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Rainfall Runoff Estimation using RRL Toolkit

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***Abstract*— The rainfall-runoff process in a catchment is a complex and intricate event governed by large number of known and unknown physiographic factors. These factors vary both in space and time. Runoff estimation in ungauged catchment is a serious challenge for the hydrologist in developing countries where most of the watersheds are ungauged. There are various approaches available ranging from lumped to physically based distributed models for runoff estimation. This paper describes the use of RRL (Rainfall Runoff Library Australian Water Balance Method Model), to investigate its performance, efficiency and suitability in Rahatgarh sub basin situated in Bina river basin of Madhya Pradesh. The AWBM is a catchment water balance model that can relate runoff to rainfall with daily or hourly data, and calculates losses from rainfall for flood hydrograph modelling. AWBM requires evapotranspiration as an input whereas most models will take potential evapotranspiration as input. The model was developed, calibrated and validated using flow data at Rahatgarh site on Bina basin. The sub basin is located in a geographical area between 123.78°N latitudes and 78.37°E longitudes. The model was found suitable for Bina rahtagarh sub basin in simulating hydrological response of the basin to the rainfall and predicting daily runoff with high degree of accuracy. The coefficient of determinations for the model calibration and validation were 0.909 and 0.835 respectively indicating good agreement between the observed and simulated runoff in terms of timing, rate and volume and shape of hydrograph. The model was evaluated based on Nash–Sutcliffe Efficiency Index (EI). The Nash Sutcliffe efficiency obtained for calibration and validation were 0.824 and 0.618 respectively.**

Keywords—Runoff, RRL, AWBM, Nash Sutcliffe efficiency, Coefficient of determinatioin

I. INTRODUCTION

Estimation of rainfall runoff is an important aspect to any hydrological structure. Estimating of runoff is required in order to determine and forecast its effects. Runoff estimation and prediction is needed in lots of water resources activities such as flood and drought management, irrigation practices, and water distribution systems, etc. Runoff is generally forecasted using rainfall-runoff models by using hydrologic data of the catchment. Computer based hydrologic models have become fashionable with practicing hydrologists and water resources engineers.

