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EVALUATION OF SCS-CN INSPIRED MODELS AND THEIR COMPARISON

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ABSTRACT

This study evaluates eight different SCS-CN inspired models including the existing SCS-CN method for comparison using the rainfall-runoff data measured from plot scale agricultural watersheds in India. It was observed that M2 with λ=0.05 performed better than the original SCS-CN model M1 with λ=0.2 and also model M8 incorporating the parameters of non-linear Ia-S relation, in which rainfall (P) is an implicit function of climatic/meteorological characteristics and antecedent moisture is a function of 5-day antecedent rainfall, M = □ P_5. It performed the best of all models followed by M7 in terms of its lower RMSE and higher NSE and n(t) values whereas, based on the ranks and scores of each individual model for each performance index, model M1 was the poorest, and model M7 was the best followed by M8, M5, M6, M3, M4 and M2.

Keywords: *SCS-CN inspired; Antecedent rainfall; Antecedent moisture; Curve Number*

INTRODUCTION

The Natural Resources Conservation Service curve number (NRCS-CN) model, formerly known as the Soil Conservation Service curve number (SCS-CN) method (SCS, 1956, 1964, 1971, 1993) is an empirical method for estimating surface runoff from given rainfall event for ungauged watersheds. It is based on a single parameter known as the curve number (CN) which depends on watershed characteristics such as hydrologic soil type, Land use/land cover and 5-day antecedent rainfall. This method is widely discussed among hydrologic research community in form of various development in SCS method which are in use for runoff prediction since last three decades (McCuen, 1982; Hjelmfelt, 1991; Hawkins, 1993; Steenhuis et al., 1995; Ponce and Hawkins, 1996; Yu, 1998; Mishra and Singh, 1999, 2002, 2003; Michel et al., 2005; Schneider and McCuen, 2005; Mishra et al., 2006; Sahu et al., 2007; Lal et al., 2015; Lal et al., 2016).

Though there are many developed forms (or models) of SCS-CN method available for computation of runoff from a given rainfall event, there is no other model existing that acquires so many advantages. SCS-CN has been originally developed for USA conditions but it is being practiced worldwide including India for estimating runoff depth in small agricultural and urban watersheds (Ponce and Hawkins, 1996). The research on modification is going on at various research stations all over the globe to address its drawbacks, and consequently, several parameters have been introduced for its application to other parts of the world.

Ponce and Hawkins (1996) critically examined original SCS-CN method; discussed its empirical basis; delineated its capabilities, uses and limitations; and identified area of research of this methodology. Grove et al. (1998) and Moglen et al. (2000) investigated the effect of spatial variability of CN on runoff determination. Yu (1998) derived SCS-CN method analytically considering exponential distribution of spatial and temporal variation of infiltration capacity and rainfall rate, respectively. Also Mishra and Singh (2002) extended the method for long term hydrologic simulation incorporating evapotranspiration and showed that the modified MS model performed better than the original SCS-CN model. Furthermore, it was observed that the incorporation of antecedent moisture in the existing SCS-CN method permits unreasonable sudden jumps in the CN-variation. To avoid such problems, Mishra and Singh (2002) suggested an SCS-CN based equation to compute the antecedent moisture from 5-day antecedent precipitation for computation of runoff. Using event rainfall-runoff data from several hundred plots, Woodward et al. (2003) used two different values of initial abstraction ratio (λ) and found that value of λ about 0.05 was more appropriate for use in runoff calculations than 0.2 as in original SCS-CN method. The work by Mishra et al. (2006) involving various initial abstractions (I_a)-potential maximum retention (S) relations incorporating antecedent soil moisture and 5-day antecedent rainfall amount was found to improve the capabilities of SCS-CN method for estimation of runoff from rainfall events. This improved relation prevents sudden jump in CN variation with AMC, an unreasonable and undesirable feature of the original SCS-CN method. Jain et al. (2006) presented an enhanced version of the SCS-CN based Mishra–Singh (1999, 2003) model incorporating the storm duration and a nonlinear relation for initial abstraction (I_a); and found that the model performed better than all other existing versions. After considering the high dependency of runoff on rainfall event distribution, Ajmal et al. (2015) recognized that the initial abstraction (I_a) as 2% of the rainfall amount, instead of the originally assumed 20% of the maximum potential retention (S) in provides optimum results in the SCS-CN model. Therefore, our objective of this study is to comparative evaluation of the SCS-CN inspired models in Indian climatic condition.

