Int.J.Curr.Microbiol.App.Sci (2017) *6*(10): 2736-2748

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 6 Number 10 (2017) pp. 2736-2748**
Journal homepage: http://www.ijcmas.com

Original Research Article

https://doi.org/10.20546/ijcmas.2017.610.322

Development of Fuzzy Logic Based Rainfall-Runoff Model for Kelo River Macro Watershed of Mahanadi Basin

Gayam Sujatha[1], Jitendra Sinha[1*], Nilima Jangre[1] and Ashish Patel[2]

[1]Department of Soil and Water Engineering, FAE, IGKV, Raipur-492006, Chhattisgarh, India
[2]National Institute of Technology, Raipur-492006, Chhattisgarh, India
Corresponding author

A B S T R A C T

A rainfall – runoff model describes the relation between the rainfall and runoff for a particular catchment area. The relationship between rainfall in a period and the corresponding runoff is quite complex. SCS-CN method is used to estimate the runoff, but, SCS-CN method does not consider the impact of rainfall intensity and did not account for the influence of forest management practices. The aim of this study is to develop Fuzzy Logic Model to estimate runoff using rainfall given for the area under consideration. The area considered for this study is Kelo macro-watershed of Mahanadi basin, Raigarh, Chhattisgarh. The daily rainfall and gauge – discharge data for past 12 years (2002 to 2013) were used. Weighted rainfall for the study area was estimated by constructing the Thiessen polygons. More than 90% of the rain falls in the active period (AP) of months 1st July – 31st October. The catchment behaviour to infiltration and other losses was found to be variable with the average runoff-rainfall ratio of 0.44. Out of 12 years, 9 years data was used for calibration/training of the model while remaining 3 years data was used for model verification. Fuzzy Logic Model developed with nine numbers of linguistic variables as extremely low (EL), very very low (VVL), very low (VL), low (L), medium (M), moderately high (MH), high (H), very high (VH) and extremely high (EH). The most common triangular and trapezoidal membership functions have been adopted for each input and output. The model operates on an 'if-then' principle, where the 'if' is a vector of fuzzy premises and the 'then' is a vector of fuzzy consequences. The developed FL model and SCS-CN method has been analyzed on basis of various performance indices, i.e., Mean Absolute Deviation (MAD), Root Mean Square Error (RMSE), Coefficient of Correlation (CC), and Coefficient of Efficiency (CE). Runoff has been estimated through developed fuzzy logic model, SCS- Curve Number and has been compared with multiyear observed flow. On comparison of SCS-CN and FL, it is visible that the MAD and RMSE values are 2.46 mm and 4.14 mm for SCS-CN method and 2.06 mm and 3.45 mm for fuzzy logic during training respectively. Similarly, it is 2.42 mm and 4.4 mm for SCS-CN method and 2.29 mm and 3.62 mm for fuzzy logic during testing respectively. Again comparison of Coefficient of Correlation (CC) and Coefficient of Efficiency (CE) values are 93.74 % and 83.99 % for SCS-CN method and 95.78 % and 88.88 % for FL during training respectively. Similarly, it is 92.03 % and 81.32 % for SCS-CN method and 94.99 % and 87.33 % for FL during testing respectively. So from MAD, RMSE, CC and CE point of view, FL is performing better than SCS-CN method. Scatter plots between observed and simulated SCS-CN values showed that the most of the values lie near 45° line and it is clear from the plots that the model is underestimating the higher values in training while slightly overestimating the lower values in testing period. Scatter plots between observed and predicted FL values showed that most of the values lie near 45° line and it is clear from the plots that the model is underestimating the higher values in training while lower values are almost perfectly matched with the observed runoff values in testing period. FL Model is very well describing runoff as compared to SCS-CN method for the study area. Thus, it can be concluded that use of FL models are certainly a much better choice than the SCS-CN method for rainfall – runoff modeling of the study area.

Keywords

SCS-Curve Number, Runoff, Fuzzy logic, Membership function, IF-THEN rules, Training, Testing.

Article Info

Accepted:
23 September 2017
Available Online:
10 October 2017

Introduction

A rainfall-runoff model is a mathematical model describing the rainfall-runoff relations of a catchment area, drainage basin or watershed. Rainfall–runoff models are conventionally assigned to one of three broad categories: deterministic (physical), conceptual and parametric (also known as analytic or empirical) (Anderson and Burt, 1985 and Watts, 1997). Deterministic models describe the Rainfall–runoff process using physical laws of mass and energy transfer. Conceptual models provide simplified representations of key hydrological process using a perceived system (such as a series of interconnected stores and flow pathways). Parametric models use mathematical transfer functions (such as multiple linear regression equations) to relate meteorological variables to runoff. Hydrological models are further classified as either lumped or distributed (Todini, 1988). Lumped models treat the catchment as a single unit. They provide no information about the spatial distribution of inputs and outputs and simulate only the gross, spatially averaged response of the catchments. Conversely, distributed or heterogeneous models represent the catchment as a system of inter-related subsystems – both vertically and horizontally. Thus, distributed models can be considered as an assemblage of sub catchments arranged either in series or as a branched network (O'Loughlin *et al.,* 1996).

The relationship between rainfall and resulting runoff is quite complex and is influenced by factors relating the watershed and climate. Various well known currently available rainfall-runoff models (HSPF, SWMM etc.) have been successfully applied in many problems and watersheds. One of the major lacunae with these models is that most of them are not quite flexible and require many parameters for accurate prediction of runoff from known values of its causative factors. Obviously, the models have their own weaknesses, especially in the calibration processes and the ability to adopt the non-linearity of processes. In operational hydrology, the system-theoretic black-box and conceptual models are usually employed for rainfall-runoff modelling because the physically based distributed models are too complex, data intensive, cumbersome to use and their regular time to time monitoring is also expensive. When limited records of the rainfall-runoff are available, it becomes extremely difficult to calibrate and validate the existing models.

