Environ Earth Sci (2017) 76:736
DOI 10.1007/s12665-017-7062-2

ORIGINAL ARTICLE

An enhanced SMA based SCS-CN inspired model for watershed runoff prediction

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Received: 18 January 2017 / Accepted: 16 October 2017 / Published online: 28 October 2017

Abstract Incorporation of initial soil moisture (V_0) in the Soil Conservation Service Curve Number (SCS-CN) methodology helps to avoid the sudden jumps in Curve Number (CN) and, in turn, in computed runoff. It invoked the development of an enhanced (yet simple) Soil Moisture Accounting (SMA) procedure-based-SCS-CN inspired model, by incorporating initial moisture (V_0). Its performance is tested using a dataset of 152 small to large watersheds of USDA (total 38,169 storm events), and compared with original SCS-CN method, Mishra and Singh (Acta Geophys Polon 50(3):457–477, 2002), Michel et al. (Water Resour Res 41(2):W02011, 2005) and Singh et al. (Water Resour Manag 29(11): 4111–4127, 2015) model using four statistical indices (RMSE, R^2, PBIAS and NSE) and rank grading system (RGS). The proposed model scores highest (= 691 marks out of maximum 2280 marks) (Rank I) followed by Singh et al. (Water Resour Manag 29(11):4111–4127, 2015) model with 642 marks (Rank II), Michel et al. (Water Resour Res 41(2):W02011, 2005) model with 376 marks (Rank III) and Mishra and Singh model with 362 marks (= Rank IV). The original SCS-CN model, however, performs the poorest of all with 209 marks (Rank V).

Keywords SCS-CN method · Initial soil moisture · Soil moisture accounting · Rank grading system

Introduction

A rainfall–runoff model forms the basis for several engineering applications such as hydraulic structure design, flood peak discharge computation, irrigation scheduling, reservoir operation, minimizing downstream flood hazards and water balance studies. One of the most globally used methods to estimate runoff is the Soil Conservation Service Curve Number (SCS-CN) method applicable for ungauged watersheds. It was developed by US Department of Agriculture (USDA)–SCS (SCS 1956/1972). This method is renamed as Natural Resource Conservation Service Curve Number (NRCS-CN) method (Hawkins et al. 2010).

The method is simple, easy to understand and apply and accounts for major runoff producing watershed characteristics (Garen and Moore 2005; Mishra et al. 2006; Sahu et al. 2012). It relies on only one parameter 'CN' which depends on watershed climatic and geographic factors (Mishra and Singh 2003). It is of common experience that a watershed can have a set of CNs which may be attributed to spatial and temporal variations of rainfall and watershed properties, quality of measured rainfall–runoff data, variability of antecedent rainfall and associated soil moisture amount (Hjelmfelt 1991; Hawkins 1993; Soulis and Valiantzas 2012). The usually identified source of variability is antecedent moisture condition (AMC) (Steenhuis et al. 1995; Soulis et al. 2009) which can be overcome by

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incorporation of initial soil moisture (Mishra and Singh 2002; Jain et al. 2006; Sahu et al. 2007). It plays a vital role in restructuring of the SCS-CN method and permits smooth variation of CN and thus avoids sudden jump in runoff estimation. It invoked the concept of Soil Moisture Accounting (SMA) procedure for development of enhanced SCS-CN-based models. Mishra and Singh (2002) incorporated the effect of antecedent moisture amount and developed an improved version of the SCS-CN inspired model. Several researchers (Mishra and Singh 2002, 2004, 2005; Jain et al. 2006; Babu and Mishra 2012) have developed different expressions of antecedent moisture on the basis of 5-day antecedent rainfall amount. Singh et al. (2010) presented an updated hydrologic review on the latest developments in SCS-CN methodology and discussed its physical and mathematical significance in hydrologic applications. More recently, Ajmal et al. (2015) examined this method and its inspired versions using the data of 15 watersheds of South Korea (total 658 large storm events). However, there are only a few studies providing an insight into the structural soundness of SMA procedure of the existing SCS-CN methodology (Verma et al. 2017).