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MODEL DESCRIPTION AND ITS PARAMETERIZATION

Original SCS-CN method

The original SCS-CN method consists of following equations:

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

where, Q (mm) is the direct surface runoff, P (mm) is the rainfall, I_a is the initial abstraction (mm), and S (mm) is the potential maximum retention. Eq. 1 is the general form of the popular SCS-CN method and is valid for $P \geq Ia$; Q= 0 otherwise.

In Eq. 1, $I_a = \lambda S$. Here, λ is the initial abstraction ratio. Therefore, the use of $I_a = \lambda S$ in Eq. 1 reduces it to a popular form as:

$$Q = \frac{(P-\lambda S)^2}{(P+(1-\lambda)S)} \quad \text{for } P > \lambda S; \text{ otherwise } Q = 0 \qquad (2)$$

In SCS-CN method λ=0.2 be considered as standard value. For available P-Q data sets, S can be calculated using Eq. 2 (using standard value of λ as 0.2) after algebraic calculation as follows (Hawkins 1973):

$$S = 5(P + 2Q - \sqrt{(Q\,(4Q+5P))} \qquad (3)$$

The S can be transformed into a dimensionless CN as

$$CN = \frac{25400}{S+254} \qquad (4)$$

In Eq. 4, S is in mm

Woodward et al. (2003) model

Using a model fitting technique with the iterative least squares procedure, Woodward et al. (2003) recognized λ = 0.05 as the best fit value and suggested it for field applications. For λ=0.05, Eq. 1 becomes:

$$Q = \frac{(P-0.05S)^2}{(P+0.95S)} \quad \text{for } P>0.05S; \text{ else } Q = 0 \qquad (5)$$

Nevertheless, a new set of CNs must be developed for λ values other than 0.2, because the CNs with λ = 0.05 are not the same as those used in estimating direct runoff with λ = 0.2. The relationship adjusted for the conversion of $CN_{0.2}$ to $CN_{0.05}$:

$$CN_{0.05} = 53.23/\,[\{(100/CN_{0.2})-1\}^{1.15}+0.5323] \qquad (6)$$

The CN determined by above two methods (i.e. Eqs. 2 and 5) represents the CN_{II} (AMC-II) of the plots/ watersheds. Furthermore, in order to get the required AMC (i.e. I and III) level based on 5-day antecedent rainfall (P_5), CNs were converted by using Hawkins (1985) formula as given in Eqs. 7 and 8.

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281\, CN_{II}} \qquad (7)$$

$$CN_{III} = \frac{CN_{II}}{0.427 - 0.00573\, CN_{II}} \qquad (8)$$

The antecedent soil moisture condition was categorised based on the prior P_5 as follows: AMC-I (if P_5 < 35.56 mm), AMC-II (if 35.56 mm $\leq P_5 \leq$ 53.34 mm), and AMC-III (if P_5 >53.34) (Mays 2005).

Ajmal et al. (2015) model

Considering the high dependency of runoff on rainfall event distribution, Ajmal et al. (2015) was found that the initial abstraction as 2% of the total rainfall amount (I_a=0.02P) is a better option to the originally assumed I_a = 0.2S. Using this interpretation for direct runoff estimation, Eq. 1 becomes:

$$Q = \frac{(P-0.02P)^2}{(S+0.98P)} = \frac{0.9604\,P^2}{S+0.98P} \qquad (9)$$

Mishra and Singh (2002)

Using the C = Sr concept, where C is the runoff coefficient (=Q/(P-Ia)) and Sr = degree of saturation, Mishra and Singh (2002) modified the original SCS-CN method (Eq. 1) incorporating antecedent moisture (M) into it as:

$$Q = \frac{(P-I_a)(P-I_a+M)}{P-I_a+M+S} \qquad (10)$$

Here, I_a is the same as in Eq. 1.

In the above Eq. 10, M is computed as:

$$M = \frac{S_I(P_5-\lambda S_I)}{P_5+(1+\lambda)S_I} \qquad (11)$$

Where P_5 is the 5-day antecedent precipitation amount and S_I is the potential maximum retention corresponding to AMC I, and λ is the initial abstraction ratio.

In Eq. 11, S_I be treated as absolute maximum retention capacity, then

$$S_I = S + M \qquad (12)$$

Where, S is the maximum potential retention.

Further the coupling of Eqs. 11 and 12 amplifies it as

$$M = 0.5[-(1+\lambda)\,S + \sqrt{((1-\lambda)^2S^2 + 4P_5S)}] \qquad (13)$$

Here + sign before the square root is retained for $M \geq 0$, and $P_5 \geq \lambda S$.