Simple methods for predicting runoff from watersheds are particularly important in hydrologic engineering and hydrological modelling and they are used in many hydrologic applications, such as flood design and water balance calculation models (Abon *et al.,* 2011; Steenhuis *et al.,* 1995; van Dijk, 2010). The Soil Conservation Service Curve Number (SCS-CN) method was originally developed by the SCS (US Department of Agriculture), to predict direct runoff volumes for given rainfall events and it is documented in the National Engineering Handbook, Sect. 4: Hydrology (NEH-4) (SCS, 1956, 1964, 1971, 1985, 1993, 2004). It soon became one of the most popular techniques among the engineers and the practitioners, because it is a simple but well-established method, it features easy to obtain and well-documented environmental inputs, and it accounts for many of the factors affecting runoff generation, incorporating them in a single CN parameter. In contrast, the main weaknesses reported in the literature are that the SCS-CN method does not consider the impact of rainfall intensity, it does not address the effects of spatial scale, it is highly sensitive to changes in values of its single parameter, CN, and it is ambiguous considering the effect of antecedent moisture conditions (Hawkins, 1993; McCuen, 2002; Michel *et al.*, 2005; Ponce and Hawkins, 1996).

Fuzzy Logic is a technique that allows us to map an input space to output space, similar to a black box which does 'something' to compute the solution, the output values. There are many ways in which we can implement the black box: neural networks, linear systems, expert systems, differential equations, and so on. But Fuzzy Logic is usually more understandable, faster and cheaper than other possibilities. In recent years many applications using fuzzy logic theory appeared, since it is an alternative and effective tool for studying complex phenomena. Fuzzy logic models can give answers to practical problems, without being time consuming. Fuzzy rule systems have been used successfully in reservoir management (Panigrahi and Mujumdar, 2000), rainfall-runoff problems (Nayak *et al.*, 2005; Yu and Chen, 2005) and in parameters of groundwater flow (Tzimopoulos *et al.*, 2004; Moutsopoulos *et al.*,2005; Chalkidis *et al.*,2006). The scope of fuzzy logic modeling in rainfall-runoff transformation has not been much explored in Chhattisgarh. With this in view, the present study has been undertaken.

Materials and Methods

General description of the study area

The study area is a macro-watershed of river Kelo, a tributary of Mahanadi River. The Kelo macro-watershed is located between 21.43°N to 21.9°N Latitude, and 83.4°E to 83.49°E Longitud at an average elevation of 215 meters above mean sea level. The Kelo River flows through the Raigarh city and is prime source of water. The total length of Kelo river is 112.60 km., joins Mahanadi near village Mahadeopali, district Sambalpur (Odisha). The study area is shown in Figure 1 and details are mentioned in Table 1.

Data collection

The daily gauge – discharge data for the years from 2002 to 2013 has been obtained from the O/o Chief Engineer, Central Water Commission, Bhubaneshwar, Odisha. The daily Rainfall data for the years from 2002 to 2013 of the rain gauge stations in and around the study area were collected from State Data Centre, Department of Water Resources, Govt. of Chhattisgarh.

The topographical characteristics of the study area were analysed by using the combination of survey of India toposheets No. 64-N and 64-O on 1:250,000 scale. The toposheets were procured from the office of the Director, Chhattisgarh Geo-Spatial Data Centre, Survey of India, Chhattisgarh.

SCS-CN method for estimating runoff

SCS-CN method developed by Soil Conservation Services (SCS) of USA in 1969 is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. It relies on only one parameter, CN. Currently, it is a well-established method, having been widely accepted for use in USA and many other countries.

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the amount of direct surface runoff Q to the total rainfall P (or maximum potential surface to the runoff) with the ratio of the amount of infiltration F_c amount of the potential maximum retention S.

The second to the potential hypothesis relates the initial abstraction Ia maximum retention. Thus, the SCS-CN method consisted of the following equations (Subramanya, 2008). The methodology is shown in Figure 2.

Water balance equation:

$P=Ia + Fc + Q$ (1)

Proportional equality hypothesis

$\frac{Q}{P-Ia} = \frac{Fc}{S}$ (2)

Ia - S hypothesis:

$I_a=\lambda S$ (3)

Where,

P is the total rainfall (mm), I_a is the initial abstraction, F_c is the cumulative infiltration excluding I_a, Q is the direct runoff (mm), S is the potential maximum retention (mm) or infiltration and λ is the regional parameter dependent on geologic and climatic factors.

Solving equation (2)

$Q = \frac{(P-Ia)^2}{P-Ia+S}$ For $P > I_a$ (4)

$Q = 0$ for $P < I_a$ (5)

The initial abstraction I_a is all the losses before runoff begins. Initial abstractions are water losses, e.g. plant interceptions, infiltration and surface storage which occur prior to runoff and are then subtracted from the total runoff (USDA-SCS 1985). So I_a is highly variable but generally is correlated with soil and cover parameters.

The original conceptualization of the curve number method did not account for the influence of forest management practices. The relationship $I_a= 0.2S$ was derived from the study of many small, experimental watersheds. In the model fitting done by Hawkins *et al.,* (2002) found that the ratio of I_a to S varies from storm to storm and watershed to watershed and that the assumption of $I_a= 0.2S$ is usually high. More than 90 percent of I_a/S ratios were less than 0.2. Based on this study, use of I_a/S ratios of 0.05 rather than the commonly used value of 0.20 would seem more appropriate. Then equation (4) becomes

$Q = \frac{(P-0.05S)2}{P+0.95S}$ (6)

Estimation of runoff using fuzzy logic

The Fuzzy Logic Model were trained to estimate runoff from current day rainfall (P_t), previous day rainfall (P_{t-1}) and previous day discharge (Q_{t-1}) data sets as "input" and runoff (Q_t) estimate as "output". Daily data of 12 years (1 July 2002 to 31 October 2013) data has been used for analysis. Out of total number 1476 samples, 1107 samples have been used for training the model while remaining 369 samples has been used for testing the model.

Membership function

Membership Function Editor was explored to define the shapes of all the membership functions associated with each variable. Input variables (P_t, P_{t-1}, Q_{t-1}) and Output variable (Q_t) were divided into 9 categories such as Extremely Low (EL), Very Very Low (VVL), Very Low (VL), Low (L), Medium (M), Moderate High (MH), High (H), Very High (VH) and Extremely High (EH). Traiangular and trapezoidal membership functions have been used in this study.

