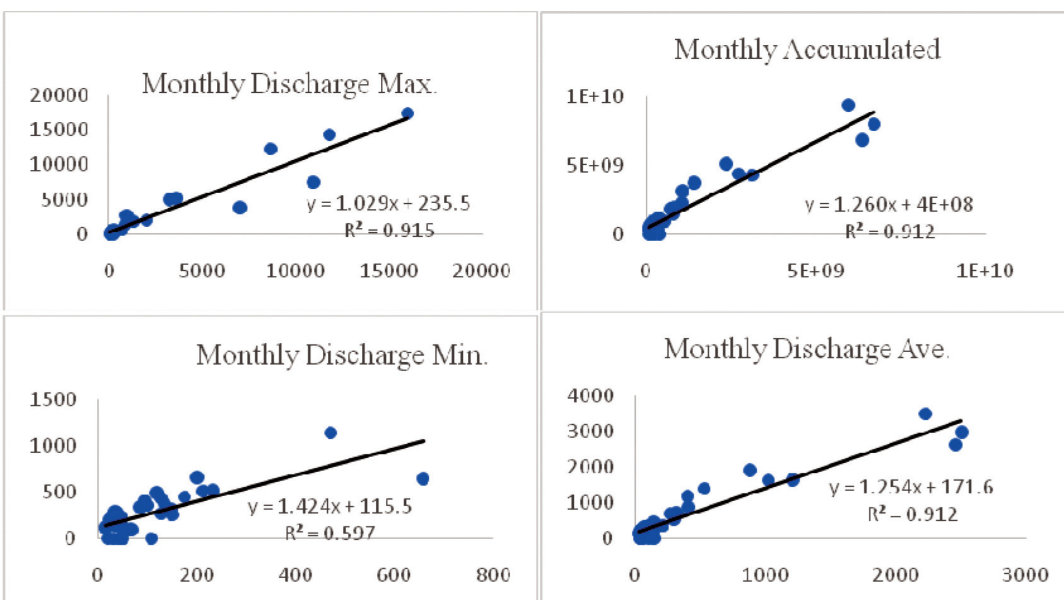

Fig. 6. Regression analysis plot (gauge VS simulated) for monthly maximum, minimum, average and accumulated flow for Tel Sub-basin.

ful to use in water management models like MIKE BASIN, WEAP as a time series. Because the monthly maximum, average, and accumulated discharge value for a basin is important than the monthly minimum discharge to calculate the design of downstream infrastructure. However, the minimum flow in the downstream areas can be moderated and managed by the reservoir's operations.

Figure 7 shows the probability of exceedance curve of monthly average observed VS simulated flow. This curve can be divided in three parts for the explanation. The first phase is from 0-30% of probability of exceedance where the simulated average monthly discharge is being over estimated but are very reasonable, which indicates that the model is able to correctly estimating the peak value of average monthly flow. The second phase is from 30-80% of probability of exceedance, where the simulated average monthly flow is again slightly the observed average monthly flow. The third phase of the graph is from 80-100% of probability of exceedance where the observed and simulated average monthly flow has relatively high over estimation which indicates that the lower value of average monthly flow are not being depicted well by the NAM model.

The comparison of yearly mean, minimum and

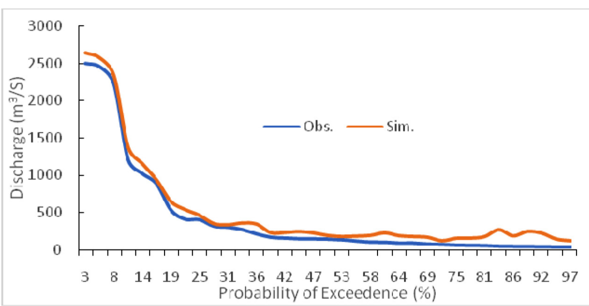

Fig. 7. The exceedance probability curve of monthly average flows forsimulated and observed discharge.

maximum flow value between observed and simulated discharge is presented in Table 2. It clearly indicated that the model has tendency to overes timate the yearly flow very much and therefore these are not good for water management or futuristic water basin wide water management. Similarly minimum yearly flow is being overes timated for more than three times that the observed minimum flow. However, mean yearly flow is over estimated by two times. From these results, it is very clear that the model is mostly over estimating the flow at the yearly time step and these results will have very limited to no use in further studies. This shows that the NAM model has limitation in evaluating the large time scale flow and therefore can be only used to calculate the event based peak flow.

Conclusion

In the present study large scale rainfall-runoff modelling was conducted using conceptual hydrological model NAM in view of ascertain its ability in different temporal scale especially for monthly peak flow. Monthly and peak flows are the two most important criteriato design the reservoirs and for water basin management planning.The MIKE 11-NAM conceptual R-R model was applied to theTel sub-catchment of Mahanadi River basin, India. The time period for the model analysis was five years. In this study, an automatic calibration procedure of MIKE-NAM was used to calibrate the model parameters against the observed daily discharge at Kantamal station in the Tel River over a period of three consecutive years (1st January 2008 to 31st December 2010). The model's performance was significantly improved after using additional groundwater parameters. After calibration, model was validated for the two years three years (1st January 2011 to 31st December 2012) on daily basis and satisfactorily (NSE 0.76, R^2 0.80) predicted the discharge at Kantamal gauge station.