Mishra and Singh Model (2003)

Using similar concept given by Mishra and Singh (2002), Mishra and Singh (2003) further amended the modified SCS-CN method (i.e. Eq. 13) for antecedent moisture M as:

$$M = \square\, P_5 \qquad (14)$$

Where, □ is proportionality coefficient. In this model, Eq.10 developed by Mishra and Singh (2002) is utilized for runoff computation.

Mishra and Singh (2006) model

Mishra et al. (2006) recommended an improved SCS-CN model incorporating antecedent moisture (M) in initial abstraction (I_a). The modified non linear relation between I_a and S incorporating antecedent moisture M is expressed as:

$$I_a = \frac{\lambda S^2}{(S+M)} \qquad (15)$$

In above Eq. 15, for M = 0 or a completely dry condition, it becomes $I_a = \lambda S$, which is the same as original SCS-CN equation (i.e. Eq. 1). Thus, Eq. 1 is specialized form of Eq. 15.

The Other relationships for determining the M developed by Mishra et al. (2006) is expressed as:

$$Mc = \alpha\sqrt{(P_5 S)} \quad (16)$$

$$Mc = 0.72\sqrt{(P_5 S)} \quad (17)$$

Jain et al. (2006) model

Based on the mathematical consideration by Mishra and Singh (1999) and Mishra et al. (2003), Jain et al. (2006) found that λ is perfectly correlated with S and P, rather than S alone. Therefore, they proposed a non linear relation between I_a and S expressed as

$$I_a = \lambda S \left(\frac{P}{P+S}\right)^{\alpha} \quad (18)$$

For α = 0, Eq. 18 becomes an Eq. 1, which shows that the former is a generalized form of the latter.

STUDY AREA AND DATA

The two watersheds (Kalu and Hemavati) and 12 plots were selected for the study. The experimental plots (size 22 m × 5 m) are located in Village Toda Kalyanpur (Latitude: 29° 50' 9" N, Longitude: 77° 55' 21" E) near Roorkee, District Haridwar, Uttarakhand, India. The land uses patterns in plots were Sugarcane, Black gram, maize and fallow. The plots were constructed in such a way that each land use should have three different (5%, 3%, and 1%) slopes. The experimental site is situated at 266 meters above mean sea level. The precipitation at the experimental plots varies from 1200 to 1500 mm and mostly (70-80%) occur in the months of June to September. Thirteen observed P-Q events were used from twelve experimental plots which were measured during period June, 2014-April, 2015.

Kalu River which is a tributary of River Ulhas, is located in Maharashtra. The location of catchment (224 km^2) is situated between latitudes 19° 17' N to 19° 26' N and longitudes 73° 36' E to 73° 49' E. The average annual rainfall in the catchment is about 2450 mm; and situated at 1200 meters above mean sea level with hilly topography. Land use pattern of the watershed is forest 50% and agriculture 50%. The seventeen P-Q events were selected for study which was monitored during the year 1990-1993.

Hemavati is a tributary of River Cauvery in Karnataka. The watershed having area 600 km^2 is situated between latitudes 12° 55' N to 13° 11' N and longitudes 75° 29' E to 75° 5' E and its elevation ranges from 890 to 1240 m above mean sea level . The average annual rainfall in the catchment is 2972 mm and topography of watershed is low land, partly hill. Forest 12 %, agriculture 59 % and coffee plantation 29 % are land use pattern of the watershed. Thirteen natural P-Q events are selected for study which was monitored during the year 1990-1992. Detail characteristics of these plots/catchments are presented in Table 1.

METHODOLOGY

Model parameter description

The total thirteen measured rainfall and runoff events for experimental plots having size 22 m × 5 m were selected for this study. On the other hand, seventeen rainfall-runoff events for Kalu and thirteen events for Hemawati were utilised for the study and in which, base flow was separated from discharge by the straight line hydrograph method for all events. The performance of eight (8) different models, including the original SCS-CN was evaluated for better runoff estimation. The details of each model are described in Table 2.

