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Calibration of Rainfall-runoff model GR4J for the Hiranyakeshi Watershed using Source Model

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***Abstract*— Rainfall runoff modelling has gaining tremendous importance in many application of operational hydrology. Hydrological models can be used for water resource management such as flood estimation, flood forecasting, design and management of irrigation systems. In this paper rainfall runoff-modelling for Hiranyakeshi watershed was assessed by using Source (GR4J) model. The modelling carried out by two stages, firstly setting up of geographic wizard scenario and secondly calibration and validation of model for the Hiranyakeshi watershed. The Nash Sutcliffe Coefficient (NSE) is used to check model accuracy. The study is intended to assess runoff generation from Hiranyakeshi watershed and to know the four parameters contributing to the runoff.**

Keywords: Rainfall-runoff model, Hydrological model, GR4J model, Hiranyakeshi watershed.

I. Introduction

To represent the natural systems many hydrological models have been developed, these models can be used to estimate the water balance components which helps for resource management and conservation practices [1]. In that, rainfall runoff modelling enables the analysts to forecast and predict the runoff generation from catchment with respect to precipitation received by the catchment [2].This runoff is depends on the topography, type of soil, land use and land cover and climate changes [3]. Different hydrological modelling approaches are used to build the rainfall-runoff model, by conceptual modelling, semi-distributed modelling and distributed modelling [2]. In lumped models, runoff is estimated at the outlet of the catchment where in this the spatial distribution of land use, soil, vegetation and topography is ignored [5]. Lumped models are simple and requires minimum data for setup and execution and for calibration [6].The use of distributed models gives the closest representation of real system [7], they are time consuming and requires large amount of data to physically represent study domain and also time consuming for calibration of model and parameter identification [8].The combination of lumped and distributed models are said to be as Semi-distributed models. This model requires less data compare to the distributed models [9]. In this paper, the main objective is to assess performance of rainfall-runoff model and secondly to identify model parameters contributing to the runoff generation. The Australian hydrological model Source (GR4J) used in this study to assess rainfall-runoff generation.

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II. Study area

Hiranyakeshi Watershed (Fig. 1) was selected as the study site in Krishna basin, India. Hiranyakeshi river is a left-bank tributary of the Ghataprabha river beginning in the Western Ghats in the Sindhudurg area of Maharashtra. The catchment of the Hiranyakeshi watershed lies in the region between the northern Lat 15° 56' N to 16° 21' N and eastern Long 74° 00' E to 74° 35' E. It covers an area of 1233.33 sq. km. Watershed basically comprises of quartzite, sandstones, minor conglomerated, shales and limestone. The climate is moderate subtropical, rainfall is not evenly distributed in the basin and it decreases from west to east from more than 3000mm/year to less than 1000mm/year respectively [11].

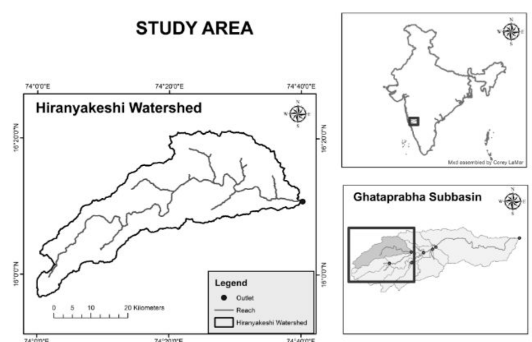

Fig. 1: Location of Study area

III. Methodology

A. Land use/ Land cover (LU/LC) Classification

LU/LC classification for the Hiranyakeshi watershed was performed by ERDAS Imagine 2014 using Landsat 7 satellite images. The Landsat 7 satellite image (Fig. 2) for path/row 146/49 were downloaded (28/April/2000) from earth explorer USGS site. Where it contains 8 bands with a spatial resolution of 30m (1 to 7 bands) and panchromatic bands is of 15m resolution (Band 8). LU/LC classification were achieved by using flowchart methodology (Fig. 3) using supervised classification with Maximum Likelihood Algorithm. The LU/LC map was prepared for the year 2000

(Fig. 4) and this reveals 34% agricultural land, 53.55% uncultivable land, 7.26% forest and 4.403% built up and 0.20% water body.

