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Rainfall Runoff Simulation of Shipra river basin using AWBM RRL Toolkit

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***Abstract*— Rainfall-Runoff simulation of any basin plays an important role for any civil engineering project and proper planning and management of the water resources. Runoff estimation in catchment is a serious challenge for the hydrologist where most of the watersheds are ungauged. Various approaches for runoff estimation are available ranging from lumped to physically based distributed models. This paper describes the use of RRL AWBM (Rainfall Runoff Library Australian Water Balance Method Model), to investigate its performance, efficiency and suitability in Shipra river basin in Madhya Pradesh, India. The AWBM is a catchment water balance model capable of simulating runoff using daily or hourly rainfall data. AWBM model was developed using daily weighted rainfall, evapotranspiration and observed runoff time series of 11 years period from 1996 to 2006. The model was calibrated for the six years period from 1996 to 2001 and validated for five years period from 2002 to 2006. The reliability and performance of AWBM model was evaluated based on Accuracy criteria such as Coefficient of determination (R^2), Nash–Sutcliffe Efficiency Index (EI), Root Mean Square Error (RMSE), and correlation coefficient (r). The coefficient of determination R^2 value for calibration and validation period was observed 0.656 and 0.496 respectively indicating good agreement between the observed and simulated runoff. The Nash–Sutcliffe Efficiency (EI) for calibration and validation is 65.40% and 48.40% respectively. The model was found suitable for Shipra basin in predicting daily runoff with good degree of accuracy.**

***Index Terms*—AWBM, RRL, Rainfall runoff modeling, Shipra basin**

I. Introduction

Water is one of the most important natural resources available to mankind, which is primarily responsible for sustenance of life on the earth. Rainfall-Runoff is a major component of the hydrologic cycle plays a key role in water resources management. A rainfall-runoff model is a mathematical representation describing the rainfall-runoff relations of a catchment area, drainage basin or watershed. Rainfall-runoff models are classified as Deterministic, Stochastic, Conceptual, Theoretical, Black box, Continuous, Event, Complete, Routing and Simplified [1] (Linsley, 1982).

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Because of its non-linear and multi-dimensional nature, rainfall-runoff modeling is extremely complicated [2] (Lipiwattanakarn et al., 2004). Many hydrologic models are available; varying in nature, complexity and purpose [3] (Shoemaker et al., 1997). The widely known rainfall-runoff models identified are the rational method, Soil Conservation Services (SCS) Curve Number method, and Green-Ampt method [4] (Galkate et al., 2011).

The AWBM stands for Australian Water Balance Model is a part of Rainfall-runoff library (RRL) developed by Cooperative Research Centre for Catchment Hydrology (CRCCH), Australia [5]. It is a computer based conceptual rainfall runoff model. Number of studies has been conducted using RRL AWBM model. Sharifi, 1994 [6] developed AWBM model for the small catchment of New England in Australia. The AWBM model was used for rainfall runoff modelling and found suitable in predicting daily runoff. Boughton, 2006 [7] worked on AWBM model for the hydrologic rainfall runoff modelling and concluded that this model gave more than two-third good calibrated values and scope of improvement of the data sets is present for further study. Kumar, 2013 [8] simulated runoff of Tadepalli mandal, Guntur, Andhra Pradesh using RRL toolkit and obtained good co relation of 0.76 between observed and simulated runoff. Balvanshi and Tiwari, 2015 [9] developed a Rainfall Runoff model using AWBM for runoff simulation in Bina river basin of Madhya pradesh. Jamal, 2011 [10], Haque, 2014 [11] and Yu, 2015 [12] also used AWBM model for rainfall runoff simulation. The main objective of this study was to develop rainfall runoff model for runoff simulation using RRL toolkit AWBM model for Shipra river basin of Madhya Pradesh in India.

II. Study Area

Shipra is one of the sacred rivers in Hinduism. The holy city of Ujjain is situated on its right bank. After every 12 years, the Kumbh Mela (also called Simhastha) takes place at Ujjain on the city's elaborate riverside Ghats, besides yearly celebrations of the river goddess Kshipra. Shipra river basin has been extended between 76^0 06ˈ 20ˈˈand 75^0 55ˈ60ˈˈ North Latitude and 22^0 97ˈ00ˈˈand 23^0 76ˈ 20ˈˈ East Longitude and covers area of 5679 sq. km. The river traverses total course of about 190 km. It originates from Kakribardi hills of Dhar and flows north across the Malwa Plateau to join the Chambal River. The average annual rainfall of area is about 931.87 mm. The rainfall in the area is due to the southwest monsoon which starts from the middle of June and ends in last week of September. The topography is generally rolling to undulating. The index map of Shipra river basin is shown in Fig. 1.