Table 1: Characteristics of study plots and watersheds

S.N.	Description	Watersheds/Plots		
		Hemawati	Kalu	Plots
1	River	Cauveri	Ulhas	Solani river catchment
2	State	Karnataka	Maharahstra	Uttarakhand
3	Topography	Low land, partly hilly	Hilly	Slopes 5%, 3% and 1%.
4	Area (km^2)	600	224	Size 22 m × 5 m per plot
5	Longitude	75° 29' E to 75° 51' E	73° 36' E to 73° 49' E	77° 55' 21" E
6	Latitude	12° 55' N to 13°11' N	19° 17' N to 19° 26' N	29° 50' 9" N
7	Soil	Red loamy and red sandy soil	Silty loam and sandy loam	Hydrologic soil group (HSG) A
8	Land use	Forest 12%, agriculture 59% and coffee plantation 29%	Forest 50% and agriculture 50%	Sugarcane, maize, black gram and fallow land
9	Climate	Hot seasonally, dry tropical savanna	Hot and humid	Semi humid and subtropical
10	Average annual rainfall (mm)	2972	2450	1200-1500
11	Elevation (m) above MSL	890-1240	1200	226

Table 2: Model and parameter description.

Model ID	Parameters					Model expression	Remarks
	λ	α	γ	a	CN		
M1	0.2	-	-	-	Median	Original SCS CN	Eq. 2
M2	0.05	-	-	-	Median	Woodward et al. (2003)	Eq. 5
M3	0.02	-	-	-	Constrained Least square	Ajmal et al. (2015)	Eq. 9
M4	Varying	-	-	-	do	Original SCS CN	Eq. 2
M5	Varying	-	-	-	do	MS Model (2002)	Eqs. 10, 13
M6	Varying	-	-	-	do	MS Model (2002)	Eqs. 10, 13 & 15
M7	Varying	Varying	-	-	do	MS Model (2006)	Eqs.10, 15 & 16
M8	Varying	-	Varying	Varying	do	MS Model (2003)	Eqs. 10, 14 & 18

Note: MS model stands for Mishra and Singh model.

Model parameter estimation

The stepwise procedure for determining the parameters mentioned in various models is as follows:

i. Employing Eqs. 3 and 4, the CN values for Models M1 and M2 were calculated from observed P-Q events based on procedures mentioned in the National Engineering Handbook, Section-4 (NEH-4), and results are presented in Table 3.

ii. The parameter for models M3 to M8 was determined using least square fitting (optimization) employing MS-Excel (Solver) software. In optimization, the CN was allowed to vary in the range (1-100) with keeping the initial estimate as 50. The λ was allowed to vary in the range (0-1) with keeping the initial estimate as 0.05. Similarly, the parameter α in Eq. 18 was permitted to vary in the range (0.01, 2) with its initial value equal to 0.1. In model M8, range of parameters λ, □ and □ were selected as 0 to 100, 0 to 10, and -10 to 10 with initial estimate values as 1, 0 and 1 respectively. The computed values of the models parameters are presented in Table 3.

Goodness of Fit

In this study, Coefficient of determination (R^2), root mean square (RMSE), the number of times

(n(t)) that the observed variability was greater than the mean error, and the Nash-Sutcliffe Efficiency (NSE) was used to check the performance of the CN determination methods in runoff prediction.

The coefficient of determination (R^2) varies from 0 to 1, and a higher value indicates good performance of the model.

$$R^2 = \left[\frac{\Sigma \left(Q_{oi} - \overline{Q_o}\right)\left(Q_{pi} - \overline{Q_p}\right)}{\sqrt{\left(Q_{oi} - \overline{Q_o}\right)^2 \left(Q_{pi} - \overline{Q_p}\right)^2}} \right]^2 \quad (19)$$

Where Q_{pi} is predicted runoff, Q_{oi} is observed event runoff, $\overline{Q_P}$ predicted mean runoff and $\overline{Q_o}$ mean of observed runoff.

The RMSE is used to measure the error and represent the deviation between observed and predicted runoff. RMSE is a measure of non-systematic variation and computes as

$$RMSE = \sqrt{\frac{1}{N}\Sigma\left(Q_{oi} - Q_{pi}\right)^2} \quad (20)$$

If the mean model error is represented by the RMSE and the variability of the observations is given by their standard deviation (SD), then n(t), according to Ritter and Munoz-Carpena (2013), is expressed as:

$$n(t) = \frac{SD}{RMSE} - 1 \quad (21)$$

The higher NSE value indicates the better performance of model and negative value of NSE indicates biased estimates which mean that the mean observed runoff is a better estimate than calculated runoff. NSE is expressed as:

$$NSE = \left[1 - \frac{\sum_{i=1}^{N} (Q_{oi} - Q_{pi})^2}{\sum_{i=1}^{N} (Q_{oi} - \overline{Q}_o)^2} \right] \times 100 \quad (22)$$

Table 4 summarizes the guidelines for categorizing the performance class of a model as per given by Ritter and Munoz- Carpena, (2013).