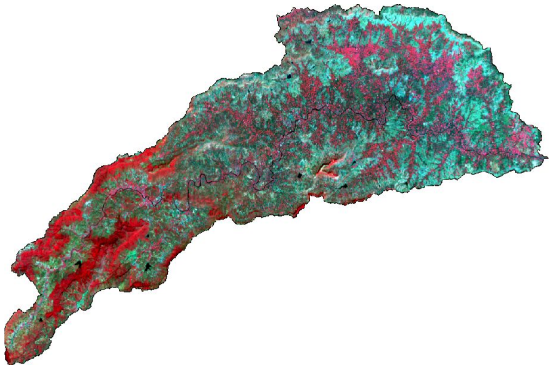

Fig. 2: Landsat 7 satellite image

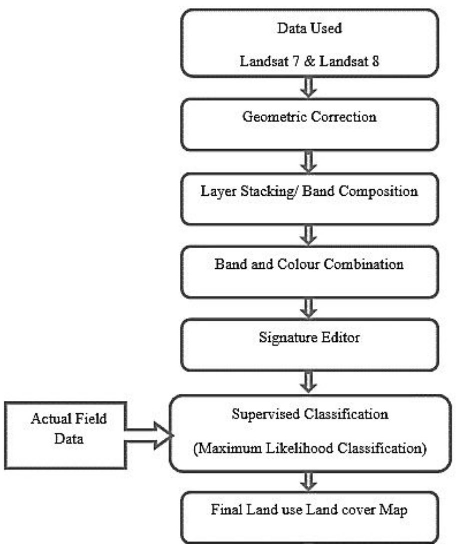

Fig. 3: Flowchart for LU/LC classification

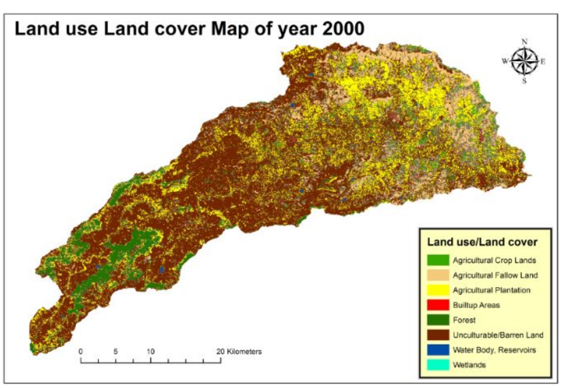

Fig. 4: LU/LC map for the year 2000

B. Description of the Source (GR4J) model

The eWater Source is an Australia's Hydrological Model applied for river modelling and the catchment modelling which helps to understand better water planning and river functions. The geological wizard is the scenario in source used to create a catchments scenario. In this paper Geographic scenario is utilized to create catchment scenario for Hiranyakeshi watershed utilizing DEM, Assigning Functional units (FU) and to build node-link network (refer Fig. 6), Fig. 5 shows the flowchart for geographic scenario. Source model contains different empirical rainfall-runoff models. GR4J empirical rainfall runoff model which was developed by Perin, model based on four parameters and is the modified version of GR3J. The model works on daily time step needs daily rainfall and potential evapotranspiration (PET) data. The GR4J model description for runoff modelling as given below.

GR4J model is divided into two stores: A Production store and A Routing store. Production store (X_1) is storage in the surface of soil, there are evapotranspiration and percolation in this storage. The capacity of this storage depends on the types of soil in that river basin. Ground water exchange coefficient (X_2) this parameter influence routing store. Routing storage (X_3) amount of water stored in soil porous, this value depends on type and humidity of soil. Time peak (X_4) ordinate of hydrograph unit UH1 (day).