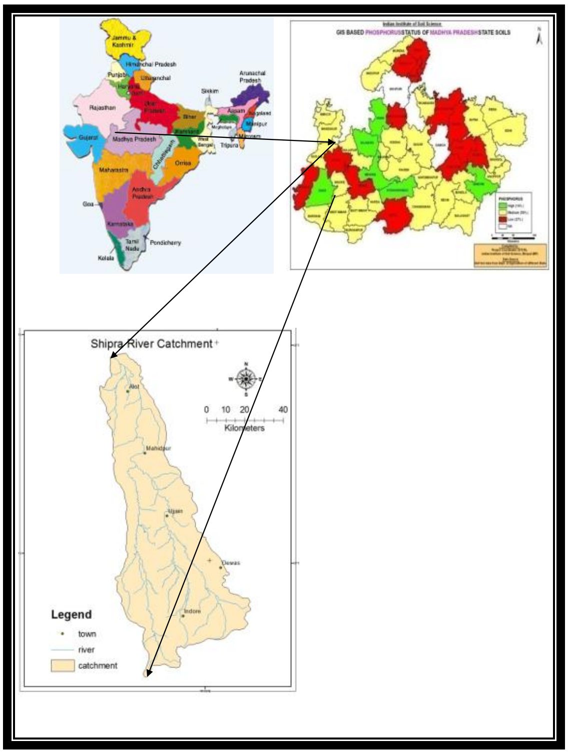

Fig. 1: Index map of Shipra river basin

III. METHODOLOGY

A. About AWBM RRL model

The Cooperative Research Centre for Catchment Hydrology (CRCCH), Australia developed the Rainfall-runoff library (RRL) AWBM model. It is available in public domain. AWBM stands for Australian Water Balance Model. This model is a conceptual, lumped rainfall-runoff model. AWBM is a catchment water balance model that develops relationship between rainfall and runoff. The AWBM takes daily time series rainfall and evapotranspiration data as input and the output we get is daily catchment runoff. Several calibration optimisers and display tools are featured in this AWBM model to aid model calibration. There are total of nine parameters involved in the model structure. The model uses 3 surface stores to simulate partial areas of runoff. A1, A2 and A3 are the partial area of smallest, middle and largest store respectively. C1, C2 and C3 are the capacity of smallest, middle and largest store respectively. The water balance of each surface store is calculated independently of the others. AWBM estimates moisture balance at either daily or hourly time steps. The rainfall is added to each of the three surface stores and simultaneous subtraction of evapotranspiration is done from each stores. If evapotranspiration is greater than the moisture content then value becomes negative and the value is set to zero. If moisture in the store becomes greater than its capacity then runoff is generated. When runoff occurs from any store, part of the runoff becomes recharge of the base flow store. The fraction of the runoff used to recharge the base flow store is BFI runoff. BFI is the base flow index which is the ratio of base flow to total flow in the stream flow. The remains of the runoff, i.e. (1.0-BFI)*runoff, becomes the surface runoff. The base flow store runs down at the rate of (1.0 - K)*BS, where BS is the current moisture in the base flow store and K is the base flow recession constant. The surface store operates in the similar way as the base flow store, and runs down at the rate of (1.0-KS)*SS, where SS is the current moisture in the surface runoff store and KS is the surface runoff recession constant. The schematic diagram of the AWBM model is shown in Fig. 2.

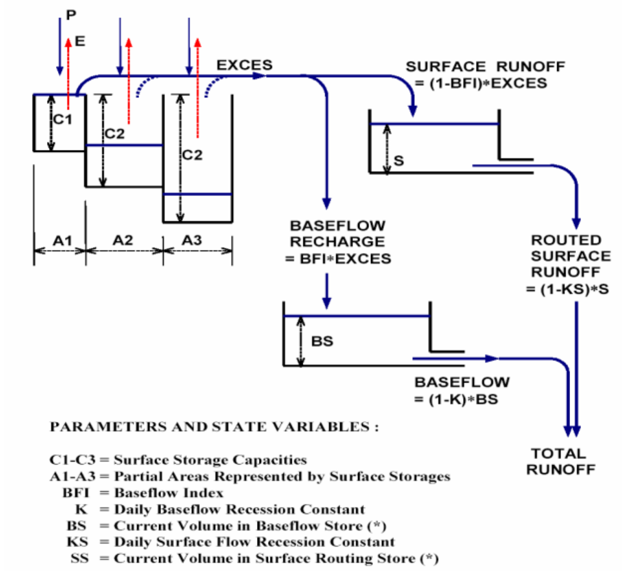

Fig. 2: Structure of the AWBM model

B. MODEL SETUP

The RRL AWBM model was setup to carry out rainfall-runoff modeling in Shipra river basin at Ujjain G/d site having catchment area 2102 km^2 and average annual rainfall 931.87 mm. The input information of daily rainfall, runoff and evapotranspiration for the period of 11 years from 1996 to 2006 was converted to *tts* format and used for model development.