Table 3: Models estimated parameters

Watersheds		Sugar 5%	Sugar 3%	Sugar 1%	Maize 5%	Maize 3%	Maize 1%	Fallow 5%	Fallow 3%	Fallow 1%	BG 5%	BG 3%	BG 1%	Kalu	Hemawati
Models		**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
M1	CN_c	79.833	83.651	84.481	81.519	80.017	82.471	83.066	81.663	81.424	79.440	81.721	79.649	72.401	45.493
M2	CN_c	69.110	77.898	73.656	71.220	65.752	70.786	71.680	67.516	72.111	63.927	65.856	62.961	67.272	37.615
M3	CN_c	58.567	64.653	59.899	63.535	58.806	72.006	47.339	46.940	48.279	39.778	55.344	63.079	67.906	31.166
	λ	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
	R^2	0.690	0.423	0.536	0.627	0.813	0.663	0.368	0.132	0.196	0.298	0.523	0.461	0.943	0.763
M4	CN_c	50.000	50.000	50.000	50.000	50.000	50.000	49.541	45.799	50.000	42.889	50.000	50.000	65.051	29.802
	λ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	R^2	0.811	0.416	0.533	0.620	0.812	0.650	0.369	0.131	0.198	0.300	0.521	0.455	0.943	0.762
M5	CN_c	46.428	50.000	50.000	50.000	60.636	50.000	39.315	41.847	41.707	34.108	47.665	50.000	62.250	28.655
	λ	0.000	0.000	0.000	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	R^2	0.717	0.586	0.635	0.824	0.854	0.889	0.410	0.284	0.405	0.584	0.607	0.603	0.945	0.749
M6	CN_c	46.851	50.000	50.000	50.000	56.221	50.000	41.474	41.575	50.000	33.995	48.903	50.000	62.250	28.905
	λ	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001
	R^2	0.718	0.586	0.635	0.824	0.843	0.889	0.411	0.285	0.392	0.585	0.608	0.603	0.945	0.750
M7	CN_c	52.125	48.578	46.758	69.559	50.104	81.624	38.661	39.068	36.680	26.018	48.437	50.000	55.068	29.701
	λ	0.000	0.000	0.000	0.249	0.001	0.538	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000
	α	0.132	0.684	0.484	1.220	0.283	1.263	0.276	0.424	0.496	0.552	0.321	0.594	2.000	0.093
	R^2	0.811	0.550	0.628	0.905	0.878	0.926	0.387	0.228	0.363	0.653	0.599	0.599	0.948	0.761
M8	CN_c	96.159	83.553	90.707	52.883	53.757	60.496	79.288	61.476	63.495	51.841	86.796	81.514	45.370	35.920
	λ	8.704	2.651	3.768	0.000	0.000	0.000	3.762	36.459	100.000	6.921	2.996	1.692	0.001	20.110
	α	4.755	2.592	2.695	2.637	2.615	2.633	2.810	4.411	5.465	2.759	2.423	1.906	-2.934	10.000
	□	0.323	0.743	0.932	1.082	0.369	1.321	0.125	0.556	0.334	0.692	0.487	0.972	10.000	0.000
	R^2	0.867	0.617	0.654	0.825	0.869	0.902	0.450	0.409	0.517	0.689	0.648	0.642	0.911	0.782

Table 4: Model goodness of fit evaluation criteria (Ritter and Munoz-Carpena, 2013)

Performance rating	Model efficiency limitation	n(t)	NSE (%)
Very good	SD≥ 3.2*RMSE	≥n (t) 2.2	≥NSE 90
Good	SD= 2.2*RMSE-3.2*RMSE 1.2	1.2≤ n(t) < 2.2	80≤NSE < 90
Acceptable	SD =1.2*RMSE-2.2*RMSE 0.7	0.7 ≤ n(t) < 1.2	65≤NSE < 80
Unsatisfactory	SD < 1.7*RMSE	n(t) < 0.7	NSE < 65

RESULTS AND DISCUSSION

Analysis based on individual watershed

The performance of the SCS-CN inspired models was evaluated using three indices, RMSE, NSE, and n (t)). The comparative performance based on RMSE is shown in Table 5. As seen, the modified model M2 with λ = 0.05 performed better than model M1 (λ = 0.2) in all watersheds except plot having maize with 1% slope. Models M3, M5, M6, and M7 performed better (for lower RMSE reason) in all 14 watersheds than M1 followed by M2, M4, and M8, which also performed well on 13 watersheds. M8 performed better

The comparative performance based on higher n(t) is shown in Table 6. Models M3, M5, M6 performed better (higher n(t)) in all 14 watersheds than M1 followed by M2, M4, M7, and M8, which performed well on 13 watersheds. Model M8 performed better in 11 watersheds followed by M7.