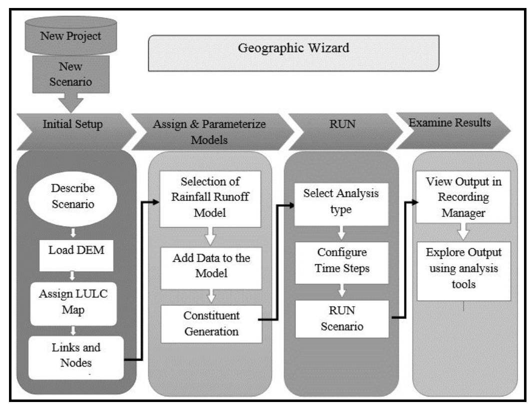

Fig. 5: Flowchart for Source Methodology

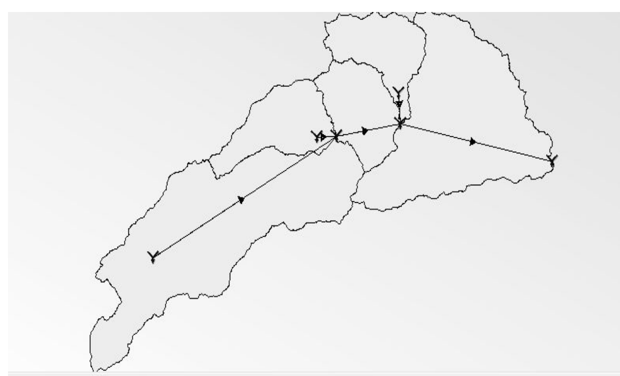

Fig. 6: Generated Nodes-Links network for Hiranyakeshi watershed

The below empirical equations were refered from (Vieux et al. 2015), and eWater site:

If P > E, then net rainfall Pn is given by eq. 1

$$Pn = P - E \quad \{1\}$$

$$En = 0 \quad \{2\}$$

$$Ps = \frac{X_1.\{1-(\frac{S}{X_1})^2\}.\tanh(\frac{Pn}{X_1})}{1+\frac{S}{X_1}.\tanh(\frac{Pn}{X_1})} \quad \{3\}$$

The remaining part Pn-Ps is used to calculate runoff. If P < E. the net evaporation and net rainfall is given in eq. {4} & {5}.

$$En = E - P \quad \{4\}$$

$$Pn = 0 \quad \{5\}$$

A part Es eq. {6}, En is extraced from the production store then the equation is rewrited by eq. {7}

$$Ps = \frac{S.\{2-(\frac{S}{X_1})^2\}.\tanh(\frac{En}{X_1})}{1+(1+\frac{S}{X_1}).\tanh(\frac{En}{X_1})} \quad \{6\}$$

$$S = S + Ps - Es \quad \{7\}$$

$$Perc = S.\left\{1-\left[1+\left(\frac{4S}{9X_1}\right)^4\right]^{-\frac{1}{4}}\right\} \quad \{8\}$$

$$Pr = Pn - Ps + Perc \quad \{9\}$$

Pr is then divided into two parts, one part (10%) for direct runoff Q1 through the HU2 hydrograph with base time 2X4; the other part (90%) for delayed runoff Q9 which reaches routing store through unit hydrograph HU1 with base time X4. The maximum content of the routing store is X3. Actual content R is rewrited usng Q9 and the value of function F(X2)

Where X2 is a groundwater exchange coefficient

$$Q1(i) = 0.1 * \Sigma_{k=1}^{m} HU2(k) * \Pr(i-k+1) \quad \{10\}$$

$$Q9(i) = 0.9 * \Sigma_{k=1}^{L} HU1(k) * \Pr(i-k+1) \quad \{11\}$$

$$F(X2) = X2 \left(\frac{R}{X_3}\right)^{\left(\frac{7}{2}\right)} \quad \{12\}$$

$$R = \max(0, R + Q9 + F) \quad (13)$$

Then the routing store is used to calculate the final delayed output Qr of the routing store. To calculate direct runoff Qd the Q1 and F(X2) are combined given in eq. {15}. The runoff generation from basin outlet for the day is given by summing Qr and Qd.

$$Qr = R.\left\{1-\left[1+\left(\frac{R}{X_3}\right)^4\right]^{-\frac{1}{4}}\right\} \quad \{14\}$$

$$Qd = \max(0, Q1 + F) \quad \{15\}$$

$$Q = Q + Qd \quad \{16\}$$

IV. Application

Application of the model follows three steps: The calibration, process used to adjust the input data and model parameters to meet the observed output value. The validation of the model is to check the output of calibrated model with the next time series of observed output data, and finally results of the study.

