Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 2, Number 15; July-September, 2015 pp. 24-27

http://www.krishisanskriti.org/jceet.html

Critical Evaluation of SAHU Model for Runoff Simulation

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Abstract—*Rainfall is the major component of the hydrologic cycle and this is primary source of runoff. Worldwide many attempts have been made to model and predict rainfall behavior using various empirical, statistical, numerical and deterministic techniques. In the present work, estimation of mean rainfall over the Mahanadi basin lying in Odisha and its total five sub-basins has been done using different deterministic methods including SCS-CN(Soil Conservation Service - Curve Number) and SCS-CN based SAHU Model. There are many approaches for the determination of runoff from rainfall and one of that is the SCS-CN(1956) method converts rainfall to surface runoff (or rainfall-excess) using a CN derived from watershed characteristics. The daily rainfall data of five rain gauge stations in and around the watershed (2003-2013) was used to estimate the daily runoff from the watershed using SCS-CN method. The objective of the project work is to compare the simulation performance of the runoff for both the original SCS-CN and SAHU Model in the five sub-basins. In the present work the SAHU Model performs better result than the original SCS-CN Method.*

1. INTRODUCTION

Water influences every sphere of the environment supporting life on earth. Its varying availability in time and space is a matter of concern to the mankind since fresh water is not an ever-present resource.

Many hydrological models have been developed in the past (Singh 1989; Singh and Frevert 2006) for transformations of rainfall into stream flow because of easy availability of rainfall data for longer time periods at different locations. In many of these models, soil conservation service curve number (SCS-CN) model has been widely used for surface runoff computations. The primary reason for its wide applicability and acceptability lies in the fact that it accounts for major runoff generating

Watershed characteristics, namely, soil type, land use/treatment, surface condition and antecedent moisture condition. Research conducted on the applicability of the SCS-CN method suggests a need for improvement (Ponce and Hawkins 1996). Although several modifications of the method have been suggested and reported in the literature, further improvement of the method is needed.

Long-term observations on stream flow are generally not available at desired locations, and these records often contain data missing attributable to variety of reasons. Therefore, many hydrological models have been developed in the past (Singh 1989; Singh and Frevert 2006) for transformations of rainfall into stream flow because of easy availability of rainfall data for longer time periods at different locations. In many of these models, soil conservation service curve number (SCS-CN) model has been widely used for surface runoff computations.

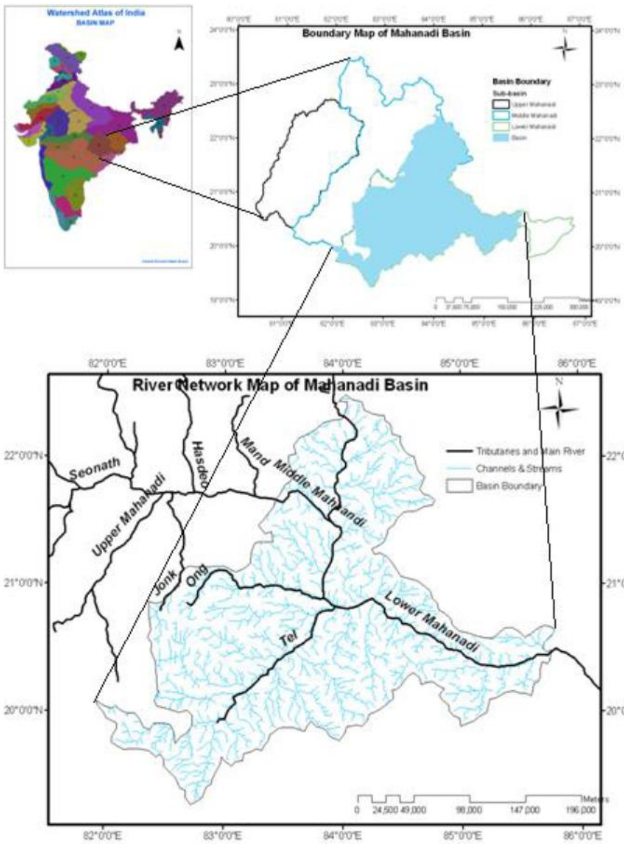
Yu (1998) provided a theoretical framework in which the SCS method can be tested. They showed that the proportionality between retention and runoff and the SCS equation would follow if the temporal distribution of rainfall intensity and the spatial distribution of the maximum rate of infiltration are independent and described by exponential probability distributions. In particular, they showed that the maximum retention S could be seen as the product of the spatially averaged maximum rate of infiltration and the effective storm duration.

