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Comparison of AMC-dependent CN-conversion Formulae

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Abstract The available antecedent moisture condition (AMC)-dependent runoff curve number (CN) (SCS, National Engineering Handbook, Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, DC, 1956) conversion formulae due to Sobhani (M.S. Thesis, Utah State University, Logan, UT, 1975), Hawkins et al. (J Irrig Drain Eng, ASCE 111:330–340, 1985), Chow et al. (McGraw-Hill, New York, 1988), and Neitsch et al. (Texas Water Resources Institute, College Station, TX, TWRI Report TR-191, 2002) were compared utilizing the NEH-4 CN-values (SCS, National Engineering Handbook, Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, DC, 1972) as target values. The Sobhani formula was found to perform the best in CN_I-conversion, and the Hawkins formula in CN_{III}-conversion. When evaluated on a large set of Agriculture Research Service (United States) data, a newly proposed formula performed the best of all, and the Neitsch formula the poorest, and therefore, the former was recommended for field use. The poorest performance of the latter is largely attributed to the occurrence of unreasonable negative CN_I-values at low CN_{II}-values.

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1 Introduction

The Soil Conservation Service Curve Number (SCS-CN) method (SCS 1956, 1964, 1971, 1993) converts rainfall to surface runoff (or rainfall-excess) using curve number, which is derived from watershed characteristics and 5-day antecedent rainfall. Amalgamation of the SCS-CN method in several standard hydrologic software packages such as Storm Water Management Model (SWMM) (Metcalf and Eddy 1971); Constrained Linear Simulation (CLS) (Natale and Todini 1977); Hydrologic Engineering Center-1 (HEC-1) (HEC 1981); Agricultural Non-point Source Model (AGNPS) (Young et al. 1995); Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Smith and Williams 1980); Areal Non-point Source Watershed Environment Response Simulation (ANSWERS) (Beasley et al. 1980); and Soil and Water Assessment Tool (SWAT) (Neitsch et al. 2002) indicates its wide use. The general form of the SCS-CN equation is given as:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{1}$$

where P = total precipitation; Q = direct surface runoff; S = potential maximum retention; and I_a = initial abstraction which is expressed as a function of S as:

$$I_a = \lambda S \tag{2}$$

where λ = initial abstraction coefficient. The existing version of the SCS-CN method assumes λ=0.2 in routine applications (SCS 1972, 1985). Of late, λ=0.05 has also been advocated for field use (Hawkins et al. 2002), which can, however, vary from 0 to ∞ (Mishra and Singh 2003). From the observed rainfall–runoff data, the SCS-CN parameter S can be determined by solving Eq. 1 for λ=0.2, as follows (Hawkins 1993):

$$S = 5\left[(P + 2Q) - \sqrt{Q(4Q + 5P)}\right] \tag{3}$$

S can be transformed to CN scale using the following empirical relation:

$$\mathrm{CN} = \frac{25400}{S + 254} \tag{4}$$

where S is in millimetres and CN is non-dimensional. For CN determination, an array of CN-values from various P–Q data sets is prepared, and median CN selected as a representative CN valid for normal antecedent moisture condition of the watershed. This ‘Median CN’ approach is commonly adopted (Hawkins et al. 1985; Hjelmfelt 1991; Hawkins et al. 2002; Schneider and McCuen 2005; and Mishra et al. 2005).

Besides the quality of the measured P–Q data, the accuracy of runoff prediction largely depends on accurate estimation of the lumped parameter CN (Ponce and Hawkins 1996) which varies with (a) spatial and temporal variability of storm and watershed characteristics and (b) antecedent rainfall and associated soil moisture. The antecedent moisture condition (AMC) is defined as the initial moisture condition of the watershed prior to the storm event of interest. Normally, AMC II is taken as the base with reference to which CNs are adjusted. It describes the watershed’s “average condition” in terms of wetness, and the corresponding CN represents the median CN (Hjelmfelt 1991). AMC I and AMC III are defined by respective lower and upper enveloping curves on the *P–Q* plot. These AMCs are generally described based on the 5-day antecedent rainfall amount (SCS 1956, 1971). In practice, curve numbers are first calculated for AMC II and then adjusted to AMC III or AMC I depending on the 5-day antecedent rainfall amount. This AMC procedure suffers from three major weaknesses (Hope and Schulze 1981): (1) The relationship between AMC and antecedent rainfall holds for discrete classes, rather than continuous (Hawkins 1978). (2) The use of 5-day antecedent rainfall is not based on physical reality, but on subjective judgment. (3) Evapotranspiration (ET) and drainage are not considered in depletion of catchment storage.