C. MODEL CALIBRATION

Calibration is a process to standardize estimated or simulated values by using deviations from observed values for a particular basin. It thus helps in deriving correction factors that can be applied to generate predicted values. These simulated values are consistent with the observed values. When the AWBM model was set up, model was calibrated from 1st Jan 1996 to 31st Dec 2001. The model was first run in auto-calibration mode using genetic algorithm. The model parameters were optimized manually to obtain best set of model parameter simulating runoff with high accuracy.

D. MODEL VALIDATION

Model validation means for judging the performance of the calibrated model over the portion of historical records which have not been used for the calibration. RRL AWBM model thus calibrated was then validated for the remaining period of five years from 2002 to 2006. During validation the set of model parameters obtained during the calibration was used. The statistics of the simulated results were analyzed and outputs of the model were checked to compare the simulated and observed runoff to verify the capability of calibrated model to simulate the runoff.

E. ACCURACY CRITERIA

Accuracy of the model can be examined on the basis of Coefficient of Determination (R^2), Efficiency Index (EI) and Root Mean Square of Error (RMSE). The use of the coefficient of determination (R^2) is to test the goodness of fit of the model and explains predictive power of model.

$$R^2 = \frac{\sum_{i=1}^{n}(q_o - \bar{q}_o)(q_s - \bar{q}_s)}{\sqrt{[\sum_{i=1}^{n}(q_o - \bar{q}_o)^2][\sum_{i=1}^{n}(q_s - \bar{q}_s)^2]}}$$

Where, q_o= observed flow, $\bar{q}_o$= mean value of observed flow, q_s= simulated flow and n = number of data points.

The reliability of the model was evaluated on the basis of Efficiency Index (EI) as described by the Nash and Sutcliffe [13]

$$EI = \frac{[\sum_{i=1}^{n}(q_o - \bar{q}_o)^2 - \sum_{i=1}^{n}(q_o - q_s)^2]}{\sum_{i=1}^{n}(q_o - \bar{q}_o)^2}$$

Where, q_o= observed flow, $\bar{q}_o$= mean value of observed flow, q_s= simulated flow and n = number of data points.

While analyzing the accuracy of the model, the objective function was to minimize the Root Mean Square of Error (RMSE) between the observed and simulated runoff.

$$RMSE = \sqrt{\sum_{i=1}^{n}(q_o - q_s)^2}$$

Where, q_o= observed flow, $\bar{q}_o$= mean value of observed flow, q_s= simulated flow

F. SENSITIVITY ANALYSIS

The sensitivity analysis is done so as to understand how sensitive a model is to certain parameters. This is useful to identify with how the model functions and also what parameters need more consideration than others. If the model is extensively affected by a particular parameter than the focus of calibration should be on that parameter. The AWBM provides a feature to examine the sensitivity of all the model parameters.

IV. RESULTS AND DISCUSSION

The RRL AWBM model was setup to carry out Rainfall-runoff modeling in Shipra river basin at Ujjain G/d site having catchment area 2102 km^2. The AWBM model was calibrated for six years period from 1996 to 2001 and then validated for the remaining period of five years from 2002 to 2006. Optimized parameters of RRL AWBM model found using genetic algorithm. The graph presenting comparison between observed and simulated discharge during model calibration is shown in Fig. 3 which gives the idea and view of best match obtained during the model calibration. Fig. 4 shows the comparison between observed and simulated discharge during the calibration of AWBM model for specific year 1998 indicates the very good match. Similarly Fig. 5 and Fig. 6 show the comparison between observed discharge and simulated discharge during the validation of AWBM model. The observed and simulated hydrographs were found matching well for peak and low flows as well reasonably.

