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Rainfall Runoff Modeling using MIKE 11 Nam – A Review

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Abstract

A Rainfall-Runoff(R-R) model is a mathematical model which describes the relation between rainfall and runoff of a watershed or catchment area. The transformation of rainfall into runoff over a catchment is known to be very complex hydrological phenomenon, nonlinear, time-varying and spatially distributed. Over the years researchers have developed many models to simulate this process. The use of these models depends on the purpose for which modeling is to be done. Based on the different problems and on the complexities, these models are categorized as empirical, black-box, conceptual or physically-based distributed models. In other words, the model converts rainfall into runoff. All R-R models or hydrologic models are simplified characterization of the real world system into models. A number of hydrologic models are being popularly used to calculate the runoff from the given rainfall. MIKE 11 NAM model is one of the most accurate rainfall-runoff models being used world over. MIKE 11NAM model is a deterministic, lumped, conceptual model. It is based on a set of linked mathematical statements describing the behavior of the land phase of the hydrological cycle. In the present paper, various features of NAM model have been discussed.

Keywords: *MIKE 11 NAM, Rainfall Runoff Modeling, Rainfall, Runoff, Hydrological cycle.*

1. Introduction

Water present in rivers and lakes is a direct and simple source for the industries, irrigation and domestic use which is obtained mainly from the rainfall; this rainfall reaches the water body through rainfall runoff process. Design of all water resources planning and management project require long term runoff data which is generally not available at the project sites. Hence runoff has to be predicted with the help of rainfall data. Transformation of rainfall into runoff over a catchment is a complex phenomenon as the process is highly non-linear, time varying and spatially distributed. If the long range data is available flood control, flood forecasting and reservoir analysis can be done and a model is established. From this model one can predict the flow for extended period also. All hydrologic models are simplified characterization of the real world system into models. The rainfall - runoff model is a mathematical model which describes the relation between rainfall – runoff of a watershed or catchment area. It is an effective tool to forecast the runoff from the given amount of rainfall of a watershed. The surface runoff is dependent on various factors such as size of catchment, length of catchment, slope of catchment and time of concentration. Whenever rainfall occurs on the earth surface, it starts flowing according to the soil condition, topography, and moisture content. It is seen that infiltration is the governing factor for the computation of runoff in a watershed. If the watershed is flat, the infiltration is increases while the runoff reduces and vice-versa if the watershed having steep slope.

2. Classification of Hydrologic models

Basically all hydrologic models simulate the various components of the hydrologic cycle. The simulation capabilities vary in terms of both space and time and hence accordingly the output of the model varies. The primary input for any rainfall-runoff model is the precipitation. The model then determines the fate of this precipitation taking into consideration the various components of the hydrologic cycle i.e. interception, surface storage, evapotranspiration all of which are functions of watershed parameters and hence gives the output in the form of runoff. Most hydrologic models have a function for determining the distribution of precipitation amongst these components of hydrologic cycle. Depending upon the approach employed in these functions for distributing the precipitation, the models can be classified into the following categories:

I. **Event based and continuous models:** Event based models are used to estimate the runoff from single storm events and are generally used for design purpose (e.g. designing a culvert to pass 100year event). The continuous models are used to simulate the flow and other watershed functions over long period of time.

II. **Conceptual and physically based (Hydrodynamic models):** In conceptual models the watershed is conceptualized as a simple system based on flow parameters each of which is simple representation of a physical relationship. Physically based models attempt to simulate the hydrologic process based on the governing physics based equations such as kinematic waves or diffusive wave equations.

III. **Lumped and distributed models:** In lumped models the entire watershed is considered as one single entity and each model parameter is an average value for the whole watershed and hence the output is not accurate. In case of distributed models the watershed is sub divided into smaller sub basins or hydrological units (grids) each being described by separate values of model parameters. Thus distributed models incorporate spatial variability of the variables and hence produce more accurate results as compared to lumped models.

3. Types of Rainfall-Runoff Models

The rainfall runoff models are mainly divided into three categories: black box, conceptual and physically based models.

I. **Black box models:** Black box is also known as metric models or empirical model. These models derive the variable parameters and model structure with the help of time series. These models are based only upon the availability of data and do not take into account the catchment behavior, hence they are known as black box models. These models consider the catchment as a single unit in which rainfall is the input and runoff is the output.