Based on the work of Williams and LaSeur (1976), Hawkins (1978) proposed a procedure for CN adjustment with the watershed's moisture status, specifically to eliminate the above quantum jump in CN values from one AMC to other. This approach however requires information on ET and CN (calculated from field data) at a known time preceding each stream flow event. Hjelmfelt et al. (1981) found that the AMC conversion table described the 90% (AMC I), 50% (AMC II), and 10% (AMC III) cumulative probabilities of exceedance of runoff depth for a given rainfall. Bales and Betson (1981) noticed that if SCS tables were used for determining a hydrologic-soil-cover complex number and if the wettest antecedent moisture condition was assumed, the runoff volumes would be regularly under-predicted in the regions represented by these data. The runoff volumes will apparently be under-predicted even for the higher yield events, for which the CN methodology best applies.

Implicit in the use of a tabulated CN is the assumption that it is the best estimate for the design conditions, which often depends on a risk level associated with annual maximum discharges. Even though the CN is treated as a constant in many cases, it actually varies from storm to storm on any one watershed. AMCs are assumed to be the primary cause of the storm to storm variation (McCuen 2002). Ponce and Hawkins (1996) suggested AMC choice to be dependent on return period. It is noted that a watershed would have more than one CN, indeed a set of CNs (SCS 1985; Hjelmfelt 1991).

Largely because of the above weaknesses, the AMC procedure was obviated from National Engineering Handbook-Section 4 (NEH-4) text (Hawkins 1996), but variability incorporated considering CN as a random variable (Hjelmfelt et al. 2001), and, in turn, the terminology changed to 'antecedent runoff condition' or ARC. Since ARC explains only a part of the CN-variation (Mullem et al. 2002), AMC (or ARC) is still considered as a primary tractable source of CN-variability and accounted for in terms of AMC I through AMC III levels to handle pragmatic situations.

The AMC-dependent CN-values given by NEH-4 (SCS 1972) in tabular form can be fairly represented by mathematical expressions given by Sobhani (1975). Later, Hawkins et al. (1985) and Chow et al. (1988) also suggested expressions for the same CN-conversion. Of late, Neitsch et al. (2002) also provided CN-conversion formulae entirely different in form and these are being used in the popular SWAT model. Since the calculated runoff is so sensitive to the curve number, it is in order to compare these conversion formulae and discuss their validity, which forms the major objective of this paper.

2 CN-conversion Formulae

(a) Sobhani (1975) Formulae

The Sobhani (1975) formulae for CN conversion from AMC II (CN_{II}) to AMC I (CN_I) and AMC III (CN_{III}) are given in Table 1. The subscripts I–III in this table and elsewhere in

Table 1 CN-conversion formulae

Method	AMC I	AMC III
Sobhani (1975)	$\mathrm{CN_I} = \frac{\mathrm{CN_{II}}}{2.334-0.01334\mathrm{CN_{II}}}$	$\mathrm{CN_{III}} = \frac{\mathrm{CN_{II}}}{0.4036+0.005964\mathrm{CN_{II}}}$
Hawkins et al. (1985)	$\mathrm{CN_I} = \frac{\mathrm{CN_{II}}}{2.281-0.01281\mathrm{CN_{II}}}$	$\mathrm{CN_{III}} = \frac{\mathrm{CN_{II}}}{0.427+0.00573\mathrm{CN_{II}}}$
Chow et al. (1988)	$\mathrm{CN_I} = \frac{4.2\mathrm{CN_{II}}}{10-0.058\mathrm{CN_{II}}}$	$\mathrm{CN_{III}} = \frac{23\mathrm{CN_{II}}}{10+0.13\mathrm{CN_{II}}}$
Neitsch et al. (2002)	$\mathrm{CN_I} = \mathrm{CN_{II}} - \frac{20(100-\mathrm{CN_{II}})}{\{100-\mathrm{CN_{II}}+\exp[2.533-0.0636(100-\mathrm{CN_{II}})]\}}$	$\mathrm{CN_{III}} = \mathrm{CN_{II}}\exp\{0.00673(100-\mathrm{CN_{II}})\}$
Proposed CN expressions	$\mathrm{CN_I} = \frac{\mathrm{CN_{II}}}{2.2754-0.012754\mathrm{CN_{II}}}$	$\mathrm{CN_{III}} = \frac{\mathrm{CN_{II}}}{0.430+0.0057\mathrm{CN_{II}}}$