As shown in Table 7, the performance based on NSE revealed that Models M3, M5, M6, and M7 performed better (higher NSE) in 13 out of 14 watersheds than M1 followed by M2, M4, and M8, which performed well in 12 watersheds. Based on RMSE, n (t), and NSE, Model M8 performed better in 10

Table 5: Comparison of RMSE (mm) in all watersheds.

Watersheds	Models							
	M1	M2	M3	M4	M5	M6	M7	M8
W1	8.39	6.69	5.25	3.06	2.94	2.94	2.44	2.00
W2	7.59	6.55	6.13	7.35	4.99	4.99	4.70	4.18
W3	8.57	6.67	4.69	5.30	3.74	3.74	3.70	3.49
W4	6.64	6.04	5.01	6.10	3.87	3.87	2.52	3.55
W5	5.26	5.02	2.86	3.51	2.53	2.62	2.46	2.43
W6	7.83	8.34	6.14	9.12	6.39	6.39	2.88	3.97
W7	9.59	7.37	3.97	4.05	3.48	3.60	3.49	2.98
W8	7.55	5.88	6.14	6.14	5.13	5.12	5.33	4.51
W9	7.54	6.30	5.40	5.42	4.16	4.97	4.26	3.60
W10	7.19	4.98	3.52	3.62	2.40	2.39	2.08	1.94
W11	7.94	6.30	4.31	4.44	3.58	3.62	3.59	3.25
W12	8.36	8.00	6.09	6.93	5.12	5.12	4.94	4.72
W13	62.04	58.61	52.36	52.67	51.23	51.23	49.61	68.51
W14	118.19	110.49	75.52	75.81	76.82	76.94	75.69	69.44

Table 6: Comparison of n (t) in all watersheds

Watersheds	Models							
	M1	M2	M3	M4	M5	M6	M7	M8
W1	-0.33	-0.15	0.08	0.85	0.93	0.92	1.32	1.84
W2	-0.07	0.07	0.15	-0.04	0.41	0.41	0.50	0.68
W3	-0.28	-0.07	0.32	0.16	0.65	0.65	0.67	0.77
W4	0.28	0.41	0.70	0.39	1.19	1.19	2.37	1.39
W5	0.31	0.38	1.41	0.97	1.74	1.64	1.81	1.85
W6	0.41	0.33	0.80	0.22	0.73	0.73	2.85	1.79
W7	-0.56	-0.43	0.05	0.03	0.20	0.16	0.20	0.40
W8	-0.19	0.04	0.00	0.00	0.19	0.19	0.15	0.36
W9	0.68	0.04	0.97	1.13	0.80	0.80	0.67	1.38
W10	-0.49	-0.27	0.03	0.01	0.52	0.52	0.75	0.88
W11	-0.28	-0.09	0.32	0.29	0.60	0.57	0.59	0.76
W12	-0.02	0.02	0.34	0.18	0.60	0.60	0.66	0.73
W13	2.61	2.82	3.28	3.25	3.37	3.37	3.51	2.27
W14	0.31	0.40	1.05	1.04	1.01	1.01	1.04	1.23