II. **Conceptual models:** Conceptual models are also known as grey box or parametric models. These conceptual models are based on storages like reservoirs filled through hydrological process i.e. rainfall, runoff, infiltration and evapotranspiration etc. In such models the different model parameters are calculated using the calibration approach based on time series of the rainfall and runoff. Such models consider the catchment as a homogenous single unit.

III. **Physical based models:** Physically based models are also known as mechanistic models. Physically based models depend directly on the hydrological processes involved uses spatial discretization or other types of hydrological based units for the generation of stream flow using this model. Such models discretize the catchment spatially into smaller unit based on homogenous hydrologic properties.

Thus conversion of precipitation into runoff completely in a catchment is nonlinear, time-varying, spatially distributed and complex hydrological phenomenon. A number of models are available for estimating the runoff from a given rainfall, however the use of these models depends on the purposes for which modeling is being done. Some of the widely used rainfall – runoff models are describe below:

3.1 AnnAGNPS

The Annualized Agricultural Non-point Source Model (AnnAGNPS) is a catchment-scale, simulation model used to estimate the influence of management on soil, nutrients and rainfall in agricultural fields. This model was developed by USDA-ARS and Natural Resources Conservation Services (NRCS). This model is having many features of other models like RUSLE (Revised Universal Soil Loss Equation), CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) etc. The basic modeling components are water, soil, nutrient, and insecticide. This model has two options for spatial representation via. Grid or Cell spatial representation or Hydrologic response unit representation characterized by homogeneous land soil properties. AnnAGNPS model has been successfully used over many countries like India, China, Australia and United States. The latest version of this model is AnnAGNPS V5.2.

3.2 GSSHA

The abbreviation of Gridded Surface Subsurface Hydrologic Analysis (GSSHA), developed by USACE ERDC, is physically based model, soil, water distributed and constituently transport model. GSSHA is formulated after reformulation and enhancement of 2D physically based Hortonian runoff model CASC2D. GSSHA model is capable of imitating stream flow generation from runoff production mechanisms both in non-Hortonian and integrated watersheds. This model can imitate stream flow generated by Hortonian runoff and saturation excess processes, and also from the infiltration and groundwater discharge to streams. This model applies mass-conserving solutions of partial differential equations and it closely relates with the hydrologic component to assure an overall mass balance. Spatial heterogeneity is considered by splitting the watershed into cells comprising a uniform finite difference grid. The action that happens before, during and after the precipitation is calculated for each single grid cell and then the results from these single grid cells are integrated to create a watershed response. GSSHA can be used as an event based model or continuous simulation model. Since this model fully links surface water and ground water models, hence it can be used for both humid and arid regions. The latest version of this model is GSSHA V6.0.

3.3 HYPE

The Hydrological Predictions for the Environment (HYPE) is a hydrological model for small-scale and large-scale assessments of water resources and water quality developed by the Swedish Meteorological and Hydrological Institute in between 2005–2007. This is a recently developed semi-distributed, conceptual model which imitates multi-basins, covering broad variations in sediment types, land and shape. HYPE integrates landscape elements and hydrological spaces along with nutrient transport along the flow path. The model divides a river watershed into number of small watersheds and each small watershed is further divided into sub-category depending upon soil type and vegetative cover. For each sub-category, the model imitates snowmelt, runoff, soil erosion, drainage, groundwater escape from different soil layers, nutrient in soil and transport to rivers and lakes. Calculations are made on a daily time step in linked small watersheds. The model parameters are related with land use, soil type. Due to this linking of parameters, it is best suited for imitations in ungauged watersheds also. This model takes input of maximum of ten data files independent of size and domain and all the input and output files are in ASCII format. There are some different HYPE models which are developed for the individual countries like S-HYPE model (S for Sweden) was employed for the country of Sweden to imitate daily rainfall runoff and nutrient concentrations. Similarly, E-HYPE model (E for Europe) for the continent of Europe, BALT-HYPE model was used for the whole Baltic Sea basin. LPB-HYPE model was applied on the La Plata Basin, Niger-HYPE model for imitating on Niger River in Africa and Arctic-HYPE model for imitating hydrological variables for the entire Arctic region. Similarly, development of In-HYPE model for simulating hydrological variables for the Indian region is in progress.