The triangular membership function is the simplest membership function, formed by using straight lines and named "Trimf". It‘s nothing more than a collection of three points forming a triangle.

In most practical applications, however, simple "trapezoid" membership functions work well, for which we use linear interpolation to get both endpoints of the interval. The analysis was carried out in

MATLAB R 2014b. Rule editor helps to edit the list of rules that defines the behavior of the system. In rule-based fuzzy systems, the relationships between variables are represented by means of fuzzy if-then rules.

Defuzzification methods

Defuzzification is the process by which a solution set is converted into a single crisp value. Solution may be contained in the fuzzy solution set. Defuzzification is a process to extract an easily comprehendible answer from the set. In the present study the most common defuzzified 'centroid' method was adopted with the help of the following equation:

$$Cg = \frac{\sum_{i=1}^{n} yi\ m_B\ (yi)}{\sum_{i=1}^{n} m_B\ (yi)} \quad (7)$$

Where Cg is the centroid of the truncated fuzzy output set B; m_B (yi) is the membership value of element yi in the fuzzy output set; B and n are the numbers of elements.

In centroid method of defuzzification, all values of output were used to judge the predictive capability of the developed models. The prediction models of runoff were developed for the study area using Fuzzy Logic Toolbox of the software MATLAB R 2014b.

Performance evaluation criteria

The network is trained on the training or calibration data set and its performance is evaluated both in calibration and in verification data sets. The training stops when there is no more improvement both in training and in verification.

The statistical performance evaluation criteria considered in this study are mean absolute deviation (MAD), root mean square error (RMSE), correlation coefficient (CC), and coefficient of efficiency (CE).

Mean Absolute Deviation (MAD)

It is a measure of mean absolute deviation of the observed values from the estimated values. It has a unit and is not a normalized criterion. It is expressed as,

$$MAD = \frac{\sum_{j=1}^{n} \left| O_j - S_j \right|}{n} \quad (8)$$

Where,

O_j = observed runoff in mm

S_j = Simulated runoff in mm

Root Mean Squared Error (RMSE)

The Root mean squared error is the difference between observed (Yu, 1994) and the estimated values of runoff. The RMSE is compared as follows:

$$RMSE = \sqrt{\frac{\text{residual} \quad \text{variance}}{\text{n}}} = \left(\frac{\sum_{j=1}^{n} (O_j - S_j)^2}{n} \right)^{1/2} \quad (9)$$

Correlation Coefficient (CC)

The correlation between the observed and simulated values is described by the correlation statistic, called the correlation coefficient. It is estimated by the equation:

$$CC = \frac{\sum_{j=1}^{n} \left\{ \left(O_j - \bar{O} \right) \left(S_j - \bar{S} \right) \right\}}{\left\{ \sum_{j=1}^{n} \left(O_j - \bar{O} \right)^2 \sum_{j=1}^{n} \left(S_j - \bar{S} \right)^2 \right\}^{\frac{1}{2}}} x\,100$$

(10)

Where,
$\bar{S}_j$= Mean simulated runoff in mm,
$\bar{O}_j$= Mean observed runoff in mm.

Coefficient of Efficiency (CE)

Nash and Sutcliffe (1970) proposed the criterion on the basis of standardization of the residual variance with initial variance and named it as the coefficient of efficiency. The dimensionless criterion of coefficient of efficiency is estimated as follows:

$$CE = \left\{ 1 - \frac{\sum_{j=1}^{n} (O_j - S_j)^2}{\sum_{j=1}^{n} (O_j - \bar{O})^2} \right\} x \ 100 \quad (11)$$

Thus, a perfect agreement between the observed and estimated values yields the CE value as 100 percent while for a no agreement, all the estimated values must be equal to the observed mean. A negative efficiency represents that the estimated values are less than the observed mean. As the efficiency depends strongly upon the initial variance of the observed records.

Results and Discussion

Observed runoff values were determined using gauge discharge data and this observed runoff values were taken as target for both SCS-CN method and Fuzzy Logic model. Simulated SCS-CN runoff values were determined. FL model was developed by considering the three significant inputs viz. current day rainfall (P_t), previous day rainfall (P_{t-1}), and previous day discharge (Q_{t-1}). The result window of one of the pattern is presented in Figure 3. As seen from figure the Current day rainfall (P_t) 11.2 mm, previous day rainfall (P_{t-1}) 41.6 mm and previous day discharge (Q_{t-1}) 10.6 mm resulted runoff (Q_t) is 7 mm. Predicted Fuzzy Logic runoff values were determined. The first 32 rules have been presented in Table 2. Performance evaluation of the models was carried out by calculating Mean Absolute Deviation (MAD), Root Mean Square Error (RMSE), Coefficient of Correlation (CC) and Coefficient of Efficiency (CE).

Comparison of models done on daily Active Period basis (1st July – 31st Oct). Comparison of observed, simulated SCS-CN and FL model done on training and testing separately as shown in Figures 4 and 5.

On comparison of Tables 3 and 4, it is visible that the MAD & RMSE values are 2.46 mm & 4.14 mm for SCS-CN method and 2.06 mm & 3.45 mm for fuzzy logic during training respectively. Similarly, it is 2.42 mm & 4.4 mm for SCS-CN method and 2.29 mm & 3.62 mm for fuzzy logic during testing respectively. Again comparison of Coefficient of Correlation (CC) & Coefficient of Efficiency (CE) values are 93.74 % & 83.99 % for SCS-CN method and 95.78 % & 88.88 % for FL during training respectively. Similarly, it is 92.03 % & 81.32 % for SCS-CN method and 94.99 % & 87.33 % for FL during testing respectively. So from MAD, RMSE, CC & CE point of view, FL is performing better than SCS-CN method.

The results of Kelo macro-watershed of Mahanadi basin was found quite satisfactory. Scatter plots between observed and simulated SCS-CN values showed that the most of the values lie near 45° line and it is clear from the plots that the model is overestimating the higher values in training (Figure 6) while slightly underestimating the lower values in testing period (Figure 7). Scatter plots between observed and predicted FL values showed that most of the values lie near 45° line and it is clear from the plots that the model is overestimating the higher values in training (Figure 8) while lower values are almost perfectly matched with the observed runoff values in testing period (Figure 9). FL Model is very well describing runoff as compared to SCS-CN method for the study area.