The present research has shown the efficient and interesting perforce in predicting the peaks along with the dates for Kantamal gauge site. Also, the monthly discharge indicators for maximum, accumulated and average had very good regression coefficient value (R^2>0.9), however for the monthly minimum discharge the regression coefficient is poor (R^2>0.6). Monthly averages and maximum discharge are vital than monthly minimum discharges to calculate the designs discharge for downstream structures manage the minimum environmental flows. Therefore, in these cases, studies may use the results of the NAM model calibrated ondaily basis and thenthe computed monthly discharges (maximum, average ad accumulated) can be utilized in water management models like Mike basin,WEAP etc. The rainfall-runoff models like MIKE-11 NAM are lumped conceptual modelswhich requires a very few input data to calculate daily and then monthly discharges. Therefore, conceptual models like NAM are very useful tools for water management on a large scale.

Acknowledgment

Authors would like to acknowledge department of civil engineering, national institute of technology Rourkela (especially Professor KC Patra) for providing the licenced MIKE-11 software to conduct this study.

References

Aredo, M. R., Hatiye, S. D. and Pingale, S. M. 2021. Modeling the rainfall-runoff using MIKE 11 NAM model in Shaya catchment, Ethiopia. *Modeling Earth Systems and Environment*, Springer International Publishing.

Bergstrom, S. 1995. The HBV model.*Computer Models of Watershed Hydrology*, S. VP, ed., Water Resources Publications, Colorado, 443–476.

Darbandsari, P. and Coulibaly, P. 2020. Inter-comparison of lumped hydrological models in data-scarce watersheds using different precipitation forcing data sets: Case study of Northern Ontario, Canada. *Journal of Hydrology: Regional Studies*, Elsevier, 31, 100730.

Devia, G. K., Ganasri, B. P. and Dwarakish, G. S. 2015. A Review on Hydrological Models. *Aquatic Procedia*. 1001–1007.

DHI. 2017a. MIKE Zero General Documentation.https://manuals.mikepoweredbydhi.help/2017/MIKE_Zero_General.htm.

DHI. 2017b. *MIKE 11 River and Channel Modelling: Short Introduction - Tutorial. DHI headquarters, Hørsholm Denmark*.

Gautam, M. R., Watanabe, K. and Saegusa, H. 2000. Runoff analysis in humid forest catchment with artificial neural network. *Journal of Hydrology*, Elsevier Science B.V., 235(1–2) : 117–136.

Hafezparast, M. 2013. A Conceptual Rainfall-Runoff Model Using the Auto Calibrated NAM Models in the Sarisoo River. *Hydrology Current Research*. 04(01): 1–6.

Kamel, A. H. 2008. Application of a Hydrodynamic MIKE 11Model for the Euphrates River in Iraq. *Slovak Journal of Civil Engineering*. 2 : 1–7.

Kumar, B., Chandola, V. K. and Mohan, D. 2013. Determination of Transmissibility of Ban-Ganga Sub-Catchment Aquifer in Chitrakoot District of Bundelkhand Region. *Environment & Ecology*. 31 : 1581–1585.

Kumar, B., Chandola, V. K., Mohan, D., and Patra, K. C. 2016. A way to identify groundwater potential zones (GWPZS) in rocky Terrains (India). *Ecology, Environment and Conservation*. 22(3) : 1237–1244.

Kumar, B. and Lakshmi, V. 2018. Accessing the capability of TRMM 3B42 V7 to simulate streamflow during extreme rain events: Case study for a Himalayan River Basin. *Journal of Earth System Science*, Springer India. 127(2) : 1–15.

Kumar, B., Lakshmi, V. and Patra, K. C. 2017a. Evaluating the uncertainties in the SWAT model outputs due to DEM grid size and resampling techniques in a large Himalayan river basin. *Journal of Hydrologic Engineering*. 22(9) : 1–12.

Kumar, B., Patra, K. C. and Lakshmi, V. 2017b. Error in digital network and basin area delineation using d8 method: A case study in a sub-basin of the Ganga. *Journal of the Geological Society of India*. 89(1) : 65–70.

Kumar, B. and Roy, D. 2019. Analysis of flooding and drying conditions through trend analysis of amsr-e satellite soil moisture over the Himalayan Gandak River basin. *Ecology, Environment and Conservation*. 25(2) : 691–697.

Madsen, H. 2000. Automatic calibration of a conceptual rainfall–runoff model using multiple objectives. *Journal of Hydrology*. 235(3–4) : 276–288.

Madsen, H. 2003. Parameter estimation in distributed hydrological catchment modelling using automatic calibration with multiple objectives. *Advances in Water Resources*, Elsevier. 26(2) : 205–216.

Nielsen, S. A. and Hansen, E. 1973. Numerical simulation of the rainfall-runoff process on a daily basis. *Nordic Hydrology*. 4 : 171–190.

Refsgaard, J. C. and Knudsen, J. 1996. Operational Validation and Intercomparison of Different Types of Hydrological Models. *Water Resources Research*. 32(7): 2189–2202.

Sugawara, M. 1995. The development of hydrological model - tank.*Time and the River: Ecssays by Eminent Hdrologists.*, G. W. Kite, ed., Water Resources Publications, 201–258.

Thompson, J. R., Sørenson, H. R., Gavin, H. and Refsgaard, A. 2004. Application of the coupled MIKE SHE/MIKE 11 modelling system to a lowland wet grassland in southeast England. *Journal of Hydrology*. Elsevier. 293(1–4) : 151–179.