3.4 WinSRM

This model is a deterministic conceptual model which was formulated to imitate and predict daily stream flow in mountainous catchments, where snowfall is the major factor for producing runoff. The model has also been employed to estimate the effect of change in climate on seasonal snow cover and runoff. WinSRM model is the windows version of the Snow melt Runoff Model which depends upon snow melting, with every 1°C in daily temperature snow melt takes place. This model is assumed to be the most successful model for estimating the runoff from the snowmelt. This SRM model takes daily precipitation; daily average temperature and snow melt cover as input variables for calibrating the model. This model has been successfully applied to various Himalayan basins situated in different countries. The main reason for the wide applicability of this model is its simple model structure with easily and readily available input parameters, accuracy and high computational efficiency. Primarily it was formulated for the small European catchments but with the advancement of remote sensing technique, it is also possible to apply this model for different sizes of the catchments. The latest version of this model is WinSRM V1.12 and it can be downloaded from its website.

3.5 SWAT

The Soil and Water Assessment Tool (SWAT) is a physical-based, conceptual, &distributed watershed scale hydrologic model formulated by USDA's Agriculture Research Service, which is basically designed to estimate the effect of watershed management practices on the runoff and soil erosion. This model has the ability to simulate various model parameters such as percolation, runoff, soil erosion, nutrients, pesticide & insecticide, irrigation, ground water flow, channel transmission losses, storage of reservoir, routing, drainage etc. Due to these reasons, the applicability of SWAT model is being increasingly day by day because of the use of various management practices in the areas of land use, climate change and pollution control. The latest version ot this model can be downloaded from its website.

3.6 WETSPA

The abbreviation of Water and Energy Transfer between Soil, Plants and Atmosphere is WETSPA. This model is based on grid type and distributed hydrological model used for estimating the water and the energy transfer between the plants, soil and atmosphere. This model was formulated by VrijeUniversiteit Brussels (VUB) and it has been validated for flood estimation on hourly (time) basis. In this, the entire catchment area is conceived as a system consisting of canopy, root zone, transmission zone and saturation zone. The catchment is divided into number of grid cells and each cell is further divided into numbers of small cells which consists of a bare soil and vegetative area in which above water and energy equation can be applied easily. This model combines various factors for the estimation of the runoff or flood hydrograph and distribution of hydrological parameters in the catchment, these factors consists of topography, land use, soil maps and daily meteorological time series. The model imitates the various processes such as precipitation, interception, snowmelt, runoff, infiltration, evapotranspiration, percolation, etc. both in time and space. The latest version of WETSPA is GIS based and has been integrated with ArcVIEW.

3.7 MIKE-SHE

MIKE SHE is a model developed by Danish Hydraulic Institute in 2007. This model is based on physical modeling and is a deterministic, distributed system model subjected to imitating all processes in the land phase of the water cycle. It consists of a mixture of simple and advanced techniques for each and every system process and hence consists of a group of preprocessing and post processing tools. Every single process of this model can be represented at different levels of simple and advanced techniques, this representation depends upon user's requirement, study and the data available to the user. It consists of the rainfall, evapotranspiration, transpiration, infiltration, interception, subsurface flow and surface runoff. Now-a-days it is widely used in different countries around the world. It is finding wide applications in different fields like water supply design, management and planning, irrigation, soil and water management, use of groundwater and surface water, groundwater management, environmental impact assessments, land use and climate change, floodplain studies etc. It is commercial software and not a freeware.

3.8 SCS-CN

The SCS-CN stands for Soil Conservation Services- Curve Number. This method is the oldest method used for the computation of rainfall runoff. In 1994, the name of this method was changed from Soil Conservation Services (SCS) to National Resources Conservation Services (NRCS). This method is a very simple, easy and tested method by the engineers and used in various hydrologic researches. The basic data required in SCS-CN method is the rainfall, soil retention, soil type which depends on infiltration, initial abstraction, and curve number. The curve number is the main factor which governs in SCS-CN method. The value of curve number depends on land cover as well as on land use of any catchment area. This method works on the empirical formula. The latest version can be downloaded from its official website. It is freeware software.

3.9 AWBM

The AWBM stands for Australian Water Balance Model. This is a lumped and conceptual rainfall-runoff model. The AWBM model is developed by the Corporative Research Centre for Catchment Hydrology, Australia. The AWBM is a tool of RRL Toolkit software. this model is a result of knowledge and experience of Corporative Research Centre for Catchment Hydrology engineers. This is computer aided software. This model takes daily time series of rainfall and evapotranspiration as a input data and the output data is the daily runoff of that given catchment. The model uses 3 surface stores to simulate the partial areas of runoff and each store of this model is calculated separately from each other. It is freeware software and its latest version can be downloaded from its official website.