Michel et al. (2005) diagnosed the structural foundation of the SCS-CN method and revealed the underlying inconsistencies arising partially from the misperception between intrinsic parameters and initial conditions and partially from an improper use of the underlying SMA procedure. They emphasized the incorporation of initial soil moisture (V_0) rather than an impractical intrinsic parameter in the form of initial abstractions (I_a). With the changed parameterization of threshold soil moisture (S_a) required for runoff generation in place of I_a and underlying SMA procedure, they proposed an advanced SCS-CN inspired model. This model does not include any expression for computing the input model parameters (V_0) and (S_a). Expressions were, however, provided for the simplified Michel et al. (2005) model. Singh et al. (2015) improved the SMA procedure proposed by Michel et al. (2005) by providing expression for initial soil moisture.

Looking into the versatility of the SCS-CN method and associated inconsistencies and changed parameterization, this study aims at to (a) propose an enhanced version of the SCS-CN inspired model based on SMA procedure for estimating runoff depth and suggest simple expressions for V_0 and S_a estimation to avoid sudden jumps in V_0 and AMC and (b) compare the performance of the proposed model with the original model, Mishra and Singh (2002) model, Michel et al. (2005) model and Singh et al. (2015) model using a large (= 38,169) storm events derived from 152 USDA watersheds varying in area from 0.3 to 12,990 ha.

Methodology

Original SCS-CN method

The SCS-CN (original) method employs the water balance equation:

$$P = I_a + F + Q \tag{1}$$

and the following two proportional equality hypotheses expressed, respectively, as:

$$\frac{Q}{(P - I_a)} = \frac{F}{S} \tag{2}$$

$$I_a = \lambda S \tag{3}$$

where P is the rainfall depth, I_a is the initial abstraction, F is the cumulative infiltration excluding I_a, Q is the runoff depth, S is the potential maximum retention and λ is the initial abstraction coefficient, which is taken as 0.2 for usual applications. Hawkins (2009) found that the variation of λ between 0 and 0.05 are more realistic. A combination of Eqs. (1) and (2) yields the popular form of the SCS-CN method:

$$\begin{aligned} Q &= \frac{(P - I_a)^2}{P - I_a + S} \text{for} \quad P \geq I_a \\ Q &= 0 \qquad \text{for } P \leq I_a \end{aligned} \tag{4}$$

Parameter S is mapped onto CN using Eq. (5) as:

$$S = 25.4\left(\frac{1000}{\text{CN}} - 10\right) \tag{5}$$

where CN is a dimensionless quantity varying from 0 to 100 and S is expressed in mm. CN varies with watershed characteristics such as soil type, land use, hydrologic condition and AMC (Chow et al. 1988; Mishra and Singh 2003).

Mishra and Singh (2002) model

Mishra and Singh (2002) used the $C = S_r$ concept, where $C = Q/(P{-}I_a)$ is the runoff coefficient and $Sr = (F/S)$ is the degree of saturation. Using this concept, they modified the equation of surface runoff by incorporating antecedent moisture equal to V_0 (Fig. 1) is given in Eq. (6):

$$\begin{aligned} Q &= \frac{(P - I_a)(P - I_a + V_0)}{(P - I_a + V_0 + S)}, \quad \text{if} \quad P > I_a \\ Q &= 0, \quad \text{otherwise} \end{aligned} \tag{6}$$

They also formulated an equation for the computation of V_0 as:

