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Analysis of variation of Curve Number with Rainfall duration

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Abstract—*Runoff is mainly generated from precipitation as rainfall is a form of precipitation which is a major contributor for the generation of runoff. At present various modifications has been done worldwide and there are various methods available for estimation of curve number. In the present work using daily rainfall data for ten years duration (2003-2013) from five watersheds of Mahanadi basin lying in Odisha, Curve Numbers are derived with the help of Original SCS-CN (1956) method. The objective of the study is to show the variation of curve number with duration from long-term daily rainfall dataset. From the results, it has been concluded that a relation has been justified that computed CN decreases with the increase in duration, picturing the characteristics of three AMC conditions. The validation of the proposed approach for watersheds of Mahanadi basin provides satisfactory workability of the method used in the present work.*

1. INTRODUCTION

The first half of the 20th century is considered to be the beginning of the dynamic development of rainfall-runoff modelling. Since 1950‘s the whole process was even faster thanks to the rapid advancement of technology. At present, it is possible to find models of various complexity designed for various problems in specific watershed conditions. With diversity of models increases the need of their better understanding in order to be able to choose a suitable one.

SCS-CN method has wide applicability and acceptability because of the fact that it accounts for major runoff generating watershed characteristics, namely, soil type, land use/treatment, surface condition and antecedent moisture condition (Mishra and Singh 2002; Mishra and Singh 2003a; Ponce and Hawkins 1996).

Richard H. Hawkins (1993) in his study took consideration of background, general instructions and examples for determining runoff curve numbers (CN) from small watershed event rainfall and direct runoff data sets. The technique matched rank-ordered rainfall and runoffs, which prevents the return period matching between the rainfalls and the runoffs. The runoff curve number for watershed data sets for event rainfalls and runoffs were determined by the variables separately and repairing the individual rainfalls and runoffs.

Dry state (AMC I), Wet state (AMC III), and Normal state (AMC II) statistically correspond, respectively, to 90%, 10%, and 50% cumulative probability of the exceedance of runoff depth for a given rainfall (Hjelmfelt *et al*., 1982). Alternatively, AMC II represents the central tendency, whereas AMC I and AMC III account for dispersion in the data.

Mishra et al. (2007) used SCS-CN method for computation of direct runoff from long duration rains for five Indian watersheds. They derived curve numbers from long-term daily rainfall-runoff data and Antecedent Moisture Condition (AMC) related with antecedent duration.

Mishra et al. (2008) presented a rain duration-dependent procedure based on the popular Soil Conservation Service Curve Number (SCS-CN) methodology for computation of direct surface runoff from long duration rains. Curve numbers were derived from long-term daily rainfall-runoff data, and antecedent moisture condition (AMC) related with antecedent duration. The derived runoff curve numbers exhibited a strong dependency on the storm duration and the reasonable match of the observed runoff with those due to the proposed approach was better than those from the original SCS-CN method.

L. silveira, F. Charbonnier & J. L. Genta discussed the applicability of the curve number procedure developed by the US Soil Conservation Service (SCS) to estimate direct runoff in basins characterized by small to gentle undulating slopes mainly covered with natural grasslands. Runoff estimates are based upon the soil types, land-use practices within a basin and the influence of the antecedent soil moisture conditions for a specific storm.

2. ORIGINAL SCS-CN MODEL

The SCS – CN method is developed in 1945 by the USDA Soil Conservation Services (SCS) National Engineering. Handbook section 4: Hydrology (NEH-4) (SCS 1985) (Ponce and Hawkins 1996). The SCS method estimates runoff in unmeasured watershed areas in regard to precipitation and the characteristics of watershed areas. Basically this method is valid until the runoff results from raining and if it is a result of slush this method will not be applicable (khojini, 1999).

The original SCS-CN method computes the direct one of with consideration to the available rainfall on daily basis without having any effect of moisture to the soil. The curve numbers are sensitive to the antecedent moisture condition (Ponce 1989). The curve number is usually represented for average antecedent moisture condition (AMC) CN and for direct runoff computation it is varied, with AMC generally described using daily rainfall.