Table.1 Details of Kelo Watershed (CWC, 2012)

Site Name	District	Catchment Area, Km^2	River Name/Tributory/SubTributory	Type	Latitude	Longitude	Code/Grid Ref.
Kelo at Raigarh	Raigarh	950	Mahanadi/Kelo	GD	21°53'19"	83°24'00"	009B

Table.2 IF THEN Rule for Kelo macro-watershed of Mahanadi basin

S.No.	IF Then rule					
1. IF P_t is	EL	and P_{t-1} is	EL	and Q_{t-1} is	EL	THEN Q_t is EL
2. IF P_t is	VVL	and P_{t-1} is	EL	and Q_{t-1} is	EL	THEN Q_t is EL
3. IF P_t is	M	and P_{t-1} is	VL	and Q_{t-1} is	EL	THEN Q_t is VL
4. IF P_t is	L	and P_{t-1} is	M	and Q_{t-1} is	L	THEN Q_t is VL
5. IF P_t is	VL	and P_{t-1} is	M	and Q_{t-1} is	VVL	THEN Q_t is VVL
6. IF P_t is	VL	and P_{t-1} is	M	and Q_{t-1} is	VL	THEN Q_t is VL
7. IF P_t is	VVL	and P_{t-1} is	VL	and Q_{t-1} is	VL	THEN Q_t is VVL
8. IF P_t is	M	and P_{t-1} is	VVL	and Q_{t-1} is	VVL	THEN Q_t is VVL
9. IF P_t is	L	and P_{t-1} is	EL	and Q_{t-1} is	VVL	THEN Q_t is VVL
10. IF P_t is	EL	and P_{t-1} is	L	and Q_{t-1} is	VVL	THEN Q_t is EL
11. IF P_t is	VL	and P_{t-1} is	L	and Q_{t-1} is	EL	THEN Q_t is VVL
12. IF P_t is	M	and P_{t-1} is	M	and Q_{t-1} is	VL	THEN Q_t is VVL
13. IF P_t is	M	and P_{t-1} is	M	and Q_{t-1} is	VVL	THEN Q_t is VL
14. IF P_t is	VL	and P_{t-1} is	M	and Q_{t-1} is	L	THEN Q_t is VL
15. IF P_t is	M	and P_{t-1} is	EL	and Q_{t-1} is	VVL	THEN Q_t is L
16. IF P_t is	EL	and P_{t-1} is	M	and Q_{t-1} is	L	THEN Q_t is VL
17. IF P_t is	VL	and P_{t-1} is	EL	and Q_{t-1} is	VL	THEN Q_t is VVL
18. IF P_t is	M	and P_{t-1} is	VL	and Q_{t-1} is	VVL	THEN Q_t is VVL
19. IF P_t is	VH	and P_{t-1} is	M	and Q_{t-1} is	L	THEN Q_t is H
20. IF P_t is	M	and P_{t-1} is	VH	and Q_{t-1} is	H	THEN Q_t is M
21. IF P_t is	MH	and P_{t-1} is	M	and Q_{t-1} is	M	THEN Q_t is M
22. IF P_t is	M	and P_{t-1} is	MH	and Q_{t-1} is	M	THEN Q_t is L
23. IF P_t is	EH	and P_{t-1} is	M	and Q_{t-1} is	M	THEN Q_t is VH
24. IF P_t is	MH	and P_{t-1} is	EH	and Q_{t-1} is	VH	THEN Q_t is MH
25. IF P_t is	M	and P_{t-1} is	MH	and Q_{t-1} is	M H	THEN Q_t is M
26. IF P_t is	EL	and P_{t-1} is	M	and Q_{t-1} is	M	THEN Q_t is VL
27. IF P_t is	VVL	and P_{t-1} is	EL	and Q_{t-1} is	VL	THEN Q_t is VVL
28. IF P_t is	VL	and P_{t-1} is	VVL	and Q_{t-1} is	VVL	THEN Q_t is VL
29. IF P_t is	VL	and P_{t-1} is	VL	and Q_{t-1} is	EL	THEN Q_t is VL
30. IF P_t is	M	and P_{t-1} is	VL	and Q_{t-1} is	VL	THEN Q_t is VL
31. IF P_t is	MH	and P_{t-1} is	M	and Q_{t-1} is	VL	THEN Q_t is M
32. IF P_t is	EL	and P_{t-1} is	VL	and Q_{t-1} is	EL	THEN Q_t is VL

Table.3 Performance evaluation of SCS-CN method during training & testing

Performance of SCS-CN method during Training & Testing							
Training				Testing			
MAD (mm)	RMSE (mm)	CC%	CE%	MAD (mm)	RMSE (mm)	CC, %	CE, %
2.46	4.14	93.74	83.99	2.42	4.4	92.03	81.32

Table.4 Performance evaluation of Fuzzy Logic during training & testing

Performance of fuzzy logic model during Training & Testing							
Training				Testing			
MAD (mm)	RMSE (mm)	CC%	CE%	MAD (mm)	RMSE (mm)	CC, %	CE, %
2.06	3.45	95.78	88.88	2.29	3.62	94.99	87.33