A. Calibration and Validation of the model

The Calibration wizard is used to calibrate the streamflow elements of a Source model. It can be used to calibrate rainfall runoff and link routing models. Flow calibration analysis used for calibration process. In order to calibrate and validate GR4J model, the daily discharge data (Gotur Station) for Hiranyakeshi watershed was obtained from Water Resource Information System (WRIS, India). The data were split into two parts one for calibration period (1995-1999) and another for validation period (2000-2005).

B. Metaparameters Definition

In the calibration tool, metaparameters are parameters identified particularly for the purposes of calibration. Metaparameter helps to minimize the number of individual model parameters that need to be calibrated. Each metaparameter having the permissible ranges (Table 1), which each of the associated model parameters can be varied as the calibration executes. To calibrate the model different optimization functions are available in Source model, in that Shuffled Complex Evolution (SCE) is used to optimize the model parameters. The process is iterative one which gives best value of objective function.

V. Results and discussions

A. Calibration of GR4J (Source) model

The results from the (GR4J) Source model are shown in Fig. 7 comparison of daily observed and simulated flow during calibration period are plotted by exporting results into the excel. The R^2 and NSE value are 0.7789 and 0.97 obtained during calibration and R^2 is 0.763 and NSE is 0.97 for validation.

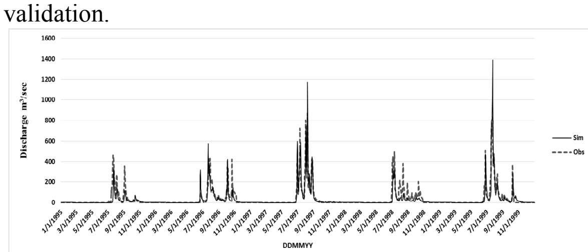

Fig. 7: Comparison of daily observed and simulated flow during calibration

B. Validation of GR4J (Source) model

The GR4J (Source) model is validated from 2000 to 2005, Fig. 8 showing comparison of simulated and observed flow during validation. Hence the R^2 and NSE values obtained are 0.65 and 0.97.

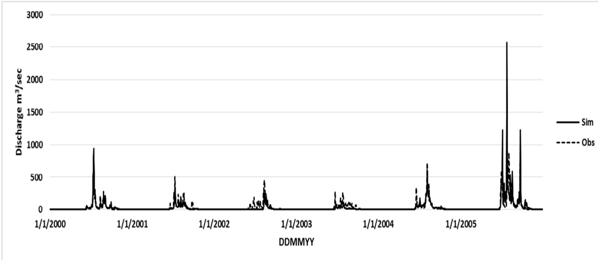

Fig. 8: Comparison of simulated and observed flow during validation.

The Table 1 represents parameters R^2 and NSE values resulted during calibration and validation of Source (GR4J) model. Moriasi et al., 2007 specified that performance ratings for $R^2>0.6$ and NSE>0.5, hence the model is giving good satisfactory results for the calibration and validation period [12].

Table 1: Results of objective functions obtained during calibration and validation period

	Calibration	Validation
R^2	0.7789	0.97
NSE	0.763	0.97

CONCLUSION

In this study, Hiranyakeshi watershed selected to model runoff generation using empirical model with conceptual framework Source (GR4J). Calibration and validation of model results are giving good satisfactory results. The daily time step GR4J model results gives good trend of simulated runoffs. From the investigation, the parameter of Production store (X_1) is 331.766 mm, groundwater exchange coefficient (X_2) is -9.397, capacity of the routing store (X_3) is 138.691 mm, and Time parameter of unit hydrograph (X_4) is 2.267 days.