Table 1: Optimized parameters of RRL AWBM model

Parameter	*Optimized Parameter Values*	*Range of the Parameters*
A_1	0.134	0.000 – 1.000
A_2	0.433	0.000 – 1.000
BFI	0.494	0.000 – 1.000
C_1	29.85	0 – 50
C_2	116.90	0 – 200
C_3	193.67	0 – 500
K_{base}	1.00	0.000 – 1.000
K_{surf}	0.252	0.000 – 1.000

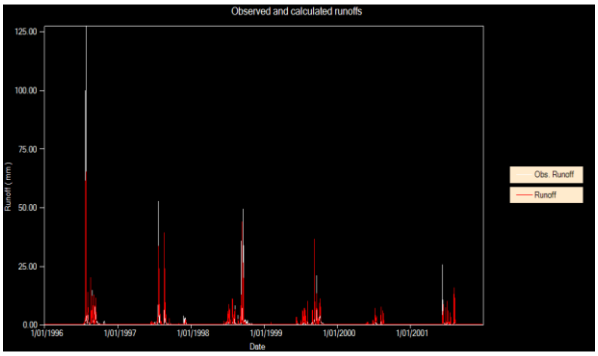

Fig. 3: Comparison between observed and simulated discharge for calibration

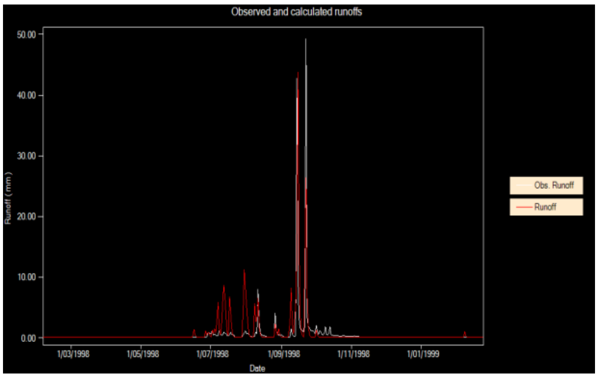

Fig. 4: Comparison between observed discharge and simulated discharge during the calibration of AWBM model for specific year 1998.

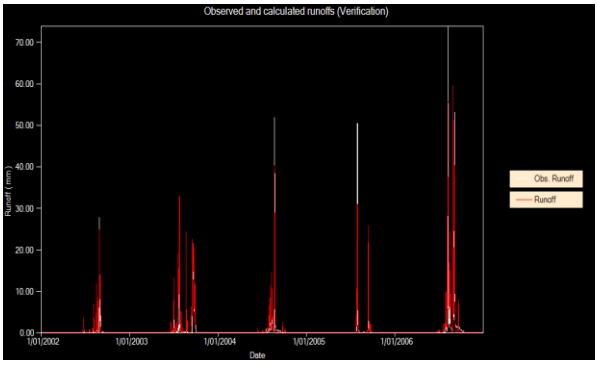

Fig. 5: Comparison between observed and simulated discharge for validation

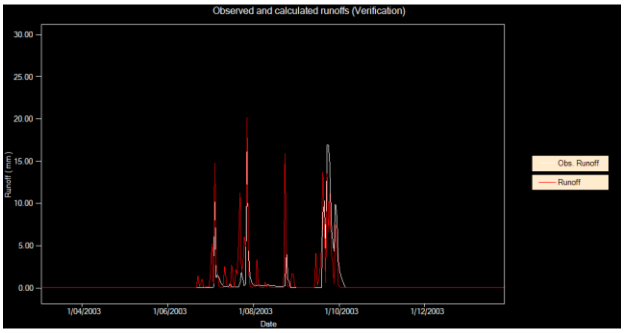

Fig. 6: Comparison between observed discharge and simulated discharge during the validation of AWBM model for specific year 2003

The Performance of AWBM model was evaluated based on Accuracy criteria such as Coefficient of determination (R^2), Nash–Sutcliffe Efficiency Index (EI), Root Mean Square Error (RMSE), and correlation coefficient (r). The coefficient of determination R^2 value for calibration and validation period is 0.656 and 0.496 respectively which indicating good agreement between the observed and simulated runoff. The Nash–Sutcliffe Efficiency (E) for calibration and validation is 65.40% and 48.40% respectively. The value of these accuracy parameters indicates that the AWBM model is performing well in predicting runoff.

Table 3: Accuracy Parameter values during calibration, validation and total period

Accuracy criteria	*Calibration*	*Validation*	*Total period*
Coefficient of determination (R^2)	0.656	0.496	0.622
Nash Sutcliff efficiency (EI) %	65.40	48.40	60.40
Correlation coefficient (r)	0.810	0.790	0.789
Root mean square error (RMSE)	58.40	56.74	57.65

The sensitivity analysis of AWBM model parameters was performed so as to understand how sensitive a model is to certain parameters. The AWBM provides a feature to examine the sensitivity of model parameters. Sensitivity analysis indicates that four parameters are sensitive and four are non sensitive.