the text refer to AMC I–AMC III, respectively. In an analysis of the SCS (1972) table for CN, Sobhani (1975) found the existence of linear relationships between the potential retention, S, for AMC II and that for AMC I or AMC III. A substitution for S from Eq. 4 into these linear relations yields the CN-relations shown in Table 1. In their development, these equations considered every 5th CNs (or 9 data-points) in the range (55, 95) (Hawkins 2005), and therefore, are applicable in the CN-range (55, 95), which encompasses the most estimated or experienced range of CN-variation.

(b) Hawkins et al. (1985) Formulae

Based on the smoothened CN-data obtained by fitting straight lines through the plot on normal probability paper (Ponce and Hawkins 1996), Hawkins et al. (1985) found the existence of the following relations:

$$S_{\mathrm{I}} = 2.281\ S_{\mathrm{II}} \qquad r^2 = 0.999 \text{ and } S_{\mathrm{e}} = 5.2324\ \mathrm{mm} \tag{5}$$

$$S_{\mathrm{III}} = 0.427\ S_{\mathrm{II}} \qquad r^2 = 0.994 \text{ and } S_{\mathrm{e}} = 2.2352\ \mathrm{mm} \tag{6}$$

where r^2 is the coefficient of determination and S_{e} is the standard error of estimate. These equations are applicable in the range $55 \le \mathrm{CN} \le 95$. Substitution of Eqs. 5 and 6 into Eq. 4 leads to expressions shown in Table 1. The $\mathrm{CN_I}$ expression was derived with r^2=0.996 and S_{e}=1.0 CN, and $\mathrm{CN_{III}}$ expression was obtained with r^2=0.994 and S_{e}=0.7 CN. These expressions, along with their derivation, are similar to those suggested by Sobhani (1975). However, unlike Sobhani (1975), all CN values in the range (55, 95) were used in the development of Eqs. 5 and 6. Here, number of data points=41. Therefore, the denominator values (Table 1) of Hawkins et al. (1985) formulae are slightly different from those of Sobhani (1975). Notably, the relationship from both formulations deteriorates quickly for $\mathrm{CN_{II}}$ less than 55 (Hawkins 2005).

(c) Chow et al. (1988) Formulae

The formulae of Chow et al. (1988) and those of Sobhani (1975) and Hawkins et al. (1985) (Table 1) resemble with the following general form:

$$Y = \frac{\mathrm{a}X}{10 \pm bX} \tag{7}$$

where Y and X are, respectively, the dependent and independent variables and a and b are empirical parameters. Here, Y corresponds to $\mathrm{CN_{II}}$; X to $\mathrm{CN_I}$ or $\mathrm{CN_{III}}$; and − sign and + sign for AMC I and AMC III, respectively. As an example, the Chow et al. equations can be recast by dividing them by 4.2 and 23 to derive the same forms as of the CN_I and CN_{III} Sobhani and Hawkins et al. equations, respectively. In the derived relations (Table 1), CN_I represents the lowest runoff potential, and CN_{III} the highest runoff potential. These equations are reportedly applicable in the whole range of CN-variation (1,100). Here, number of data points used=100.