REFERENCE

[1] Dilip Kumar, (2011), Distributed rainfall Runoff modeling, International journal of earth sciences and engineering, pp.270-275

[2] K.Narasayya,U.C.Roman, B.L.Meena, S.Sreekanth, S.Naveed Ali, (2013), Prediction of storm-runoff using physically based hydrological model for burhanpur watershed, India. International journal of remote sensing and geosciences (IJRSG), vol.2, pp.76-85

[3] Zhiyu Liu and Ezio Todini, (2002), Towards a comprehensive physically-based rainfall model. Hydrology and Earth system sciences, 6(5), pp. 859-881

[4] Yuyu Zhou and Y.Q.Wang,(2008), A distributed and object-oriented rainfall-runoff simulation model with hich spatial resolution impervious surface, annual conference Portland, Oregon, pp.1-12.

[5] Md. Sharif Imam Ibne Amir, Mohammad Masud Kamal Khan, Mohammad Golam Rasul, Raj H. Sharma, and Fatema Akram,(2013), Automatic multi-objective calibration of rainfall runoff model for the Fitzroy basin, queensland, Australia. International journal of environmental science and development, vol 4, pp .311-315

[6] K.Narasayya,U.C.Roman, B.L.Meena, S.Sreekanth, S.Naveed Ali, (2013), Prediction of storm-runoff using physically based hydrological model for burhanpur watershed, India. International journal of remote sensing and geosciences (IJRSG), vol.2, pp.76-85

[7] Koffi, F.K. and Monique BERNIER, Droh L. GONE, Mahaman B. SALEY, Rene LEFEBVRE, Nagnin SORO et Aime KOUDOU, (2007) ≪Integrating geo space in a distributed hydrological model for the simulation of water flow in the humid tropics of Ivory Coast (West Africa), Journal Remote Sensing, 2007, vol. 7, No. 1-2-3-4, pp. 217-23

[8] Y. Tang, P. Reed, K. van Werkhoven, and T.Wagener, (2007). Advancing the identification and evaluation of distributed rainfall-runoff models using global sensitivity analysis. Water Resources Research, Vol. 43, pp.1-14.

[9] Vahid Nourani, Arash Roughani and Mekonnen Gebremichael, (2011). TOPMODEL Capability for rainfall-runoff modeling of the ammameh watershed at different time scales using different terrain algorithms. Journal of urban environment engineering, vol.5.n.1, PP.1-14

[10] Dhemi Harlan, Muljana Wangsadipura., and Cecep Muhtaj Munajat (2010), Rainfall-Runoff Modeling of Citarum Hulu River Basin by Using GR4J, Proceedings of the World Congress on Engineering 2010 Vol II

[11] Sachin S. Panhalkar, Sagar P. Mali, C.T. Pawar, 2014. Land Capability Classification in Hiranyakeshi Basin of Maharashtra (India): A Geoinformatics Approach, International Journal of Engineering and Technical Research (IJETR), ISSN: 2321-0869, Volume-2, Issue-6, pp. 18-21.

[12] Moriasi D N., Arnold J G., Van Liew M W., Bigner R L., Harmel R D. & Veith T L. 2007, Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulation: *American Society of Agricultural and Biological Engineers* ISSN 0001-23351, Vol. 50(3): 885-900.

[13] Yasmine Ytoui (2014), Rainfall-runoff modeling at monthly and daily scales using conceptual models and neuro-fuzzy inference system, 2nd International Conference - Water resources and wetlands, Pages: 263-270.

[14] Xike Zhang, David Waters, and Robin Ellis, (2013), Evaluation of Simhyd, Sacramento and GR4J rainfall runoff models in two contrasting Great Barrier Reef catchments, International Congress on Modelling and Simulation, pages 3260-3266.

[15] Perrin, V. Andréassian, C. Michel, L. Oudin (2005), GR4J : a parsimonious model for rainfall-runoff Simulations, European Geosciences Union, Vol. 7, 09642

[16] Vieux Boukhaly TRAORE, Soussou SAMBOU, Séni TAMBA, Sidy FALL, Amadou Tahirou DIAW, Mohamed Talla CISSE, (2014), Calibrating the rainfall-runoff model GR4J and GR2M on the Koulountou river basin, a tributary of the Gambia river, American Journal of Environmental Protection, 2014; 3(1): 36-44

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