Table 2: Sensitivity analysis of AWBM model parameters

Model Parameters	*Sensitivity Analysis*
A_1	Non sensitive
A_2	Non sensitive
BFI	Sensitive
C_1	Non sensitive
C_2	Non sensitive
C_3	Sensitive
K_{base}	Sensitive
K_{surf}	Sensitive

V. CONCLUSION

In this study, AWBM RRL model has been developed and tested for the performance and suitability in Shipra river basin of Madhya Pradesh, India. AWBM is lumped and conceptual rainfall-runoff model developed by CRCCH, Australia and available in public domain. AWBM model was calibrated and validated using daily weighted precipitation, daily evapotranspiration and daily observed runoff time series of 11 years period from 1996 to 2006. The model was calibrated for the six years period from 1996 to 2001 and validated for five years period from 2002 to 2006. Genetic algorithm was used for the optimization of the model parameters of the AWBM model. The sensitivity analysis was carried out on all the AWBM parameters so as to find the sensitive parameters. The AWBM model was tested evaluated based on Accuracy criteria such as Coefficient of determination (R^2), Efficiency Index (EI), Root Mean Square Error (RMSE), and correlation coefficient (r). The coefficient of determination R^2 value for calibration and validation period is 0.656 and 0.496 respectively which indicating good agreement between the observed and simulated runoff. The Nash–Sutcliffe Efficiency (E) for calibration and validation is 65.40% and 48.40% respectively. The model was found suitable for Shipra basin in simulating hydrological response of the basin to the rainfall and predicting daily runoff with good degree of accuracy.

REFERENCES

[1] Linsley, (1982) "Rainfall-runoff models - An overview in rainfall-runoff relationship", Proceedings of the International Symposium on Rainfall-Runoff Modeling, May 18-21, 3-22.

[2] Lipiwattanakarn, S, Sriwongsitanon N, Saengsawang S.(2004) "Improving neural network model performance in runoff estimation by using an antecedent precipitation index". Journal of Hydroscience, 22(2), 141-154.

[3] Shoemaker, L., Lahlou, M., Bryer, M. D. & Kratt, K. (1997) Compendium of tools for watershed assessment and TMDL development. U.S. Environmental Protection Agency (EPA), 841-B-97-006.

[4] Galkate, R. V, Jaiswal, R. K., Thomas, T., Nayak T.R., (2011) "Rainfall Runoff Modeling Using Conceptual NAM Model India Madhya Pradesh Map of Bina Basin up to Rahatgarh Site", Institute of Management and Technology, Nagpur.

[5] CRC for Catchment Hydrology (2004), Rainfall Runoff Library User Guide, 1.0.5, Australia.

[6] Sharifi, F and Boyd, M.J. (1994), "A Comparison of the SFB and AWBM Rainfall-Runoff Models", Surface Hydrology and Water Resources Papers, 15, 491-494.

[7] Boughton, W. (2006), "Calibration of Daily Rainfall Runoff Model with Poor Quality Data", Environmental Modeling and Software, Elsevier, 21(8), 1114–1128.

[8] kumar, P. and Hanuma Rishi, K. (2013), "Simulation of Rainfall Runoff using SCS & RRL (Case Study Tadepalli Mandal)", International Journal of Engineering Research and General Science,1(1), 23-33.

[9] Balvanshi, A. and Tiwari, H.L. (2015), "Rainfall Runoff Estimation Using RRL Toolkit", International Journal of Engineering Research & Technology, 4(5), 595-599.

[10] Jamal, J.F.,(2011), "Comparison of Conceptual and Neural Network Models for Daily Rainfall-Runoff Modelling", ICCEES, Pattaya.

[11] Haque, MD., Rahman A., Hagare, D. and Kibria, G. (2015), "Parameter Uncertainty of the AWBM Model when Applied to an Ungauged Catchment", Hydrological Processes, 29(6), 1493–1504.

[12] Yu, B. (2015), "How would peak rainfall intensity affect runoff predictions using conceptual water balance models?" International Association of Hydrological Sciences, 371, 109-115.

[13] Nash, J.E.,(1958) "Determination of runoff from rainfall", Institute of Civil Engineering, Proc., vol. 10, pp. 163-184, 1958.