Fig.1 Location map of study area

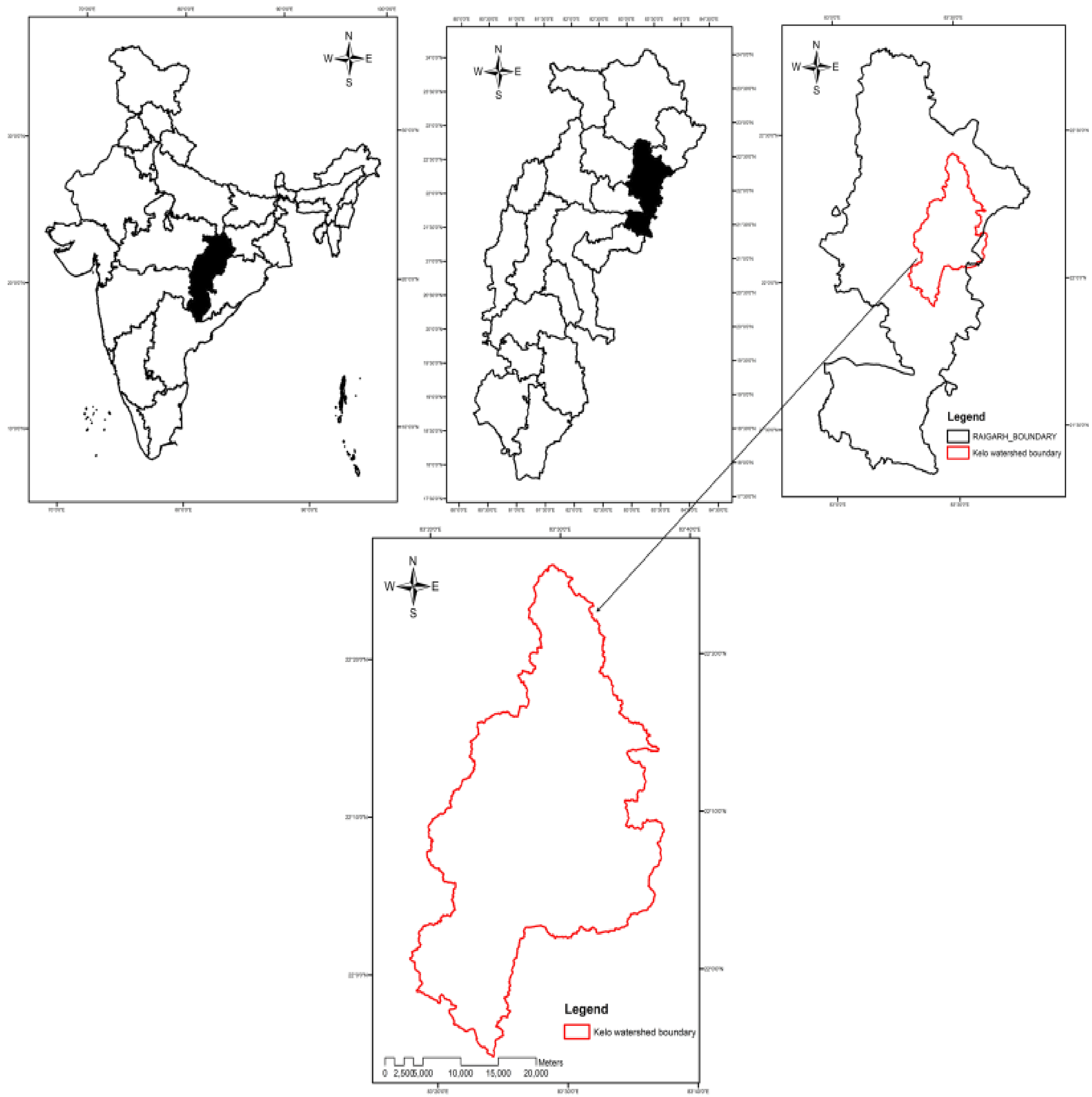


Fig.2 Methodology for estimating runoff

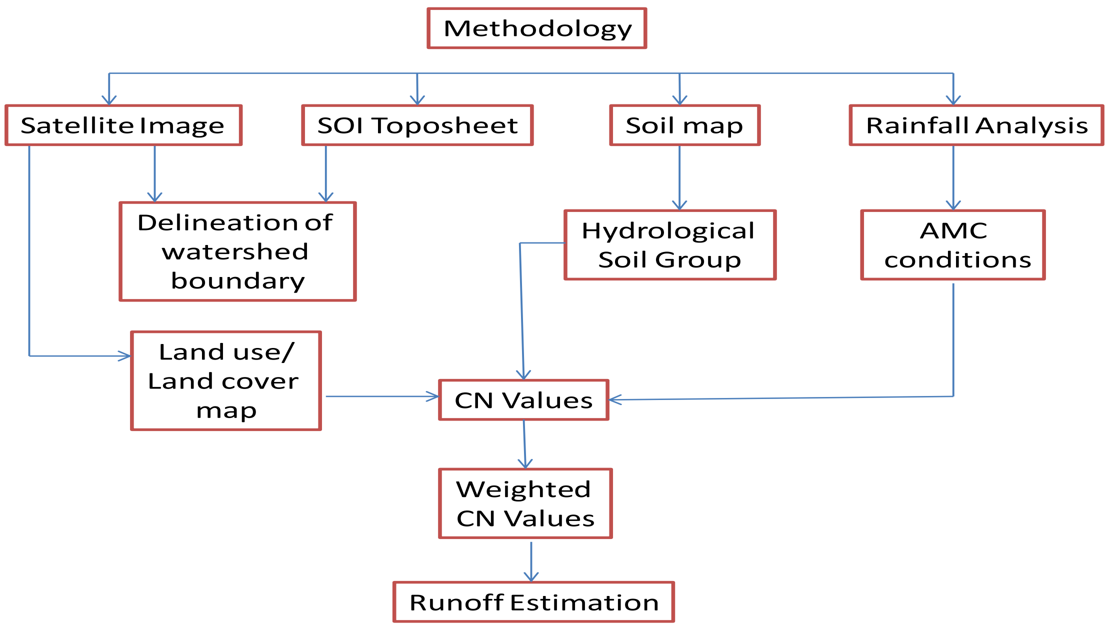


Fig.3 Result window of a pattern for estimation of runoff (Q_t)