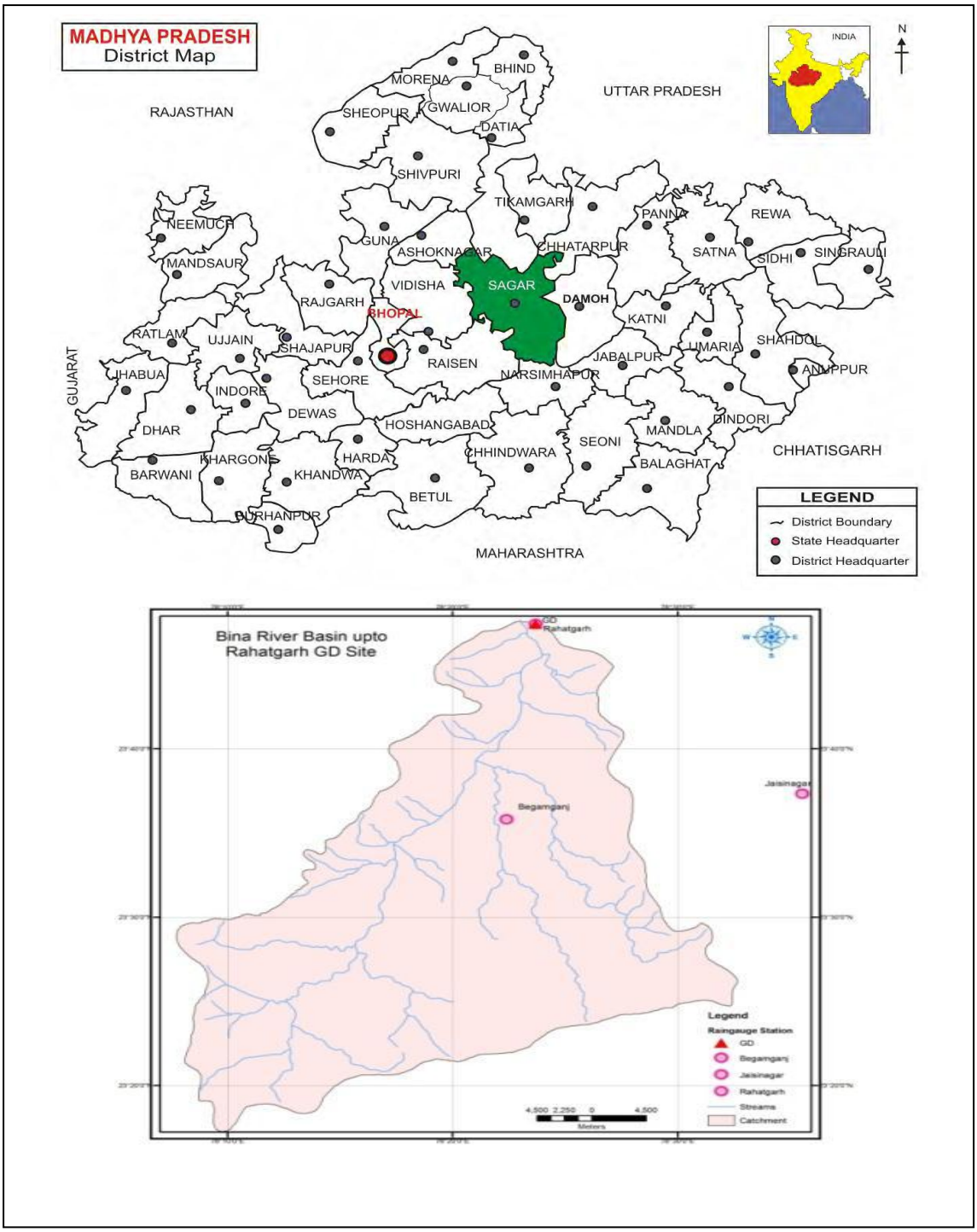
Many software tools were developed in the past which proved to be helpful for the hydrologists. The Dynamic Integration Architecture System (DIAS) (Sydelko et al., 1999), the Interactive Component Modelling System (ICMS) (Rizzoli et al., 1998; Reed et al., 1999), Tarsier (Watson et al., 1998), the Spatial Modeling Environment (SME) and associated module specification formalism (Maxwell, 1999; Voinov et al., 1999), Modular Modeling System (MMS) (Leavesley et al., 1996), named MMS-OUI, etc are some good examples of tools developed.

Recently European Open Modelling Interface and Environment (OMI) of the HaromonIT project (Gijsbers et al., 2002) was developed. The Catchment Simulation Shell (Argent and Grayson, 2003), Tarsier model (Watson and Rahman, 2004) and ICMS (Cuddy *et al.*, 2002) were also developed.

Rainfall-runoff library (RRL) is computer software developed by Cooperative Research Centre for Catchment Hydrology (CRCCH), Australia. Cooperative Research Centre for Catchment Hydrology (CRCCH) developed a wide range of tools. These tools were developed using practical experiences of CRCCH researchers and hydrologists. The CRCCH recently created E2, a whole-of-catchment modelling system. It is now available from the Catchment Modelling Toolkit at www.toolkit.net.au. Computer simulation of catchment water balance for estimating runoff from rainfall began in the early 1960s **(**Boughton, 2005**).** P.Sundar Kumar(2013) estimated runoff of Tadepalli mandal, Guntur, Andhra Pradesh using SCS CN and RRL toolkit and obtained good co relation of 0.76 between observed and simulated runoff. In this paper effort was made to estimate the rainfall runoff using RRL toolkit AWBM model for Rahatgarh sub basin of district Sagar Madhya Pradesh in India.

II. STUDY AREA

The Rahatgarh sub basin (Bina basin) is chosen for the simulation of runoff. Rahatgarh is a town and a nagar panchayat in Sagar district in the Indian state of Madhya Pradesh. Rahatgarh is located at 23.78°N 78.37°E. It is just 150 kms away from Bhopal (capital of MP, India)and 40 kms from Sagar district. It has an average elevation of 461 metres (1512 feet).