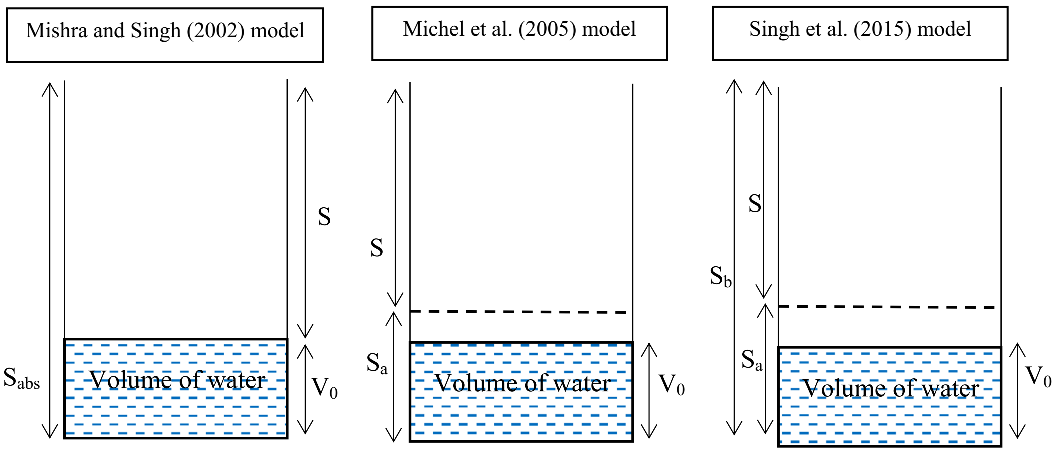

Fig. 1 Explanatory diagram showing soil moisture store in the SCS-CN inspired models

$$\begin{aligned} &V_0 = 0.5\left[-1.2S + \sqrt{0.64S^2 + 4P_5S}\right], \quad \text{if} \quad P_5 \geq 0.2S, \\ &V_0 = 0, \quad \text{otherwise} \end{aligned} \qquad (7)$$

where P_5 is the 5-day antecedent rainfall.

Michel et al. (2005) model

Michel et al. (2005) reviewed SMA procedure of the SCS-CN method and unveiled major inconsistencies in treatment of AMC and proposed a renewed sounder methodology. They assumed that the SCS-CN model is valid not only at the end of the storm but at any instant along a rainfall event. Their findings are based on an analysis of the continuous SMA procedure based on the concept that higher the moisture store level, higher the portion of rainfall that is transformed into surface runoff. They developed a procedure which is more stable from SMA viewpoint, by introducing the term $V_{0,}$ i.e., initial soil moisture store level.

Based on their hypothesis and water balance theory, Michel et al.(2005) model shows several variations in the original procedure of SCS-CN method due to confusion between intrinsic parameters and the initial condition and partially from an inappropriate use of the basic SMA procedure. The model eliminated initial abstraction I_a and introduced a new parameter 'S_a' threshold moisture for generating surface runoff ($S_a = I_a + V_0$) to compute the surface runoff (Fig. 1).The generalized Michel et al. (2005) model with new insight into SMA procedure is given as follows:

$$\text{If} \quad V_0 \leq S_a - P, \quad \text{then} \quad Q = 0 \qquad (8)$$

$$\text{If} \quad S_a - P < V_0 < S_a, \quad \text{then,} \quad Q = \frac{(P + V_0 - S_a)^2}{(P + V_0 - S_a + S)} \qquad (9)$$

$$\text{If} \quad S_a \leq V_0 \leq S_a + S, \quad \text{then,} \quad Q = P\left[1 - \frac{(S + S_a - V_0)^2}{S^2 + (S + S_a - V_0)P}\right] \qquad (10)$$

With the introduction of initial soil moisture (V_0) and replacement of parameter I_a by S_a, the procedure became more reliable from SMA viewpoint.

Singh et al. (2015) model

Singh et al. (2015) used the concept of $C = S_r$ and modified the proportionality hypothesis (Eq. 2) as:

$$\frac{Q}{P - Ia} = \frac{F + V_0 + Ia}{S + V_0 + Ia} \qquad (11)$$

They incorporated the concept of $S_a = I_a + V_0$, and proposed a set of equations for runoff estimation as:

$$\text{If} \quad V_0 \leq S_a - P, \quad \text{then} \quad Q = 0 \qquad (12)$$

$$\text{If} \quad S_a - P < V_0 < S_a, \quad \text{then} \quad Q = \frac{(P + V_0 - S_a)(P + V_0)}{P + S + V_0} \qquad (13)$$

$$\text{If} \quad S_a \leq V_0 \leq S_b, \quad \text{then} \quad Q = P\left[1 - \frac{(S_b - V_0)^2}{SS_b + (S_b - V_0)P}\right] \qquad (14)$$

where S_a is the threshold soil moisture, $S_b = S + S_a$ is the absolute potential retention (Fig. 1), V_0 is the initial soil moisture. For computing V_0 and S_a, they used the existing equations as:

$$V_0 = \alpha\sqrt{P_5S} \qquad (15)$$

$$S_a = \beta S \qquad (16)$$

Need of modification in existing concept

Equation 7 (Mishra and Singh 2002) yields unrealistic negative values of V_0 when $P_5 < 0.2S$, leading to occurrence of inconsistent sudden jumps in SMA computation. Later, Michel et al. (2005) model suggested Eqs. (8–10) to account for these jumps. Since this model relies on the original SCS-CN model (Eq. 4), it does not incorporate V_0 in its expressions. Recently, Singh et al. (2015) further modified Mishra and Singh (2002) model employing the same $C = Sr$ concept and including initial abstraction in proportionality hypothesis (Eq. 11). This, however, does not appear to be rational considering the initial abstraction to be a component of precipitation loss contributing neither to infiltration nor to runoff. It invokes the development of the proposed model.

Proposed model

For the proposed version, the modification began from Mishra and Singh (2002) model which was developed on $C = S_r$ concept employing antecedent moisture (V_0). To make this model suitable within a continuous watershed model, the model should be valid not only at the end of the storm but at any instant along a storm. In this perspective, rainfall (P) and runoff (Q) are assumed as functions of time t and it holds at the completion of the storm too when the continuous model overlaps the concept of Mishra and Singh (2002) model.

Let us assume the rainfall rate (p) and the runoff rate (q) are equal to $\mathrm{d}P/\mathrm{d}t$ and $\mathrm{d}Q/\mathrm{d}t$, respectively. Also, consider soil moisture volume store which collects that portion of rainfall trapped in soil profile and not converted into runoff. Assume V_0 is the level of soil moisture at the beginning of the storm and V is the level of soil moisture at any instant of time t, when the collected rainfall depth equals P.

The water balance Eq. (1) can be written as:

$$V = V_0 + P - Q \tag{17}$$

Replacing Q by Eq. (6) (Mishra and Singh 2002) to derive the following:

$$V = V_0 + P - \left[\frac{(P - I_a)(P - I_a + V_0)}{(P - I_a + V_0 + S)}\right] \tag{18}$$

Differentiating Eq. (6) with time (t) yields

$$q = \frac{(P - I_a + V_0)(P - I_a + V_0 + S) + S(P - I_a)}{(P - I_a + V_0 + S)^2}p,\ \text{if}\ P > I_a \tag{19}$$

where $q = \mathrm{d}Q/\mathrm{d}t$

Substituting P from Eqs. (18) into (19) yields

$$q = \frac{2S(V - I_a - V_0) - (V - I_a - V_0)^2 + SV_0}{S(S + V_0)}p$$
$$\text{if},\quad V > V_0 + I_a,\quad q = 0,\quad \text{otherwise} \tag{20}$$

Replacing (I_a + V_0) with the intrinsic parameter (S_a) gives

$$q = \frac{(V - S_a)(2S + S_a - V) + SV_0}{S(S + V_0)}p,\quad \text{if}\quad V > S_a$$
$$q = 0,\quad \text{otherwise} \tag{21}$$

Thus, hydrologically, the soil moisture store initially collects all the rainfall until it reaches the threshold value (S_a). Since the soil moisture store has a fixed volume, the extreme capacity of soil moisture store can be reached to V when the soil is fully saturated and all rainfall converts to runoff, i.e., $q = p$. At this point of time, there is no space in the soil moisture store for rain to enter; according to the derivative of Eq. (17) which suggests $\mathrm{d}V/\mathrm{d}t = 0$. For maximum capacity of V, i.e., when $V = S + S_a$, Eq. (21) yields

$$q = p. \tag{22}$$

The continuity equation can be obtained by differentiating Eq. (17) as:

$$\frac{\mathrm{d}V}{\mathrm{d}t} = p - q \tag{23}$$

A coupling of Eqs. (21) and (23) results into complete model of soil moisture store.Equation (6) can be rewritten using intrinsic parameter S_a instead of I_a as:

$$Q = \frac{(P - S_a + V_0)(P - S_a + 2V_0)}{(P - S_a + 2V_0 + S)}\ \text{if}\ \ P + V_0 > S_a,$$
$$Q = 0\ \ \text{otherwise} \tag{24}$$

Here, if $V_0 = S + S_a$, Q should be equal to P because the soil moisture store is completely filled and there is no space left in the store where the excess rainfall can enter. Q derived from Eq. (24) is larger than P, as below:

$$Q = P + \frac{S(2S + S_a)}{(P + S_a + 3S)} \tag{25}$$

which is not possible in reality and it is a drawback of Mishra and Singh (2002) model. Thus, Eq. (24) is flawed.