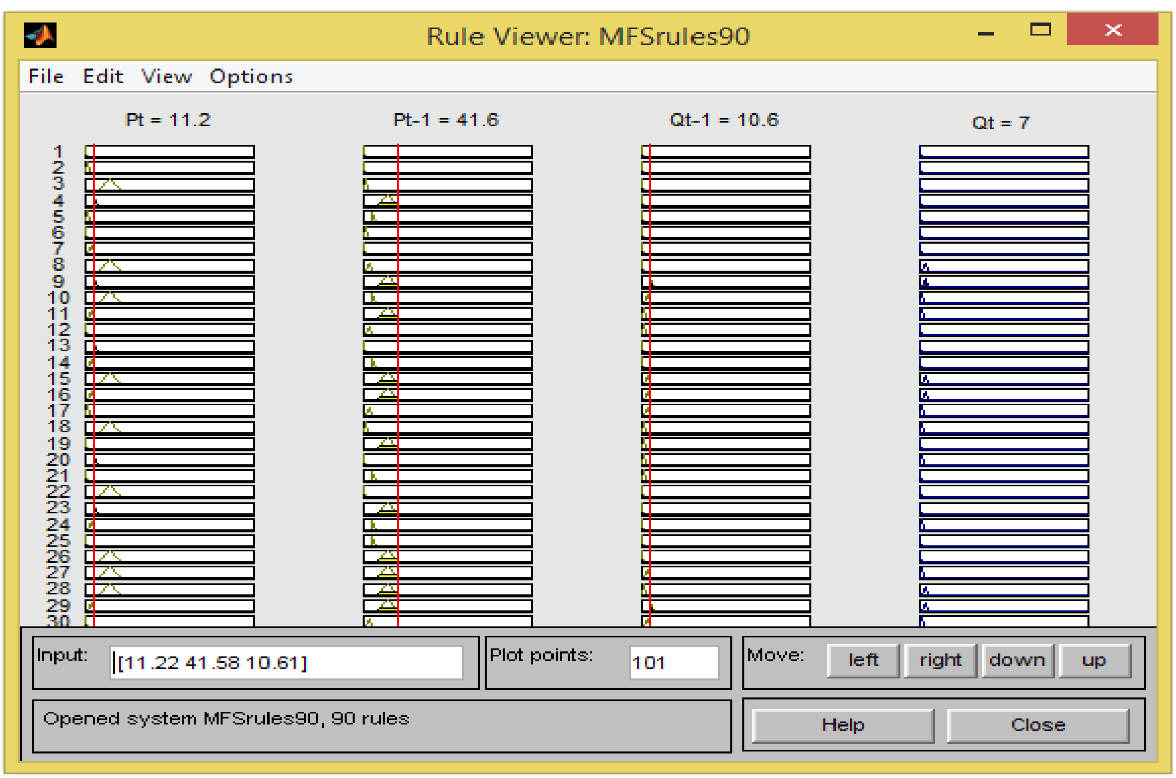


Fig.4 Active Period Daily (APD) observed, simulated and predicted FL for training period in 2008

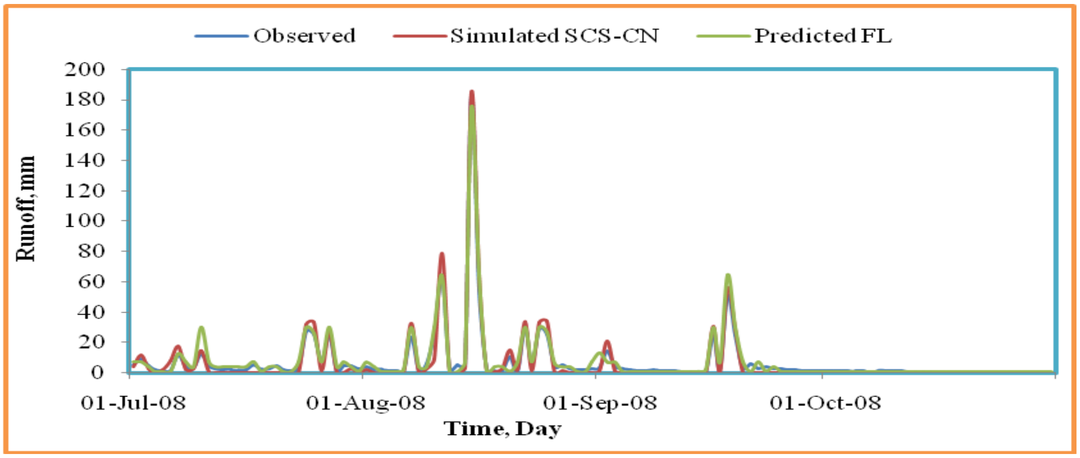


Fig.5 Active Period Daily (APD) observed, simulated and predicted FL for testing period in 2004

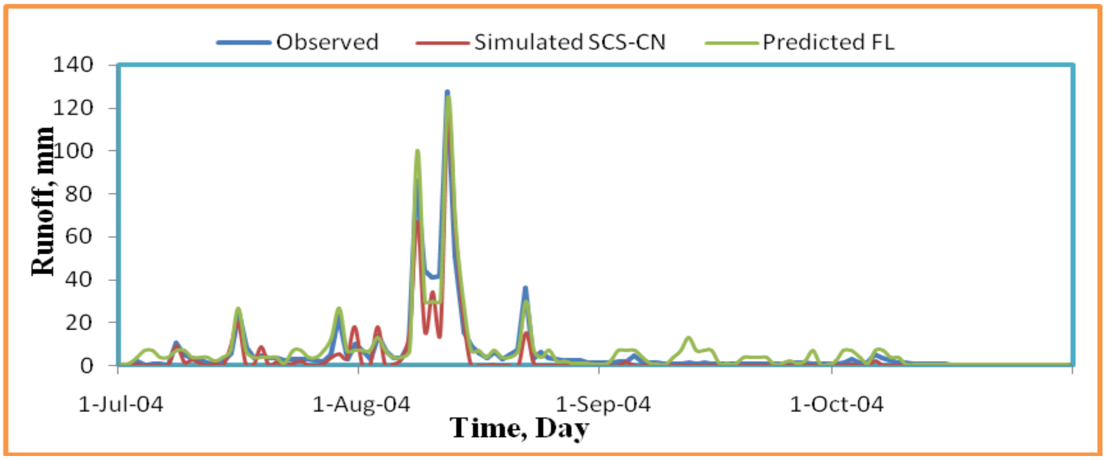


Fig.6 Relation between observed and simulated runoff using SCS- CN method in training period