(d) Neitsch et al. (2002) Formulae

The CN-conversion formulae (Table 1) given by Neitsch et al. (2002) are entirely different in form from all others and these are used in the SWAT model developed by Agricultural Research Service of the United States Department of Agriculture (USDA-ARS). This is a continuous long-term simulation model that predicts the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions (Neitsch et al. 2002). Its documentation, however, does not provide clear guidelines for the applicability of the conversion formulae (Table 1), except CN_I and CN_{III} (Table 1) are further adjusted for actual moisture content. The full development details of the formulae and the size of the dataset used (N) are not available, except that the formulae are based on the NEH-4 CN table values.

(e) Proposed CN Conversion Formulae

Similar to the derivation of the Hawkins et al. (1985) formulae, a new set of mathematical expressions based on Fourier filtration smoothening procedure for noisy data are obtained using SPSS (2000) and these are given below:

$$S_I = 2.2754\ S_{II} \qquad r^2 = 0.9992 \text{ and } S_e = 4.4373 \text{ mm} \tag{8}$$

$$S_{III} = 0.430\ S_{II} \qquad r^2 = 0.9967 \text{ and } S_e = 1.8616 \text{ mm} \tag{9}$$

Notably, for both AMCs I and III, these relations exhibit improved fit with the NEH-4 CN data exhibiting greater r^2 and lesser S_e than do the Hawkins et al. (1985) formulae (Eqs. 5 and 6). It leads to inferring that the former relations exhibit more closeness to the NEH-4 data than do the latter. The proposed equations considered number of CN data points equal to 41 in their development and are applicable to CN range (55, 95) as this range is of practical interest, as above. The resulting CN expressions are shown in Table 1.

3 Performance Evaluation Criteria

The performance evaluation criteria used in this study are root mean square error (RMSE), and relative error (RE). RMSE is defined as:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}\left[O_i - \widehat{O}_i\right]^2}{N}} \tag{10}$$

which describes the difference between the model simulations and observations in the units of the variable. RMSE=0 means perfect agreement of the model results with the observed.

The relative error (RE) is expressed in percent (%) as:

$$\text{RE}(\%) = \frac{\left(O_i - \widehat{O}_i\right)}{O_i} \times 100 \tag{11}$$