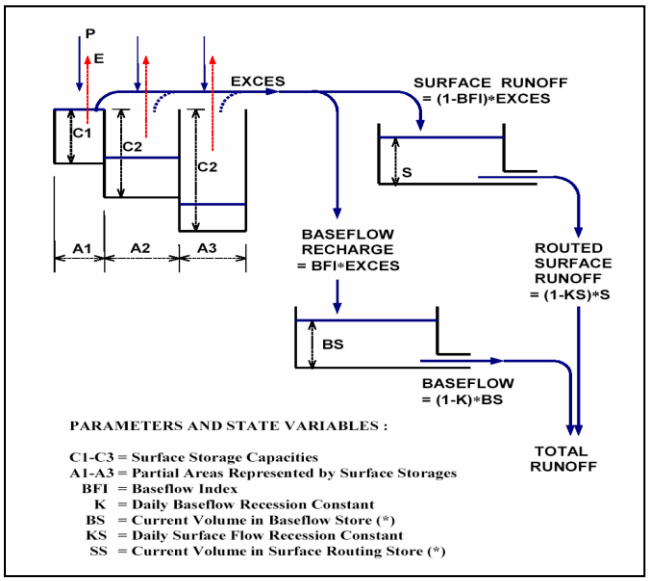


Location map of Bina basin upto Rahatgarh G/D site

III. ABOUT RRL

The Rainfall Runoff Library is a toolkit developed by the CRCCH, Australia. The RRL currently contains 5 rainfall-runoff models, 8 calibration optimisers, a choice of 10 objective functions and 3 types of data transformation for comparison against observed data. There is a graphical user interface that comprises menus, dialogues and graph display tools. The rainfall-runoff models included in the library are AWBM, Sacramento, Simhyd, SMAR and TANK model. The calibration optimisers included in the library are Uniform random sampling Pattern search, Multi start pattern search, Rosenbrock search, Rosenbrock multi-start search, Genetic algorithm, Shuffled Complex Evolution (SCE-UA) and AWBM custom optimiser. The objective function provided in RRL are Nash-Sutcliffe criterion (Coefficient of efficiency), Sum of square errors, Root mean square error (RMSE), Root mean square difference about bias, Absolute value of bias, Sum of square roots, Sum of square of the difference of square root, Sum of absolute difference of the log, There are three options available for calibration based on two objective functions which are Runoff difference in %, Flow duration curve and Base flow method 2 (Boughton, Chapman and Maxwell)

IV. METHODOLOGY



In this study we have chosen the AWBM model for runoff estimation. The AWBM model uses 3 surface stores to simulate partial areas of runoff. The water balance of each surface store is calculated independently of the others. The model calculates the moisture balance of each partial area at either daily or hourly time steps. At each time step, rainfall is added to each of the 3 surface moisture stores and evapotranspiration is subtracted from each store. The water balance equation is:

$$store_n = store_n + rain - evap \quad (n = 1 \text{ to } 3)$$

The default parameters set in AWBM model is given in table 1 below.

Table 1

Parameter	Default value	Default minimum	Default maximum
A1	0.134	0.000	1.000
A2	0.433	0.000	1.000
BFI	0.350	0.000	1.000
C1	7	0	50
C2	70	0	200
C3	150	0	500
KBase	0.950	0.000	1.000
KSurf	0.350	0.000	1.000

a. Model setup

AWBM model was setup to carry out rainfall-runoff modeling in Bina river basin at Rahatgarh G/d site having catchment area 1180 km^2. The input information of daily rainfall, observed runoff and daily evapotranspiration was collected for the period of two years from 1990 to 1991. The data was then written in ASCII text format which was used for the model development.

b. Model Calibration

Calibration is a process of standardizing predicted values, using deviations from observed values for a particular area to derive correction factors that can be applied to generate predicted values that are consistent with the observed values. Once the AWBM model was set up, model was calibrated for 1st Jan 1990 to 31st Dec 1990. During calibration, the default model parameters were kept same and model was run in auto-calibration mode.

c. Model warm up

When rainfall runoff models start some estimate of the contents of each of the soil moisture stores needs to be made. This can be done by assessing the rainfall conditions prior to the start of the model or by selecting a warm up period such that the soil store will be at a known level. If the warm up period is wet then all of the soil stores may be full or if the warm up period is dry then the stores may be empty. The RRL provides a tool for automatically setting the model warm up period for both calibration and validation. The RRL estimates the warm up period by starting the model at different initial conditions and determining where the answers converge. If there is no convergence found a warning message is displayed and the warm up period is not set.