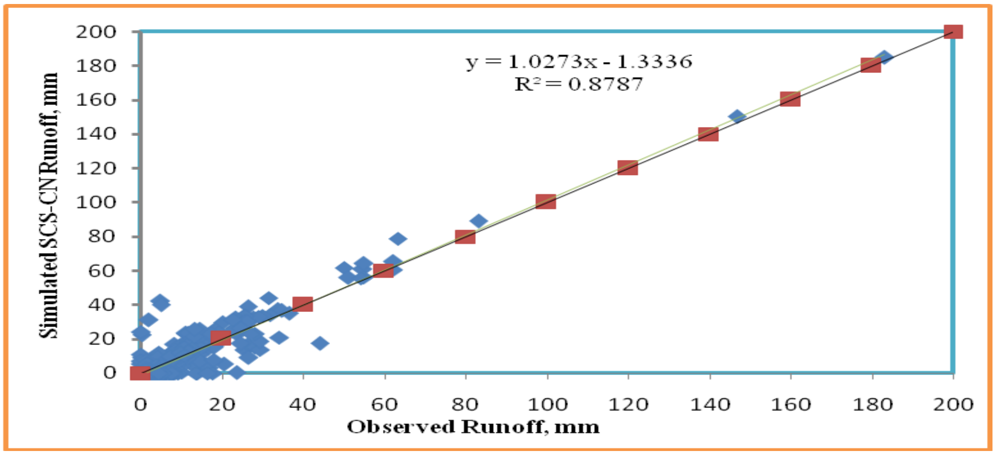


Fig.7 Relation between observed and simulated runoff using SCS-CN method in testing period

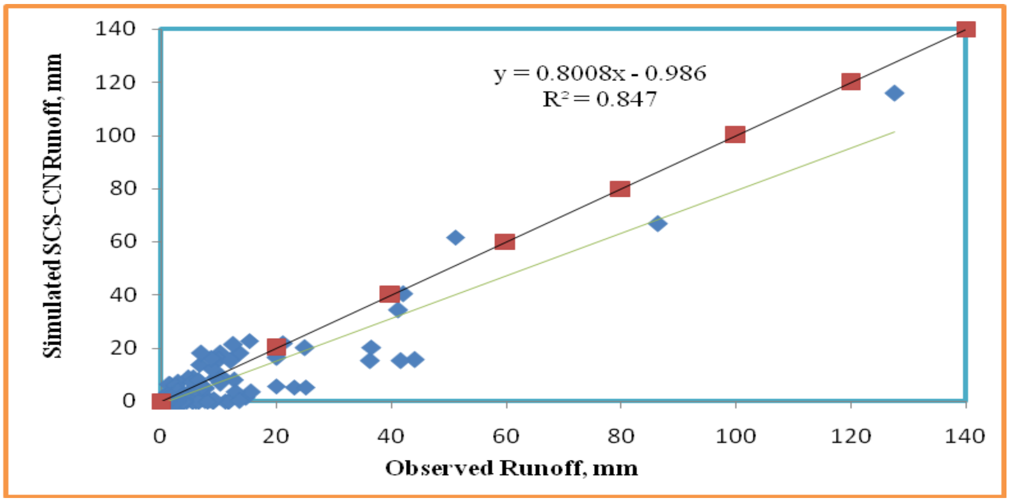


Fig.8 Relation between observed and predicted runoff using fuzzy logic in training period

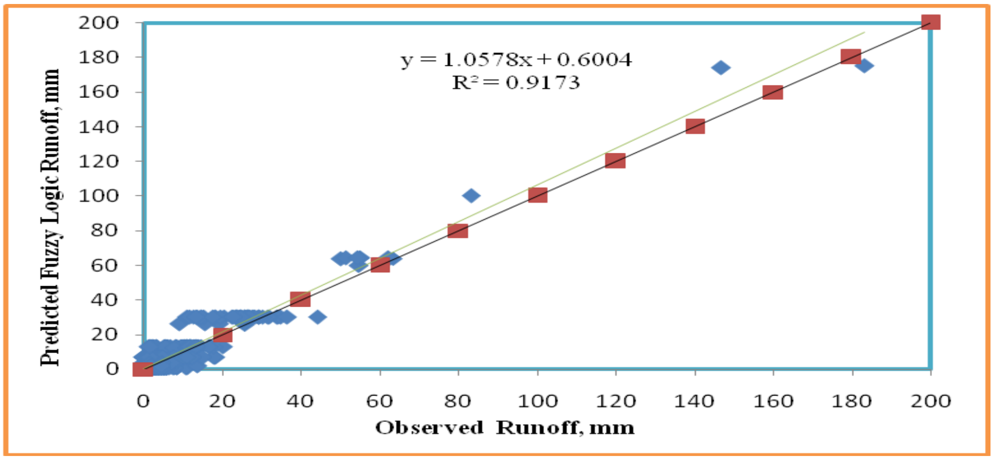
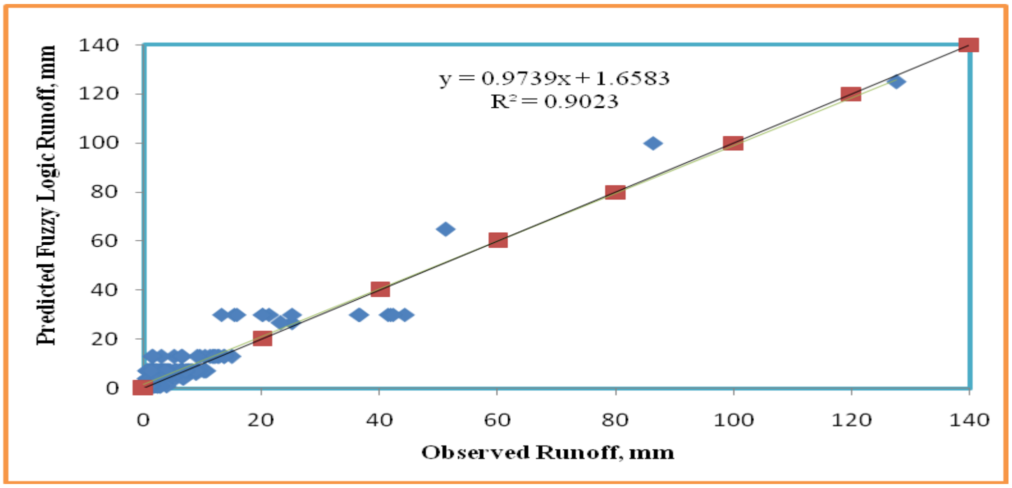


Fig.9 Relation between observed and predicted runoff using fuzzy logic in testing period



From the above findings it could be inferred that for rainfall-runoff modelling of the study area, use of FL model is a better choice than the SCS-CN method. The study also reveals that for study area use of FL is slightly better than SCS-CN method on the basis of overall performance.