SCS-CN method is based on the water balance equation and two fundamental hypotheses. The water balance equation is as follows:

$$P = I_a + F + Q$$

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 two hypotheses can be expressed mathematically, respectively, as follow:

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

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 abstraction coefficient 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 potential maximum retention S (in mm) is being represented in the form of CN, which is as follows:

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

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

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

Here in this case the value of initial abstraction coefficient (λ) is considered as 0.2 which is accepted globally.

3. METHOD

For carrying out the process the Original SCS-CN method has been utilized. The following procedure to execute the solution is as follows:

1. From the available daily rainfall (P) and runoff (Q) data in same units prepare a series for the period the data are available.
2. By selecting the pairs of P-Q data filter the data which lies between the runoff factors (Q/P) value 0 to 1.
3. After filtering the P-Q data sort the remaining P-Q data in the descending order of P and by taking the P-Q data S is calculated using the equation 4, and S is transmuted to Curve Number scale using relation mentioned in equation 3.
4. After that step, the column is arranged in the descending order of Curve Number and the median of the total CN values in that column is determined and is taken as CN-II which is the normal condition.

The 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. Using two relations specified below, CN-I and CN-II is estimated

CN I = CN II / (2.281 – 0.01281 CN II)

CN III = CN II / (0.427 + 0.00573 CN II)

4. RESULT AND DISCUSSION

The CN values derived for the study area watersheds which has further application in the simulation of daily runoff are estimated on daily basis not on weekly, half-monthly or monthly basis. As the curve number varies on monthly, half yearly, annually, it also varies on daily, weekly basis. So it’s necessary to estimate the curve number on basis to establish the best relationship for a better decision making. The method used to derive curve number shows the best results for all the watersheds.

For the present analysis, daily rainfall and runoff data for the period of ten years 2003-2013 has been used for the watersheds of Mahanadi lying in Odisha. The CN variation for the five watersheds are shown below:

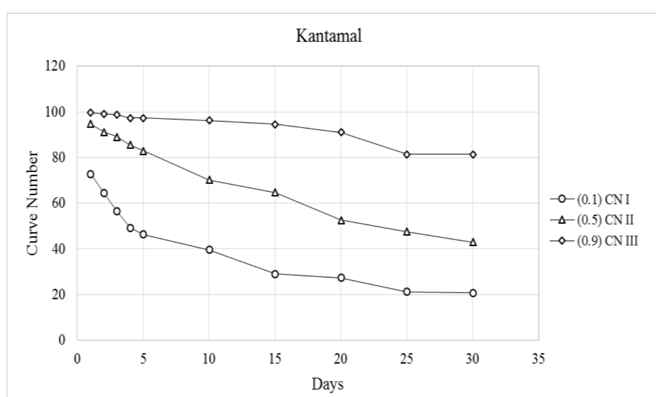

Fig. 1: CN Variations with Rainfall Duration for Kantamal watershed.

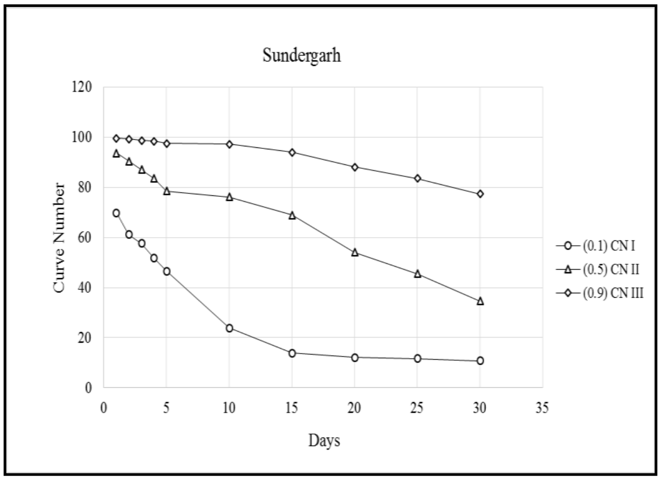

Fig. 2: CN Variations with Rainfall Duration for Sundergarh watershed.