Table 2 Comparison of various AMC dependent CN's and their respective RE's

CN_{II}	NEH-4		Sobhani (1975)				Hawkins et al. (1985)				Chow et al. (1988)				Neitsch et al. (2002)				Proposed formula			
			Computed		RE (%)		Computed		RE (%)		Computed		RE (%)		Computed		RE (%)		Computed		RE (%)	
	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}	CN_I	CN_{III}
1	0.40	2.60	0.43	2.44	−7.73	6.09	0.44	2.31	−10.22	11.12	0.42	2.27	−5.61	12.67	−19.00	1.95	4848.83	25.12	0.44	2.30	−10.49	11.72
5	2.00	13.00	2.21	11.54	−10.26	11.26	2.26	10.97	−12.77	15.59	2.16	10.80	−8.14	16.94	−14.99	9.48	849.69	27.11	2.26	10.91	−13.04	16.11
10	4.00	22.00	4.54	21.59	−13.61	1.88	4.64	20.65	−16.12	6.14	4.46	20.35	−11.46	7.48	−9.99	18.33	349.77	16.70	4.66	20.53	−16.40	6.66
15	6.00	30.00	7.03	30.42	−17.16	−1.41	7.18	29.24	−19.68	2.52	6.90	28.87	−15.01	3.77	−4.99	26.58	183.11	11.41	7.20	29.10	−19.96	3.01
20	9.00	37.00	9.67	38.25	−7.50	−3.38	9.88	36.93	−9.75	0.20	9.50	36.51	−5.58	1.33	0.02	34.27	99.78	7.39	9.90	36.76	−10.00	0.64
25	12.00	43.00	12.50	45.23	−4.14	−5.19	12.75	43.84	−6.25	−1.95	12.28	43.40	−2.34	−0.92	5.03	41.41	58.10	3.69	12.78	43.67	−6.48	−1.55
30	15.00	50.00	15.51	51.50	−3.42	−3.00	15.82	50.09	−5.45	−0.18	15.25	49.64	−1.69	0.72	10.04	48.05	33.05	3.89	15.85	49.92	−5.67	0.17
35	18.00	55.00	18.75	57.16	−4.14	−3.92	19.10	55.77	−6.10	−1.40	18.44	55.33	−2.47	−0.59	15.06	54.21	16.32	1.44	19.14	55.60	−6.31	−1.09
40	22.00	60.00	22.22	62.29	−0.99	−3.82	22.62	60.96	−2.80	−1.60	21.88	60.53	0.57	−0.88	20.09	59.90	8.67	0.17	22.66	60.79	−3.00	−1.32
45	26.00	65.00	25.96	66.97	0.17	−3.03	26.40	65.71	−1.54	−1.09	25.58	65.30	1.63	−0.46	25.14	65.16	3.32	−0.24	26.45	65.55	−1.72	−0.85
50	31.00	70.00	29.99	71.25	3.25	−1.78	30.48	70.08	1.68	−0.11	29.58	69.70	4.59	0.43	30.21	70.00	2.56	0.00	30.53	69.93	1.51	0.10
55	35.00	74.00	34.37	75.18	1.80	−1.59	34.89	74.11	0.32	−0.15	33.92	73.76	3.08	0.32	35.31	74.45	−0.90	−0.61	34.94	73.97	0.16	0.03
60	40.00	78.00	39.12	78.80	2.19	−1.02	39.67	77.84	0.82	0.20	38.65	77.53	3.37	0.61	40.48	78.54	−1.21	−0.69	39.73	77.72	0.67	0.36
65	45.00	82.00	44.31	82.15	1.53	−0.18	44.88	81.31	0.27	0.85	43.82	81.03	2.62	1.18	45.75	82.26	−1.66	−0.32	44.94	81.20	0.13	0.98
70	51.00	85.00	49.99	85.25	1.97	−0.30	50.57	84.53	0.85	0.55	49.49	84.29	2.95	0.83	51.17	85.66	−0.34	−0.78	50.63	84.44	0.73	0.66
75	57.00	88.00	56.24	88.14	1.33	−0.16	56.81	87.54	0.34	0.52	55.75	87.34	2.19	0.75	56.86	88.74	0.24	−0.84	56.87	87.46	0.23	0.61
80	63.00	91.00	63.15	90.83	−0.24	0.18	63.68	90.35	−1.09	0.71	62.69	90.20	0.50	0.88	63.00	91.53	0.00	−0.58	63.74	90.29	−1.18	0.78
85	70.00	94.00	70.83	93.35	−1.18	0.69	71.30	92.99	−1.86	1.07	70.41	92.87	−0.59	1.20	69.89	94.03	0.16	−0.03	71.35	92.95	−1.93	1.12
90	78.00	96.00	79.41	95.71	−1.80	0.30	79.78	95.47	−2.28	0.55	79.08	95.39	−1.38	0.63	78.00	96.27	0.00	−0.28	79.82	95.44	−2.33	0.58
95	87.00	98.00	89.06	97.92	−2.37	0.08	89.28	97.80	−2.62	0.20	88.86	97.76	−2.14	0.24	87.94	98.25	−1.08	−0.26	89.31	97.79	−2.65	0.22
100	100	100	100	100	0.00	0.00	100	100	0.00	0.00	100	100	0.00	0.00	100	100	0.00	0.00	100	100	0.00	0.00

Table 3 RMSE values for different AMC-dependent CN conversion formulae taking SCS (1972, 1985) CN-values as target values

Method	RMSE	
	CN_I	CN_{III}
Sobhani (1975)	0.8293	1.2703
Hawkins et al. (1985)	0.9247	0.7652
Chow et al. (1988)	0.8937	0.8106
Neitsch et al. (2002)	6.8255	1.6038
Proposed formula	0.9445	0.7681

A high value of RE indicates greater deviation of the computed values from the observed ones, and vice versa, where as RE equal to zero shows a perfect fit.