3.10 ANSWERS

The ANSWERS stands for Areal Non- point Sources Watershed Environmental Responds a Simulation. This is a continuous and distributed model. This model was formulated by on the hypothesis that each and every point in a catchment area watershed exists an interconnected relation between runoff and the factors that govern it. Rainfall-runoff model having various components include rainfall, infiltration, interception, and surface detention. This model also incorporates a sediment continuity equation which describes the process of soil erosion, deposition & transportation. In this, the whole catchment area is divided into series of small sub-catchment areas. This model performed well, (good) with catchment area more than 1000 hectares. The use of these small sub-catchment areas allows enough spatial detail in respect to topography, soil and land use. However, the generation of input files requires a lot of time. The latest version can be downloaded from its official website. It is freeware software.

3.11 Hec-HMS

Hydrologic Modeling System (Hec-HMS) was formulated by the US Army Corps of Engineers, Hydrologic Engineering Center. It is designed for event-based as well as continuous hydrologic modeling. Principally it was planned to simulate the rainfall-runoff modeling of watershed. However its latest version can be used to solve a wide range of problems such as large catchment basin water supply, flood hydrographs and watershed runoff, etc. For the modeling, mode it contains various components viz. basin model, meteorological model, control specification model, and input data. Primarily, all the watershed physical details are attained only through the basin component. Basin component also contains component of basin, their connectivity and runoff. Meteorological model includes the evapotranspiration, rainfall and snowmelt data. Control model includes timing for the start/stop and calculation intervals for the run. The latest version of this model can be downloaded from its website. It is freeware software.

3.12 PRMS

The Precipitation Runoff Modeling System or PRMS is a modularly designed; physically based watershed model developed to evaluate the rainfall runoff combinations, and also determines sediment yields. This model is also incorporates the effect of snowmelt in runoff estimation through its snowmelt module. Each module used in this model is based on the physical laws or empirical relationships. PRMS model may function as a lumped or a distributed type model and it imitates both average daily flows and storm flow hydrograph. The PRMS model zones the watershed on the basis of slope, vegetation, and soil type and rainfall distribution. It is freeware software and if latest version V3.0.4 can be downloaded from its website.

3.13 MIKE 11 NAM

MIKE 11 NAM software was developed by Danish Hydraulic Institute (DHI), Denmark. It is a one dimensional modeling tool which was formulated in 1972 particularly for the water resources planning and management applications. It is specifically meant for imitation of river flows, irrigation systems and channels. The quality analysis of rivers & channels, and sediment transport studies can also be performed through different modules of MIKE 11 software. MIKE 11 uses the Nedbor Afrstromnings Model (NAM) to establish the rainfall-runoff calculation.

The NAM model is a lumped &conceptual model for imitating the runoff from the rainfall. NAM rainfall runoff model divides the flow into overland flow (surface flow), interflow (subsurface flow), and base flow. It has a set of linked mathematical statements describing the behavior of the land phase of the hydrological cycle. The simulation in NAM model is done by four dissimilar and interconnected storages which are surface storage, ground water storage, root zone storage and snow storage. In addition to these storages the NAM model also incorporates the other depletions with the help of irrigation and ground water pumping modules. The snow storage is considered only in cases where snowmelt contributes considerably to runoff , of the other three main storages like upper zone storage represents vegetation, depressions and near surface (cultivated) soil, lower zone storage represents the root zone and the main soil horizons while the groundwater storage represents water bearing rocks. Overland flow together with interflow generated from the upper zone and base flow generated from the groundwater experience additional routing and is summed to give the total model flow at the basin outlet.