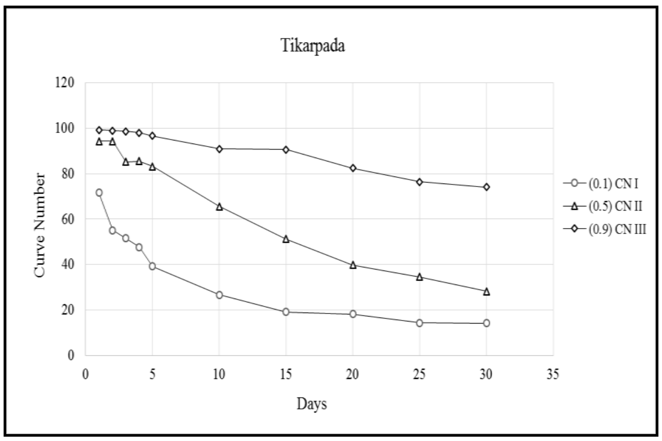

Fig. 3: CN Variations with Rainfall Duration for Tikarpada watershed

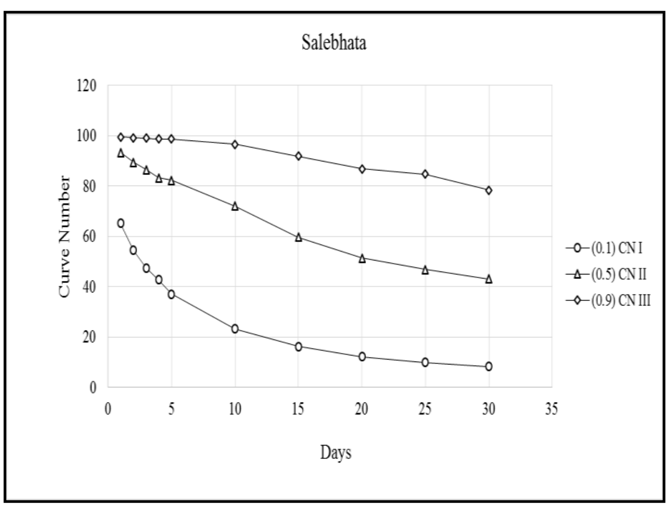

Fig. 4: CN Variations with Rainfall Duration for Salebhata watershed.

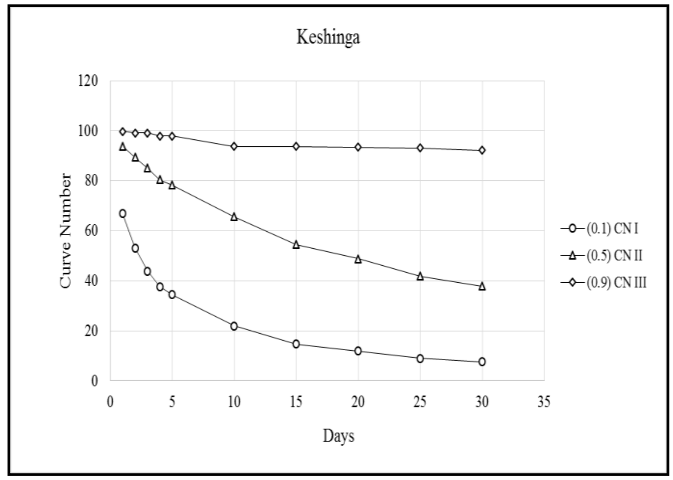

Fig. 5: CN Variations with Rainfall Duration for Keshinga watershed.