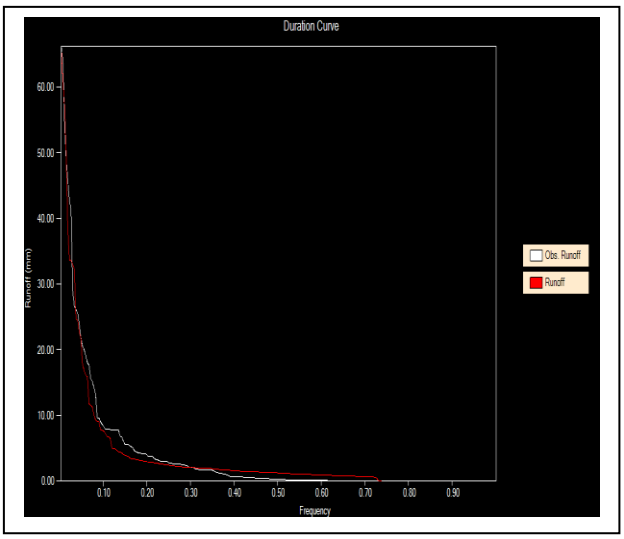
d. Model Validation

Model validation means judging the performance of the calibrated model over the portion of historical records which have not been used for the calibration. The AWBM model thus calibrated was then validated for the remaining period from 01st Jan 1991 to 31st Dec 1991. During validation the set of model parameters obtained during the calibration was used and model was run without auto-calibration mode to simulate runoff. The statistics of the simulated results were analysed and output of the model were checked to compare the simulated and observed runoff to verify the capability of calibrated model to simulate the runoff.

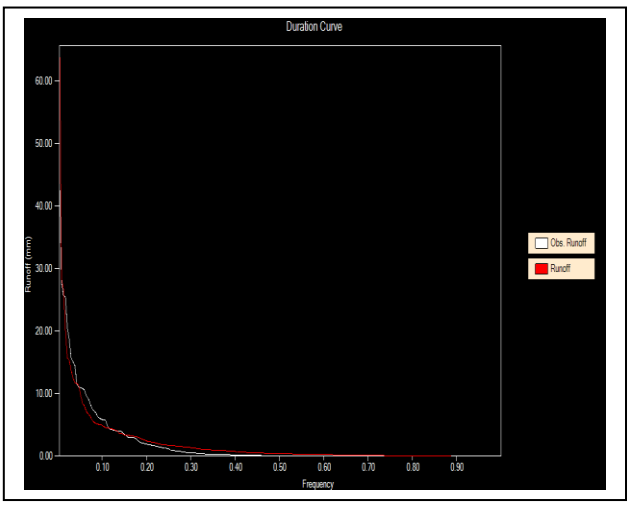
V. RESULT AND ANALYSIS

CALIBRATION RESULTS
==========
Genetic Algorithm
==========
TIME.Models.AWBM.AWBM
Objective value (Nash-Sutcliffe Criterion) :
0.820379580509034
A1 0.134
A2 0.433
BFI 0.665044138052056
C1 32.8028592200963
C2 108.898667296813
C3 352.843051242103
KBase 0.0784087065041106
KSurf 0.98410137928282