Table 7: Comparison of NSE (%) in all watersheds

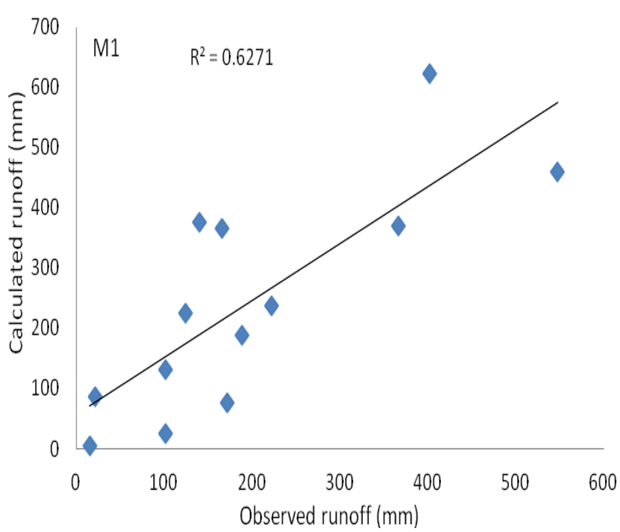
Watersheds	Models							
	M1	M2	M3	M4	M5	M6	M7	M8
W1	-138.06	-51.30	6.84	68.41	70.80	70.68	79.89	86.53
W2	-2.34	23.87	33.23	4.00	55.81	55.81	60.86	68.96
W3	-97.27	-19.43	41.00	24.53	62.38	62.38	63.21	67.32
W4	33.28	44.80	62.01	43.56	77.31	77.31	90.39	80.86
W5	37.17	42.80	81.35	71.96	85.50	84.45	86.27	86.64
W6	49.31	42.47	68.78	31.26	66.27	66.27	93.16	86.95
W7	-417.42	-206.07	11.28	7.55	31.72	27.21	31.24	50.02
W8	-57.08	4.68	-3.96	-4.07	27.37	27.56	21.67	43.95
W9	79.44	63.93	39.78	42.89	34.11	34.00	26.02	51.84
W10	-138.85	-14.60	42.68	39.65	73.48	73.55	80.03	82.61
W11	-111.57	-33.29	37.70	33.90	57.05	55.92	56.88	64.66
W12	-11.75	-2.30	40.71	23.20	58.07	58.07	60.93	64.36
W13	97.48	97.75	98.20	98.18	98.28	98.28	98.39	96.92
W14	75.90	78.93	90.16	90.08	89.82	89.79	90.12	91.68

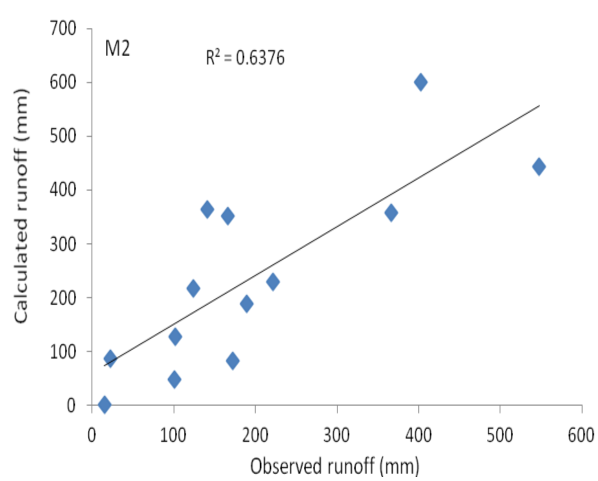
out of 14 watersheds followed by M7, which performed well in 3 watersheds.

Fig. 1 compares the observed and calculated runoff for Hemawati watershed. On this watershed data, M8 performed better than all other models and showed higher coefficient of determination (R^2). The performance rating and model efficiency limitation criteria as per Table 4 were calculated as shown in Table 8. As seen, models M1 and M2 performed unsatisfactorily in 13 out of 14 watersheds based on RMSE and n (t), whereas in 11 watersheds based on NSE. On the other hand, model M8 showed high rating in two watersheds based on NSE and in one watershed in terms of RMSE and n(t). Similarly, M8 exhibited a good rating in five watershed/plots based on RMSE and NSE, and in 6 watersheds/plots in terms of n (t). Compared to the other models, model M8 showed either a very good or good rating in maximum number of watersheds, followed by M7. In contract, the model M8 showed unsatisfactory rating only in 3, 4 and 5 watersheds/plots based on n(t), RMSE and NSE respectively, which was less unsatisfactory rating compared to other models.

Performance based on the results of all watersheds data

For the overall performance of the models in runoff prediction, the models were ranked based on cumulative mean RMSE, NSE, and n(t) statistics derived from the data of all 14 watersheds. Ranks of 1-8 were assigned from the lowest to the highest for the mean RMSE, and from the highest to the lowest for both the mean n(t) and mean NSE. The score of 16 to 2 was assigned to each model with 2 score for each rank based on performance of RMSE, NSE, and n(t). The highest score (16) was assigned to the method which had highest NSE, and n (t) (or lowest RMSE). Similarly, lowest score (2) was assigned to the method which has lowest NSE, and n (t) (or highest RMSE). Table 9 shows the ranking and scoring of