These curves are analyzed with the help of regression analysis and second order polynomial equations are derived for the three AMC conditions viz. AMC I, AMC II and AMC III. The equations are as follows:

For Kantamal watershed

AMC I $y = 0.0761x^2-3.8349x + 69.281$

AMC II $y = 0.0355x^2-2.8606x + 96.855$

AMC III $y = -0.0164x^2-0.1544x + 99.24$

For Sundergarh watershed

AMC I $y = 0.1257x^2-5.7303x + 72.87$

AMC II $y = -0.0084x^2-1.6643x + 92.382$

AMC III $y = -0.0224x^2-0.0692x + 99.331$

For Tikarpada watershed

AMC I $y = 0.1041x^2-4.7594x + 66.532$

AMC II $y = 0.0542x^2-4.0063x + 99.794$

AMC III $y = -0.0049x^2-0.7727x + 100.56$

For Salebhata watershed

AMC I $y = 0.0986x^2-4.6665x + 62.674$

AMC II $y = 0.0399x^2-2.9547x + 95.618$

AMC III $y = -0.0126x^2-0.3496x + 100.31$

For Keshinga watershed

AMC I $y = 0.1024x^2-4.7282x + 60.923$

AMC II $y = 0.0535x^2-3.4926x + 95.446$

AMC III $y = 0.0132x^2-0.6449x + 100.41$

Here, y is the curve number and x is the rainfall duration.

The equations obtained for the calculation of curve numbers (CN) values for any given rainfall duration between 1-day to 30-days are validated for its application in the Mahanadi basin and CN values are calculated for different cumulative rainfall durations.

Validation of the proposed approach

Kantamal watershed has been considered as a sample for demonstrating the validation procedure. Considering 7 day as rainfall duration and relating on equation of AMC I condition for Kantamal watershed the curve number is estimated as 97.35. Similarly considering 7 day as rainfall duration and relating on equation of AMC II condition and AMC III condition, the curve is estimated as 78.57 and 42.80. For a better demonstration another case is shown. Considering 12 days as rainfall duration and relating on equation of AMC I condition for Kantamal watershed, the curve number is estimated as 95.025 and likewise relating in equations for AMC II condition and AMC III condition, the curve number is estimated as 67.634 and 34.220. Likewise for the other watershed it has been calculated following the similar procedure.

The proposed approach was validated to check the performance for its applicability. For the validation process rainfall durations equal to 7-day, 12-day, 18-day, 22-day and 28-day were chosen then respective curve number estimated from the scatter plots. From the scatter plots plot between observed runoff and computed runoff (which has not been shown here) R^2 values estimated proves to be satisfying for each watershed.

Table 1: R^2 values for the watersheds

Watersheds	7 days	12 days	18 days	22 days	28 days
Kantamal	0.730	0.860	0.882	0.907	0.848
Sundergarh	0.667	0.573	0.606	0.762	0.805
Tikarpada	0.341	0.492	0.614	0.455	0.453
Salebhata	0.504	0.416	0.476	0.437	0.505
Keshinga	0.705	0.590	0.428	0.380	0.439

The variation of Curve Number with duration of rainfall has been shown in table 2. Here the curve number variation for AMC I, AMC II and AMC III condition for 1 day rainfall duration has been illustrated and for the rest period the curve number variation shows the similar trend. From this variation it is understood that curve number decreases with the increase in duration.

Table 2: Curve Number variation for 1 day duration

Watershed	1-d curve numbers (CN)		
	AMC I	AMC II	AMC III
Kantamal	72.85	94.66	99.69
Salebhata	65.18	93.36	99.61
Keshinga	66.97	93.88	99.73
Tikarpada	71.54	94.32	99.14
Sundergarh	69.91	93.77	99.61

5. CONCLUSION

It has been established that curve number varies daily, weekly, monthly, annual basis. So it is necessary to for carrying out analysis to derive curve number for any given rainfall duration between 1-day and 30-day for a better decision making. Second order polynomial equations for AMC I, AMC II, AMC III derived for each watersheds are validated for their applicability with various other rainfall duration between 1-day and 30-day.

It has been justified that curve number decreases with increase in rainfall duration underlines a linear relationship among them.

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