4 Numerical Comparison Using NEH-4 CN Tables

Treating the NEH-4 CN-values (SCS 1972) as target values, the performance of the existing and proposed CN conversion formulae was evaluated using the above described two statistical measures. To that end, the O and $\widehat{O}$ values in Eqs. 10 and 11 were replaced by the corresponding CN-values taking NEH-4 table values as observed and those derived from the above formulae (Table 1) as computed.

The results of comparison are presented in Tables 2 and 3. It is apparent from Table 2 showing only every 5th CN values in the CN range 1–100 that the Sobhani, Hawkins et al., Chow et al., Neitsch et al., (designated by the first name in the forthcoming text), and the proposed formulae yield RE values in the respective percent range of (3.25, −17.16) and (11.26, −5.19); (1.68, −19.68) and (15.59, −1.95); (4.59, −15.01) and (16.94, −0.92); (4848.83, −2.04) and (27.11, −1.68); and (1.51,−19.96) and (16.10,−1.55). It indicates that the Neitsch formulae yield the abnormally high RE-values, especially for low (1, 40) CN, showing the poorest performance in fitting NEH-4 values. On the other hand, the Hawkins formulae exhibit the narrowest range of RE-variation, and therefore, are closest to NEH-4 data. As shown later, the proposed expressions however fit better with the field data than do the Hawkins formulae, signifying their proposition.

The RMSE values of Table 3 and the depiction of Figs. 1 and 2 lead to infer that the formulae of Sobhani, Hawkins, Chow, and the proposed formulae perform equally well, and these are, in general, not much different, except for the CN values computed using the Neitsch formulae showing the largest deviation from line of perfect fit and yield the undesirable negative values of CN_I in CN_{II} range (1, 19). Here, it is noted that the CN-values obtained for most soil-cover-moisture complexes in the field are generally greater than 40 (SCS 1972). However, the occurrence of negative CN-values is conceptually not rational.

As seen, there exists about 0.1% (or insignificant) difference in the CN_I or CN_{III} values resulting (in the range 50 to 100) due to the above formulae. However, since the CN forms to be the most sensitive parameter in runoff computation, as shown later, it is in order to rank the (RMSE-based) performance of various formulae as follows:

$$\text{Sobhani} > \text{Chow} > \text{Hawkins} > \text{Proposed} > \text{Neitsch} \quad (\text{For } CN_{II} \text{ to } CN_I)$$

$$\text{Hawkins} > \text{Proposed} > \text{Chow} > \text{Sobhani} > \text{Neitsch} \quad (\text{For } CN_{II} \text{ to } CN_{III})$$