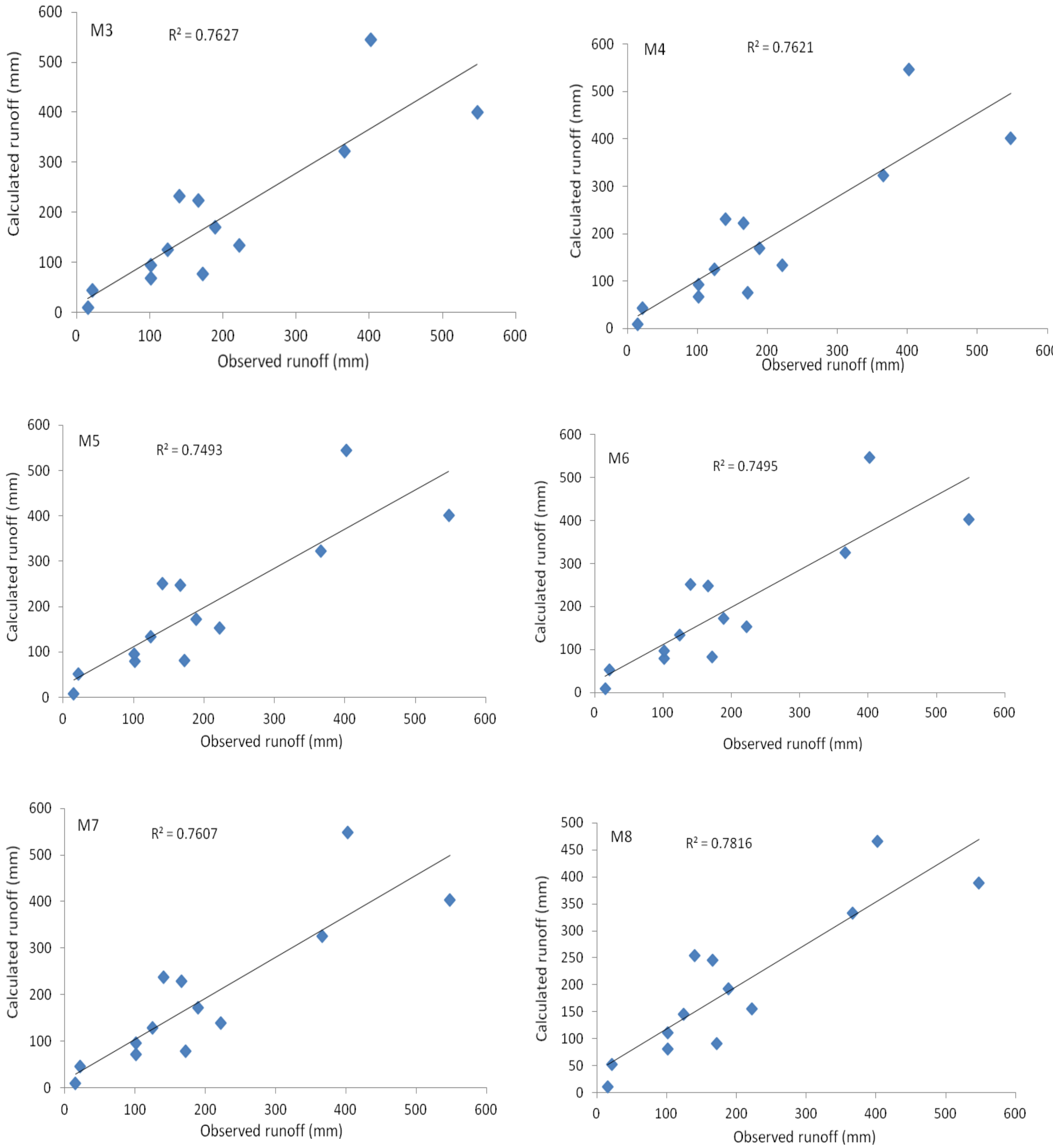


Fig. 1: Observed runoff versus calculated runoff for models M1 to M8 in Hemawati watershed

the models cumulative mean values of all three performance indices. Based on the ranks and scores of each individual model for each performance index, model M7 performed the best followed by M8, M5, M6, M3, M4 and M2; and M1 the poorest.

CONCLUSION

The following conclusions can be derived from the study:

- With lower RMSE and higher NSE and n(t) values, M2 (λ=0.05) performed better than M1 (λ=0.2) model.
- Model M8 performed the best of all followed by M7 with lower RMSE, higher n(t), higher NSE, and based on the performance rating and model efficiency limitation criteria.
- Based on the ranks and scores of each individual model for each performance index, the model M7 performed the best followed by M8, M5, M6, M3, M4, and M2 whereas M1 performed the poorest of all.

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