3.13.1 Description of MIKE 11 NAM

The NAM model can be prepared using a number of model parameters but as a default it considers only 9 parameters automatically, accounting the surface zone storage, root zone storage and ground water storage. During calibration the model parameters are adjusted in such a way so as to get the best possible relationship between the simulated and the observed discharges. A minimum of 3 years data is required by the model to get the more reliable model results. The 9 default parameters of NAM are as follows:

1. **Maximum water content in surface Storage (U_{max}):** This parameter represents the cumulative water content of interception storage (i.e. on vegetation and depression storage), and storage in the upper layers of soil.
2. **Maximum water content in root zone storage (L_{max}):** This parameter represents the maximum moisture content in soil in the root zone, available for transpiration by vegetation.
3. **Overland flow runoff coefficient (CQOF):** This parameter determines the division of excess rainfall between overland flow and infiltration.
4. **Time constant for routing interflow (CKIF):** This parameter determines the amount of interflow which decreases with larger time constants.
5. **Time constants for routing overland flow (CK_1, CK_2):** These two parameters determine the shape of hydrograph peaks. The routing takes place through the two linear reservoirs which are serially connected with different time constants in hours. High sharp peaks are linked with shorter time durations and vice-versa.
6. **Root zone threshold value for overland flow (TOF):** This parameter determines the relative value of the moisture content in root zone above which the overland flow is generated. The effect of this value can be mainly seen in rainy season where an increase in parameter value will delay the start of runoff.
7. **Root zone threshold value for interflow (TIF):** This parameter determines the relative value of the moisture content in root zone above which interflow is generated.
8. **Time constant for routing base flow (CKBF):** This parameter can be determined from the hydrograph recession in dry periods. In rare cases,

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the shape of the measured recession changes to a slower recession after some time. To simulate this, a second groundwater reservoir may be required.

9. **Root zone threshold value for groundwater recharge (TG):** This parameter determines the relative value of moisture content in root zone above which ground water recharge is generated. By increasing the value of this parameter, recharge to the ground water storage reduces.

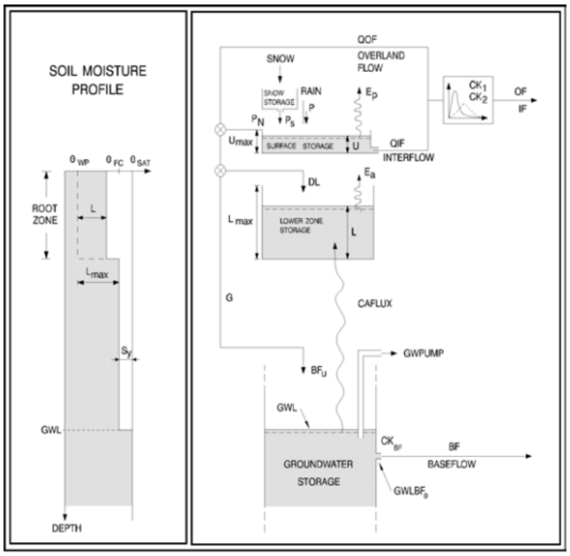

Figure 1 Structure of NAM Model

The default ranges for these 9 parameters are given below:

Table 1 Parameters Range Values of NAM Model

Parameter	Lower bound	Upper bound	Units
U_{max}	10	20	mm
L_{max}	100	300	mm
C_{QOF}	0.1	1.0	-
C_{KIF}	200	1000	hours
CK_1, CK_2	10	50	hours
T_{OF}	0	0.99	-
T_{IF}	0	0.99	-
C_{KBF}	1000	4000	hours
T_G	0	0.99	-

3.13.2 Basic Modeling Components

The elements of NAM model representing the various phases of hydrological cycle are represented mathematically by the following functions:

1. **Evaporation:** The evaporation E_a demands are initially met at the potential rate from the surface capacity. On the off chance that the moisture content U in the surface capacity is less than these requirements (U <Ep), the remaining part is thought to be pulled back by root movement from the lower zone capacity at an actual rate Ea. Ea is corresponding to the potential evapotranspiration and fluctuates directly with the relative soil dampness content as.
   a. $$Ea = \begin{cases} L & U \geq E \\ U + \dfrac{L}{L_{max}}(E - U) & otherwise \end{cases}$$
2. **Net rainfall and infiltration:** Net rainfall P_N is not clearly defined by the MIKE 11 NAM but appears to be given by mathematical equation as below
   i. P_N = max (0, P-E_a-QIF-(U_{max}-U))
   b. This leaves infiltration to the lower zone capacity will be defined as
      a. $I = P_n - QOF$
3. **Overland flow:** At the point when the surface storage spills, i.e. at the point when U >U_{max}, the overabundance water P_n offers rises to overland stream and also to infiltration. QOF indicates the part of P_n that adds to overland flow. It is thought to be corresponding to P_n and to differ directly with the relative soil dampness content, L/L_{max}, of the lower zone storage. It only happens when the saturated fraction of the lower zone exceeds threshold value.
$$QOF = \begin{cases} CQOF\ P_n \left[\dfrac{L/L_{max} - TOF}{1 - TOF}\right] & L/L_{max} > TOF \\ 0 & otherwise \end{cases}$$
4. **Interflow:** The interflow share, QIF, is thought to be relative to U and to shift directly with the relative dampness of the lower zone storage. It occurs only when a critical saturation fraction of the lower zone exceeds the threshold value. This interflow should be subjected to restraint that there is enough availability of water to the upper zone storage to keep this interflow.
$$QIF = \begin{cases} CQIF\ \left[\dfrac{L/L_{max} - TIF}{1 - TIF}\right] & L/L_{max} > TIF \\ 0 & otherwise \end{cases}$$
5. **Interflow and overland flow routing:** The interflow is directed through two straight reservoirs in arrangement with the same time consistent CK12. The overland stream routing is

also based on the linear reservoir idea but with a variable time consistent. To hold a linear response for nearly surface flows and a kinematic response for above surface flows at higher discharges, the time constants will be modified as

$$CK = \begin{cases} CK_{12} & OF < OF_{min} \\ CK_{12}\left[\dfrac{OF}{OF_{min}}\right]^{-\beta} & otherwise \end{cases}$$

Where OF is the overland flow (mm/hour) and OF_{min} is the upper limit for linear routing (=0.4 mm/hour) and β=0.4.

6. **Groundwater recharge:** The quantity of infiltrating water *G* recharging the groundwater capacity depends upon the soil moisture content in the root zone capacity. It is related to the infiltration entering the lower zone. It happens when the saturated fraction exceeds the threshold value.

$$G = \begin{cases} I\left[\dfrac{L/L_{max} - TG}{1 - TG}\right] & L/L_{max} > TG \\ 0 & otherwise \end{cases}$$

7. **Groundwater storage and base flow:** the groundwater capacity allows the water as base flow in two ways. The simple one is that it uses a linear reservoir concept such that base flow is

$$q_g = \begin{cases} CKBF\, S_g S_g > 0 \\ 0 \quad otherwise \end{cases}$$

The second one directs to use the concept of a shallow reservoir typical of depression catchments with little topographic variations and have possibility for water logging. In this case base flow is directly related to water table depth above the maximum drawdown of groundwater zone and is given by

$$q_g = \begin{cases} CK_{BF}\, S_Y\left(D_g^{max} - D_g\right) D_g^{max} \geq D_g \\ 0 \quad otherwise \end{cases}$$

Where,

S_g = water in groundwater storage above zero reference (negative values are possible)

D_g = depth of water table below zero datum

a. D_g^{max} = depth of water table attaining a maximum value

8. **Capillary flux:** Water can transfer upwards from the ground water to the lower zone storage by capillary action. The capillary flux, C, is related to the square root of the shortage in the lower zone and inversely related to the drawdown in the groundwater reservoir.

$$C = \left(1 - \frac{L}{L_{max}}\right)\left(\frac{D_g}{D_g^1}\right)^{-\alpha}$$

If C has units of mm/day then the parameter α is given by

i. $\alpha = 1.50 + 0.45 D_g^1$

Where D_g^1 is the depth of the groundwater table at which the capillary flux is 1 mm/day when L=0

NAM model requires various input data which includes the parameters to define the catchment, model parameters, initial conditions, hydro-meteorological data and stream flow data. The basic meteorological data requirements are precipitation, potential evapotranspiration and temperature. Using these, the model produces the output in the form of catchment runoff, 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. All the input and output for the model is in time series format. The NAM model has been applied to a number of catchments around the world, representing many different hydrological regimes and climatic conditions. It is observed that the model can satisfactorily predict the river discharge. It is observed that the model results show a good agreement between observed and simulated flow values in respect of rate, timing and volume and shape of hydrograph.

4. Literature Review

Fleming (1975) has evaluated the reliability of the MIKE 11 NAM model by introducing the Root Mean Square error method. This method is a measure of absolute error between observed and simulated flows. The values of Root Mean Square Error tend to zero for observed and simulated flows.