Mishra et al. (2004) modified the existing SCS-CN method, which is based on the Soil Conservation Service Curve Number (SCS-CN) methodology but incorporates the antecedent moisture in direct surface runoff computations and named it as MS model. They evaluated the modified version and by comparing with the existing SCS-CN method they found that the modified MS model performs far better than the existing SCS-CN model.

Gajbhiye et al. has examined seasonal and monthly effects on the runoff Curve Number for four watersheds of Narmada basin. The periods between April-June and October-December has been defined as the Pre-Monsoon and Post-Monsoon seasons, respectively. The Curve Number method has been used to determine Curve Numbers using these observed rainfall and runoff values. Based on the date that rainfall and runoff volume which has been observed, the Curve Number values were grouped to their respective seasons for statistical analysis. The results from all watersheds showed monthly

Curve number which indicated a homogeneous pattern of variation in all the four watersheds in the basin.

2. STUDY AREA



Mahanadi river is the second major river in peninsular India after Godavari with respect to the water potential and flood producing capacity and is located in East Central India within geographical co-ordinates of 80º30' to 86º50' E and 19º20' to 23º35' N (Fig. 3.1). Mahanadi river basin is the largest river of Odisha State and extends over an area of 141589 sq. km which is nearly 4.3% of the total geographical area of India and covers five different states namely Maharashtra, Madhya Pradesh, Chhattisgarh, Odisha and Jharkhand (CWC, 2009). Mahanadi River originates from a fall of Pharsiya village near Nagri town in Dhamtari district of Chattisgarh at an elevation of 442 m above mean sea level. About 65580 km2 of the basin lying in Odisha extending within geographical co-ordinates of 82º to 86º E and 19º30' to 22º30' N approximately, has been considered in the present work. The total length of the river from its origin to confluence at the Bay of Bengal is about 851 km, of which 357 km is in Chhattisgarh and 494 km is in Orissa. Drainage density of the basin is extremely thick. During its traverse, a number of tributaries join the river on both the banks. Principal tributaries of the tributary joining on Odisha are Ib, Ong and Tel (CWC, 2009). The tributary upstream of Hirakud dam is Ib, whereas Ong and Tel are the downstream tributaries. The average annual flow of the basin measured at different places such as Sarangarh, Sambalpur, Sonepur and Munduli are 30586, 41816, 54881 and 66640 cumecs, respectively.

3. ORIGINAL SCS-CN MODEL

The SCS-CN method is developed in 1954 by the USDA Soil Conservation Service (Rallison 1980), and is described in the Soil Conservation Service (SCS) National Engineering Handbook Section 4: Hydrology (NEH-4) (SCS 1985) (Ponce and Hawkins, 1996). The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis states that the ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual infiltration to the amount of the potential maximum retention. The second hypothesis states that the amount of initial abstraction is some fraction of the potential maximum retention. The water balance equation and the two hypotheses can be expressed mathematically, respectively, as follow:

$$P = I_a + F + Q$$

$$Q/(P - Ia) = F/S$$

where P is total precipitation, Ia is initial abstraction, F is cumulative infiltration excluding Ia, Q is direct runoff, S potential maximum retention or infiltration, and λ initial abstractioncoefficient accounting for surface storage, interception, and infiltration before runoff begins.

$$Q = \frac{(P - Ia)^2}{P - Ia + S}, \text{ if } P>Ia$$

$$= 0 \text{ otherwise} \quad (1)$$

$$Ia = \lambda S \quad (2)$$

Further the parameter S(in mm) is being represented in the form of CN , which is

$$S = \frac{25400}{CN} - 254 \quad (3)$$

The potential maximum retention (S) for each of the maximum annual storm volume Q, and the rainfall volume P can be computed using the following expression

$$S = 5(P+2Q-\sqrt{(4Q^2 - 5PQ)}) \quad (4)$$

In this equation λ=0.2 is substituted in the original equation.

SAHU MODEL

The antecedent or initial soil moisture (V0) depends not only on P5 but also on S. The dependency on S is based on the fact that the watershed with larger retention capacity S must retain higher moisture compared to the watershed with lesser S for a given P5. An expression for initial soil moisture store level (V0) is taken as AMC-dependent, which leads to a quantum jump in V0 and, in turn, runoff computations. Therefore an expression for V0 is suggested by Sahu et al. (2007) for continuous simulation.