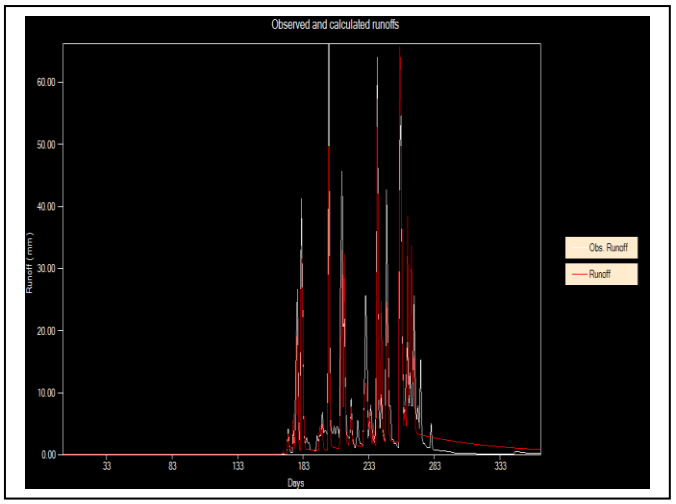
The parameters obtained by calibration are tested for validation.



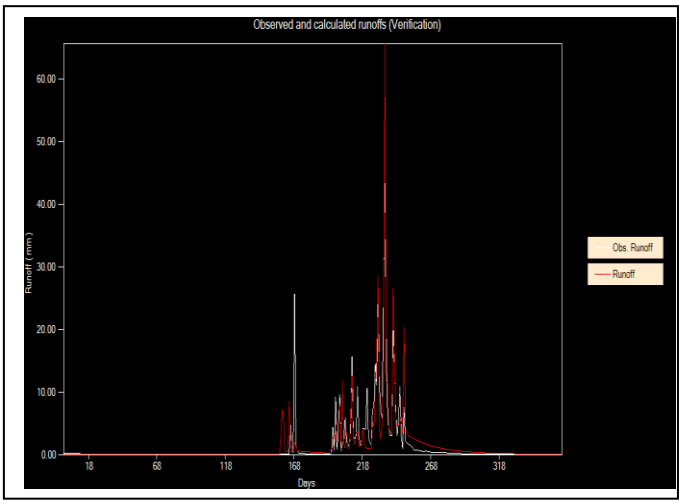
Duration curve for calibration period



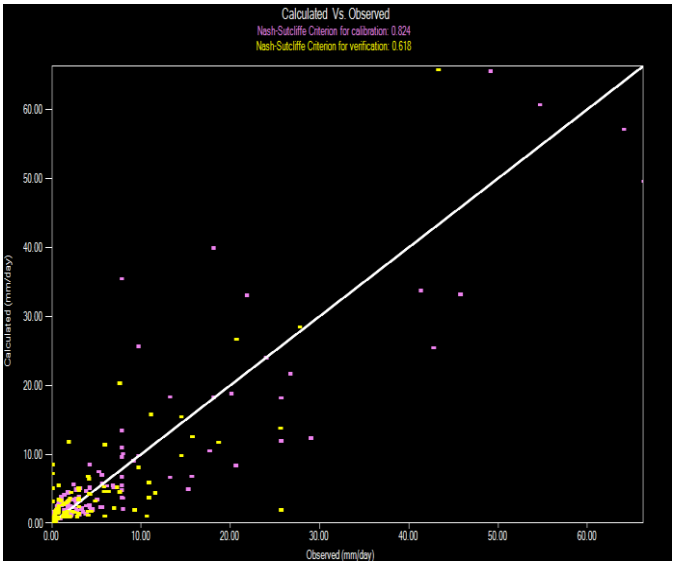
Duration curve for validation period



Graph between observed and simulated runoff (calibration)



Graph between observed and simulated runoff (validation)



Nash Sutcliffe chart between simulated and observed data

The final results obtained by the AWBM model are as follows:

Calibration Runoff Nash Sutcliffe $\eta = 0.824$ correlation = 0.909

Verification Runoff Nash Sutcliffe $\eta = 0.618$ correlation = 0.835.

The RRL AWBM model was found suitable for the Rahatgarh site of Bina basin. The model gave good performance in simulation of runoff. We found good Nash Sutcliffe efficiency and good correlation between observed and observed. The model was found efficient and hence it could be used for further water resources planning and management for this basin.

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