Supiah Shamsudin et al. (2002) have carried out his study on Layang river using MIKE 11 NAM model. The satisfactory and reliable results of the model were obtained. The peak flow observed in the year 1992 was 20.94m^3/s. The model was calibrated and validated which provide Efficiency Index and Root Mean Square Error values were 0.75 and 0.08 respectively, further, better runoff discharge estimation can be obtained if more automatic rainfall stations are made to be available.

Faith Keskin et al. (2007) has carried out his study at Yuvacik Dam basin, Turkey using MIKE 11 NAM model to simulate the runoff by using rainfall as well as snowmelt as inputs. The main aim of this study is to supply water to

Izmit municipality and to control the downstream flood which occurs due to runoff. The calibration and validation of the model was done and concluded that the model can reproduce well the observed inflow starting time, peak and time base with coefficient of determination is more than 0.7 in most of the events.

Doulgeris et al. (2010) has carried out his study in the Strymonas River catchment using MIKE 11 NAM model, the model's parameters are calibrated using auto calibration and afterward trial and error approach was used and concluded that it satisfactorily predicted the river discharge.

Nguyen et al. (2010) has carried out his study on Ben Hai river basin, with the idea of combining auto calibration with the trial and error approach in MIKE 11 NAM model. They concluded that the good agreement of hydrograph's shape and total flow volume between simulation and observation indicates the model parameters are consistent.

Galkate et al. (2011) has carried out his study on Rahatgarh site on Bina basin, Madhya Pradesh using MIKE 11 NAM model. The model was developed, calibrated and validated using stream flow data at the Rahatgarh site. The coefficient of determinations for calibration and validation were 0.796 and 0.609 respectively, which shows a good relation between observed and simulated flow values in respect of rate, timing and volume & shape of hydrograph. The model was also measured in terms of Nash-Sutcliffe Efficiency Index (EI) and Sum of Square of Error (SSE). The mode was found efficient with Efficiency Index is 81% and found suitable for extended time period in Bina basin.

Odiyo et al. (2012) has conducted his study on Latonyanda River Quaternary catchment using MIKE 11 NAM model. They concluded that the observed and the simulated runoff flow for LRQ catchment correlated well except for under-prediction of peak events and a few low flows, in addition to this, a few over predictions occurs due to illegal irrigation abstractions as they reduce the observed values.

Hafezparast et al. (2013) has carried out his study at the Sarsoo River basin using MIKE 11 NAM model using auto calibration. The calibration of the model was done using stream flow data and then validated for three years. They concluded that the runoff values have significantly good relation between the observed and simulated flow values with the value of coefficient of determination is 0.74.

Abu El-Nasr et al. (2013) has carried out his study at Jeker Catchment, Belgium using the two different methods viz. MIKE 11 NAM and MIKE SHE and has concluded that MIKE NAM model performed better than MIKE SHE during calibration as well as validation periods.

S.I.I. Amir et al. (2013) has carried out his study at Fitzroy basin, Australia using MIKE 11 NAM model with auto calibration approach for model parameters, used for many sub-catchments. The calibration and validation of the model were done and it was found good and represented in the form of hydrographs. The reliability of the model is given by efficiency index (EI) lies between 0.849-0.961 and index of agreement (IA) lies between 0.821-0.951.

Satish et al. (2015) has carried out his study in the Ujjain Basin part of Shipra Basin, Madhya Pradesh for the availability of water in the Ujjain city mainly for the Khumb Mela which is to be held in 2016. The rainfall runoff model is developed by using MIKE 11 software for the whole Shipra basin and Narmada-Shipra link is added for the year 1992. The dependable flow volumes are calculated for various probabilities. After the addition of Narmada-Shipra link there is always a minimum flow of $1.72m^3/s$ in the river throughout the non-monsoon period. The river was having a highest flow of $9.21m^3/s$ at 70% probability and $0.02m^3/s$ at 100% probability.

5. Conclusion

Rainfall-Runoff modeling is a very important part of any water resources planning and management project. There are a variety of well-established models available for rainfall-runoff modeling. NAM model is one such model which can predict the runoff from a basin accurately if it is calibrated properly. Larger the length of input time series data used for calibration better is the efficiency of the model. Once a NAM model is developed it can be used to estimate the dependable flows for a basin as well as to predict the flood flows which are essential inputs for water resources management at basin level.

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