For practical applications, Sahu et al. (2007) developed a one-parameter model, described by the following set of equations,

$$\text{If } P_5 \leq 0.1S \text{ then}, V_0 = 0.4P_5$$

$$\text{If } P_5 > 0.1S \text{ then}, V_0 = S\left[\frac{0.44P_5 - 0.004S}{P_5 + 0.9S}\right]$$

From known V0, Q can be computed as follows:

$$\text{If } V_0 + P \leq 0.1S, \text{ then } Q = 0.$$

$$\text{If } 0.1S \leq V_0 + P \leq 0.1S + P, \text{ then} Q = \frac{(P + V_0 - 0.1S)^2}{(P + V_0 + 0.9S)}.$$

$$\text{If } 0.1S \leq V_0 \leq 1.1S, \text{ then} Q = P\left[1 - \frac{(1.1S - V_0)^2}{S^2 + (1.1S - V_0)P}\right]. \quad (5)$$

4. METHODOLOGY:

A. Original SCS-CN Method:

Here the procedure to execute the desire result in the SCS-CN method is:

1. Prepare a series of available daily rainfall(P) and runoff(Q) data in same bunits for the period the data are available.
2. Filter the data by selecting the pairs of P-Q data which lies between the runoff factor(Q/P) value 0 to 1.
3. Sort the remaining P-Q data in the descending order of P and by taking the P-Q data S can be calculated using the equation- 4, and S can be transformed to CN scale using the empirical relation of equation – 3.
4. After that, the column is set in the descending order and then the median of the total CN values in the column is determined and is to be taken as CN-II which is the normal condition. After that CN-I and CN-II is calculated by using the formulae given below:

   CNI = CNII / (2.281 – 0.01281 CNII)

   CNɪɪɪ = CN II / (0.427 + 0.00573 CNII)

This formulae of CN-I(dry condition), CN-II(normal condition) and CN-III(wet condition) was proposed by Hawkins et al. (1985) as the AMC-dependent CN conversion formulae.

5. After the CN-I,II and III values are determined then the S can be again calculated by depending upon the CN values by using the equation-4
6. At last the runoff can be calculated by using the combined equation 1&2 , where the λ is taken as 0.2 which is the universal value.

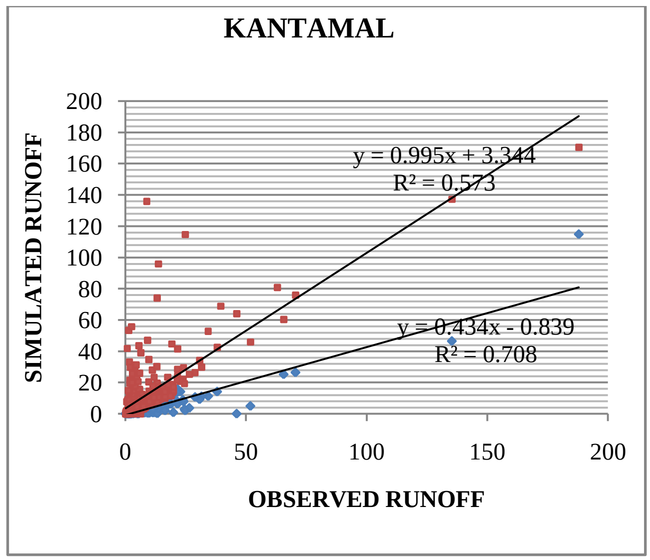
B. Sahu Model:

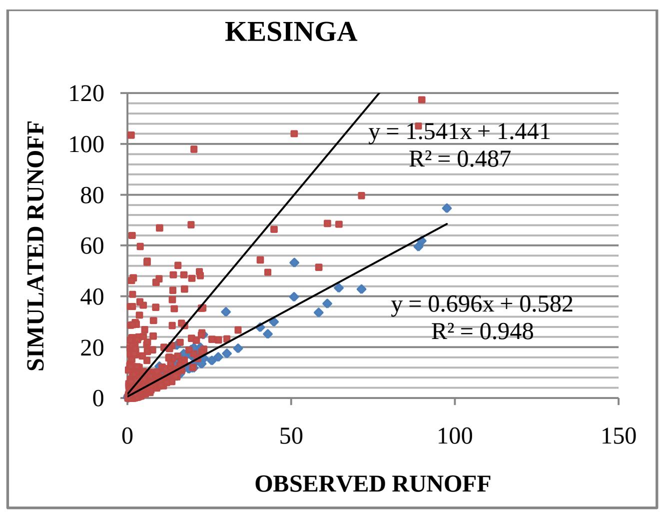
Here the procedure to execute the desire result in the SAHU model is:

1. Available data set is to be prepared in the form of P and Q , then the P5 (5 days cumulative rainfall) is being determined from the daily rainfall (p).
2. Filter the data by selecting the pairs of P-Q data which lies between the runoff factor(Q/P) value 0 to 1.
3. From these values now the S can be calculated by using the equation- 4.
4. After the determination of S now Vo can be calculated easily by using a comparison of P5 is greater than or smaller than 0.1S, as per the given expression above.
5. At last , the runoff is determined using equation- 5.