Fig. 1 Performance of various AMC-dependent CN_I conversion formulae

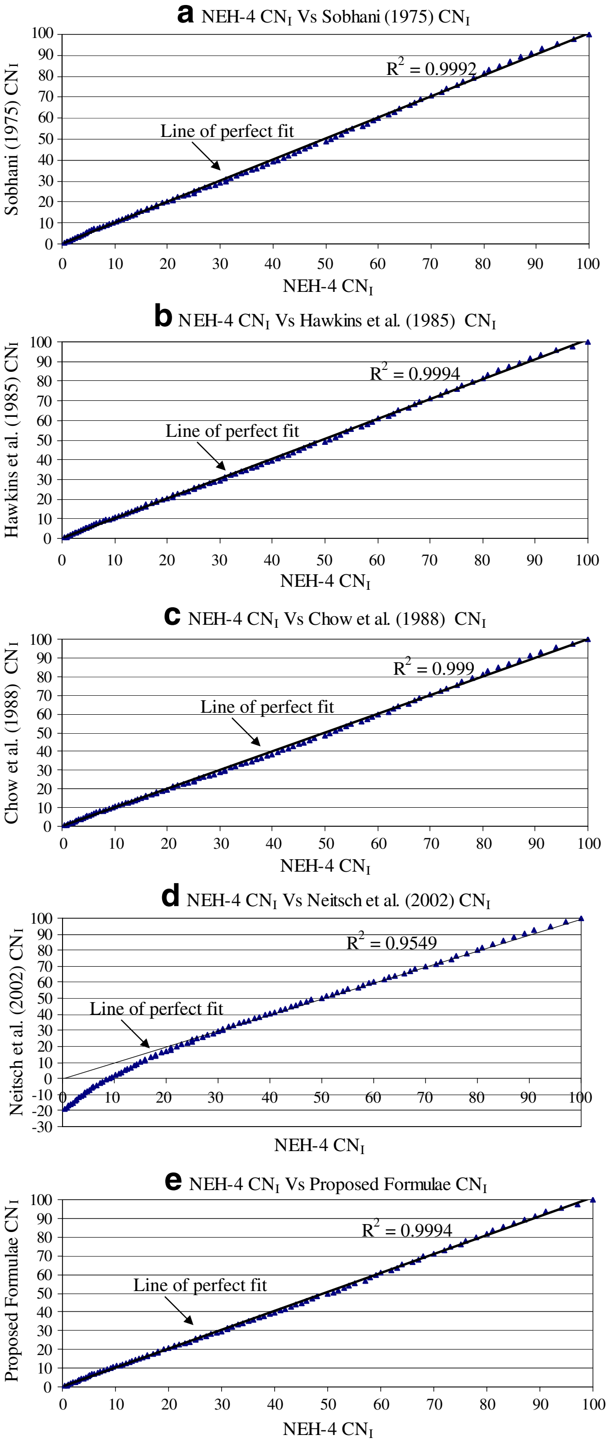

Fig. 2 Performance of various AMC-dependent CN_{III} conversion formulae

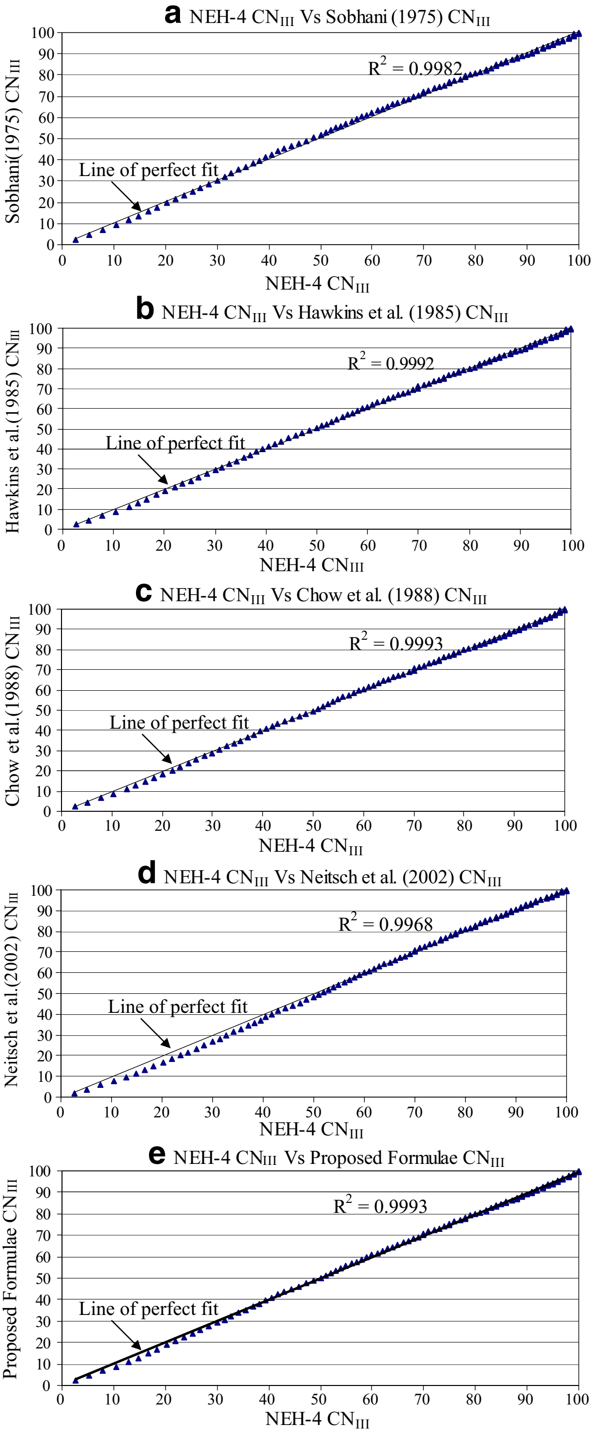

Table 4 Average RMSE values of CN-conversion formulae on field data

Method	RMSE (mm)
Sobhani (1975)	13.6836
Hawkins et al. (1985)	13.5090
Chow et al. (1988)	13.7763
Neitsch et al. (2002)	13.8657
Proposed Formula	13.4889