The foregoing discussions clearly suggested that the choice of parameters have a significant effect on the model simulations. The results obtained in this investigation in respect of rainfall-runoff modelling, in general, supported the findings of Pawar, *et al.*, (2013), and Ratansharan A. Panchal, *et al.*, (2014). These researchers also used Rainfall-runoff modeling using fuzzy technique and found FL models predicted the daily runoff yield satisfactorily.

Training and testing results revealed that the SCS-CN and FL models predicted the daily runoff yield satisfactorily. But, SCS-CN method did not account for the influence of forest management practices. Therefore, FL model based on simple inputs can be used for estimation of runoff. The study concludes that Fuzzy Logic is simulating the phenomenon very well for Kelo macro-watershed of Mahanadi basin. It can be concluded that the Fuzzy Logic Rainfall – Runoff Models gives good output for the period considered for the study.

Thus, it can be concluded that use of FL model is a better choice than the SCS-CN method for rainfall – runoff modeling of the study area.

References

Abon, C. C., David, C. P. C., and Pellejera, N. E. B. 2011. "Reconstructing the Tropical Storm Ketsana flood event in Marikina River, Philippines." *Hydrol. Earth Syst. Sci*., 15, 1283–1289.

Anderson M G., Burt T P. 1985. Hydrological Forecasting. Chichester, Wiley.

Chalkidis I., Tzimopoules C., Evangelides C., Yannopoulos S. 2006. Application of Linear and Fuzzey Linear Programming for Water Management of an Aqufier, WSEAS Transaction on System, 12(5): 2844-2849.

Hawkins, R. H. 1993. Asymptotic determination of runoff curve numbers from data, J. Irrig. Drain. Eng. ASCE, 119, 334–345.

McCuen, R. H. 2002. "Approach to confidence interval estimation for curve numbers." *Journal of Hydrologic Engineering*, ASCE, Vol. 7, No. 1, pp. 43–48.

Michel, C., Andr´eassian, V., and Perrin, C. 2005. Soil Conservation Service Curve Number method: How to mend a wrong soil moisture accounting procedure. Water Resour. Res., 41.

Moutsopoulos K., Chalkides I., Tzimopoulos C. 2005. Fuzzy analysis of ground water resources including incomplete data of aquifer spatial extent, Journal of the Mechanical Behaviour of Materials, 16: 95-101.

Nash, J.E. and Sutcliffe, J.V. 1970. River flow forecasting through conceptual models. Journal of Hydrological Science, 41: 399-417.

Nayak, P., sudheer K., Ramasastri K. 2005. Fuzzy computing based rainfall-runoff model for real time flood forecasting, Hydrological Processes, 19:955-968.

Nilima Jangre. 2016. Modelling of Daily Reference Evapotranspiration using Fuzzy Logic for Chhattisgarh Plains, M. Tech. Thesis, Indira Gandhi Krishi Vishwavidyalaya Agricultural University, Raipur.

O'Loughlin G, Huber W, Chocat B. 1996. Rainfallrunoff processes and modelling. J. Hyd. Res., 34(6), 733 - 751.

Panigrahi D. P. and Mujumdar P. P. 2000.

Reservoir Operation Modelling with Fuzzy Logic, *Water Resources Management* 14: 89–109.

Pawar, D. B., Kumar P. & Kyada P. 2013. Rainfall-Runoff Modeling using Fuzzy Technique for a small Watershed in Maharashtra, India, International Journal of Engineering and Management Science, vol.4 (3) 388-394.

Ponce, V. M. and Hawkins, R. H. 1996. Runoff curve number: Has it reached maturity? J. Hydrol. Eng. ASCE, 1, 11–18.

Ratansharan A. Panchal, Suryanarayana T. M. V., F. P. Parekh. 2014. Rainfall-Runoff Modeling: A Fuzzy Logic Approach, *International Journal for Scientific Research & Development,*Vol. 2, Issue 05.

SCS (1956, 1964, 1969, 1971, 1972, 1985, 1993, 2004) *Hydrology*, National Engineering Handbook, Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, D.C.

Steenhuis, T. S., Winchell, M., Rossing, J., Zollweg, J. A., and Walter, M. F.1995. SCS runoff equation revisited for variable-source runoff areas, J. Irrig. Drain. Eng. ASCE, 121, 234–238.

Subramanya K. 2008. “Engineering Hydrology” Publisher Tata McGraw Hill, 4th edition, pp.185-194.

Todini E. 1988. Rainfall-runoff modelling - past, present and future. J. Hydrol., 100(1-4), 341 - 352.

Tzimopoulos C., Chalkidis I., Motsopoulos K., Yannopoulos S., Sakellariou M, Evangelides C. 2004. Fuzzy Simulation of soil Water Balance for the case of the two dimensional Unsteady Flow, In: EWRA Symposium Water Resources Management, Izmir- Turkey Proc. Vol.3, pp.1017-1026.

Van Dijk, A. I. J. M. 2010. Selection of an appropriately simple storm runoff model, Journal of Hydrol. Earth Syst. Sci., 14, 447–458.

Watts G. 1997. Contemporary hydrology: towards holistic environmental science. Chichester, Wiley, 151-93.

Yu Pao-Shan, Shien –Tsung Chen. 2005. Updating real-time flood forecasting using a fuzzy rule-based model, Hydrol, Sc.Journal, 50 (2).

Zadeh L A. 1965. Fuzzy set, Information and Control, 8, 338-353.

Zadeh, L.A. 1973. Outline of a new approach to the analysis of complex system and decision processes. IEEE Trans. System, man, and Cybernetics 3, 28-44.

How to cite this article:

Gayam Sujatha, Jitendra Sinha, Nilima Jangre and Ashish Patel. 2017. Development of Fuzzy Logic Based Rainfall-Runoff Model for Kelo River Macro Watershed of Mahanadi Basin. *Int.J.Curr.Microbiol.App.Sci.* 6(10): 2736-2748. doi: https://doi.org/10.20546/ijcmas.2017.610.322