5. RESULT AND DISCUSSION:

As applying the above procedure described in both the methods we can get the result and the comparison can also be done between both the methods.





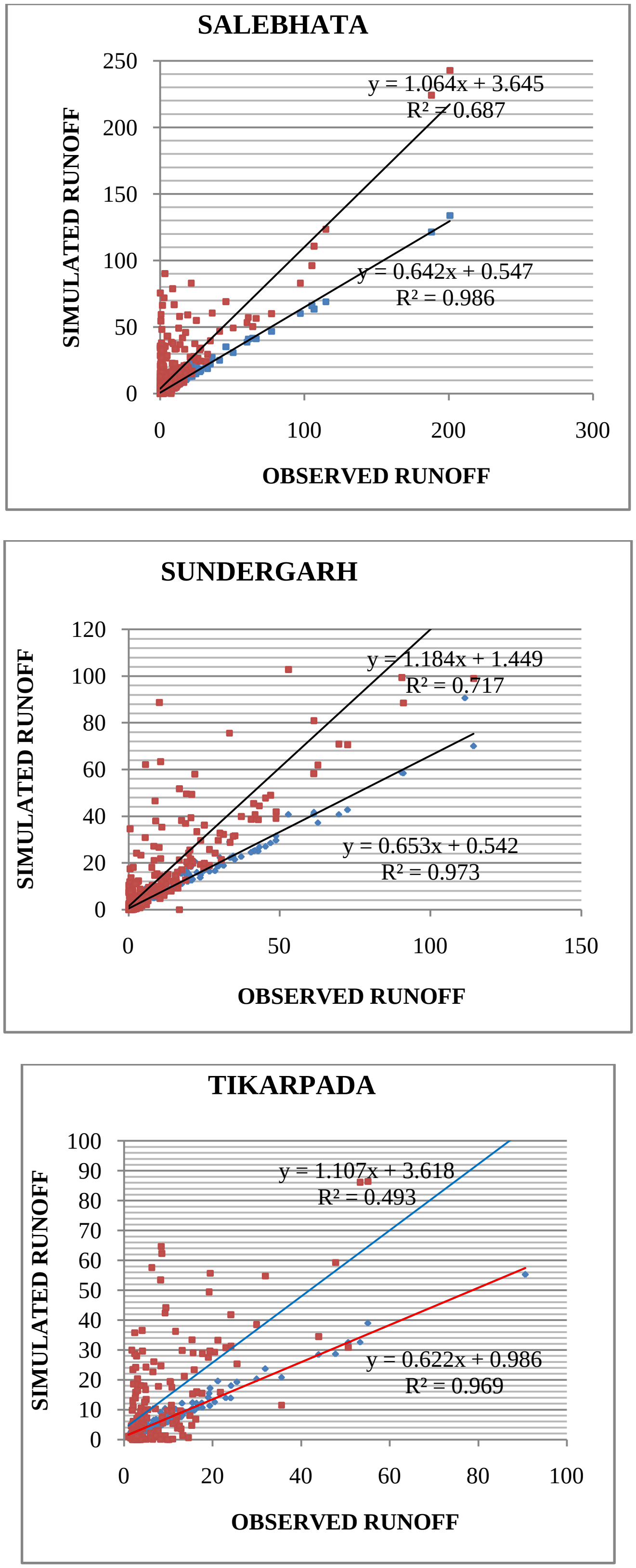


Fig. 1: Daily simulation performance of original SCS-CN method and SAHUModel.

Table 2: Comparison of the R^2 value in the Original SCS-CN method and the SAHU Model

SUB-BASINS	R2 VALUE	
	ORIGINAL SCS-CN METHOD	SAHU MODEL
KANTAMAL	0. 573	0.708
KESINGA	0.478	0.948
SALEBHATA	0.687	0.986
SUNDARGARH	0.717	0.973
TIKARPADA	0.493	0.969

The above graph shows the daily simulated performance for the five sub-basins in the term of the scatter plot which shows the R^2 value. The above table represents the comparison between the R^2 values of both the method in the five sub-basins.

Here we found out that the result of the SAHU Model was better than the original SCS-CN method. SAHU Model performed better than the original method because in the method instead of the AMC I, II & III it takes the V_o value, which is the soil moisture store level and instead of the daily rainfall here P5 (means five days rainfall) is taken into consideration. So, for the P5 and the V_o value we get better result in the SAHU Model.

6. CONCLUSION

After comparing both the method in the all five sub-basins it is concluded that the SAHU Model performs better than the original SCS-CN method.

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