Here, the formula on the left hand side of greater than (>) sign performs better than that on its right hand side. It is apparent that the Neitsch formulae for both CN_I and CN_{III}-conversion formulae perform the poorest of all. The Sobhani formula performed the best in CN_I-conversion while the Hawkins formulae performed the best in CN_{III}-conversion. Similarly, the performance of the other formulae can be explained. Thus, the Sobhani and Hawkins formulae can be asserted to be closer to NEH-4 values than any other formulae.

5 Performance Evaluation Using Field Data

The performance of the above conversion formulae (Table 1) is also compared using the field data derived from the USDA-ARS Water Database, which is a collection of rainfall and streamflow data from small agricultural watersheds of the United States. This national archive of variable time-series readings for rainfall and runoff contains sufficient detail to reconstruct storm hydrographs and hyetographs. The database is available on WWW at URL: http://www.ars.usda.gov/arsdb.html and http://hydrolab.arsusda.gov/arswater.html. It is of common experience that the existing SCS CN method should be applied to large storms only due to the presence of method's bias to small storms (i.e., Low P-High CN bias). Therefore, only large storms (i.e., $P/S>0.456$) were selected following the Hawkins et al. (1985) procedure. In the present study, data for 7,141 storm events from 82 watersheds varying from 0.2 to 8,097.2 ha were used.

For performance evaluation of the above five conversion formulae using field data, the S-values were computed using Eq. 3 for each value of rainfall and the corresponding runoff of a watershed and these were then mapped on to CN using Eq. 4. Median of the resulting CN-series was taken as CN_{II} for that watershed and, depending on the 5-day antecedent rainfall amount, it was converted to CN_I or CN_{III} using the above five formulae. Following the usual NEH-4 procedure for runoff estimation (SCS 1972), RMSE was computed using Eq. 10, in which O and $\widehat{O}$ values were replaced by the observed and computed runoff, respectively. Here, it is noted that the NEH-4 AMC defining table and the Neitsch et al. is not the same, as the latter adjusts CNs for AMCs using soil moisture content of a day. However, since this yield undesirable negative values of CN_I in CN_{II} range (1, 19), the resulting negative S-values, are conceptually not rational. In using the NEH-4 procedure, the season was taken as growing season.

Table 4 compares all the five methods based on average RMSE (range of variation: 0.02–0.38 mm) values derived from their application to P–Q data sets of 82 watersheds and these methods can be ranked as follows:

$$\text{Proposed} > \text{Hawkins} > \text{Sobhani} > \text{Chow} > \text{Neitsch}$$

Here, it is noted that the RMSE variation (0.02–0.38 mm) might appear to be insignificant, it is however significant in volumetric terms, when the depth is multiplied by a large value of catchment area. Thus, it is clear that the proposed formulae perform the best, and those due to Neitsch the poorest in field application. Hawkins formulae ranked second, while Sobhani and Chow ranked third and fourth. On the whole, the overall performance of the proposed and Neitsch formulae is the best and poorest on field data, respectively.

6 Conclusion

For accuracy in runoff prediction using the popular SCS-CN method, correct estimation of AMC-dependent CN-values is necessary. The analysis of the available four and proposed formulae for CN-conversion finds the Sobhani and Hawkins formulae to perform the best in CN_I- and CN_{III}-conversions, respectively, when compared with the NEH-4 table values as target values. However, their application to field data yields the proposed new formulae to perform the best, and the Neitsch formulae the poorest. The Hawkins formula ranks next to the proposed one. As the proposed formulae perform next to the Hawkins formulae in numerical comparison utilizing target NEH-4 CN-values and best on field data, the former are recommended for field use for enhanced accuracy reasons.

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