The exact formulation can be obtained by recalculating the formula for the total amount of P and Q by integrating Eq. (23) and using the value of q from Eq. (21) as:

$$\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{(V - S_a - S)^2}{S(S + V_0)}p \tag{26}$$

It can be rewritten as:

$$\frac{\mathrm{d}V}{(V - S_a - S)^2} = \frac{p\mathrm{d}t}{S(S + V_0)} \tag{27a}$$

Since the soil moisture varies from V_0 to V, after integration, one gets

$$\int_{V_0}^{V} \frac{\mathrm{d}V}{(V - S_a - S)^2} = \frac{1}{S(S + V_0)} \int_{0}^{t} p\mathrm{d}t \tag{27b}$$

$$\left[\frac{-1}{(V - S_a - S)}\right]_{V_0}^{V} = \frac{P}{S(S + V_0)} \tag{27c}$$

$$\frac{1}{S_a + S - V} - \frac{1}{S_a + S - V_0} = \frac{P}{S(S + V_0)} \tag{27d}$$

Now, replacing V from Eq. (17), one obtains

$$Q = P\left[1 - \frac{(S_a + S - V_0)^2}{(P(S_a + S - V_0) + S(S + V_0))}\right] \tag{28}$$

The computations reveal that the derived model, i.e., Eqs. (24) and (28) are two different parts of the complete proposed model. Three cases arise from the presence of S_a as below:

Case I When P is not enough to overcome the initial moisture deficit of the soil moisture store (less than threshold value, S_a), i.e., $V_0 + P < S_a$, then $Q = 0$, Thus,

$$\text{If} \quad V_0 \le S_a - P, \quad \text{then} \quad Q = 0 \tag{29}$$

Case II When $V_0 < S_a$ but P is large enough to overcome the initial moisture deficit and generate surface runoff, an initial part of P will be used to overcome the initial moisture deficit without generating runoff and the remaining part ($P + V_0 – S_a$) will generate runoff.

$$\text{If} \quad S_a - P < V_0 < S_a, \quad \text{then} \quad Q = \frac{(P - S_a + V_0)(P - S_a + 2V_0)}{(P - S_a + 2V_0 + S)} \tag{30}$$

Case III When $V_0 > S_a$, an amount (= $V_0 – S_a$) of water is taken out from the soil moisture store and added to P to further increase runoff.

$$\text{If} \quad S_a \le V_0 \le S_a + S, \quad \text{then} \quad Q = P\left[1 - \frac{(S_a + S - V_0)^2}{(P(S_a + S - V_0) + S(S + V_0))}\right] \tag{31}$$

Equations (29)–(31) represent the proposed SCS-CN model as it is more logical and physically more stable compared to the other models under study for surface runoff estimation. For computation of V_0 and S_a, the formulations used by Singh et al. (2015) (Eqs. 15 and 16) is used here. The advantage of this expression is that it physically relates V_0 to P_5 and S, in the sense that a higher P_5 or S will give a higher V_0. Moreover, it obviates the sudden jump of V_0 with S or CN.

For convenience, the original SCS-CN model, Mishra and Singh (2002) model, Michel et al. (2005) model, Singh et al. (2015) and the proposed model are referred as M1, M2, M3, M4 and M5, respectively, in the forthcoming text. Table 1 summarizes the formulation of all these models.

Table 1 Model formulations

Model	Parameter	Model formulation for computing runoff (Q)
M1	CN	Equations (3), (4) and (5)
M2	CN	Equations (3), (5), (6) and (7)
M3	V_0, S_a, S	Equations (8), (9) and (10)
M4	α, β, S	Equations (12)–(16)
M5	α, β, S	Equations (29)–(31) and Eqs. (15)–(16)

Application

Study watersheds and data

The proposed model is evaluated and compared with existing models (M1, M2, M3 and M4) using the data derived from 152 USDA agricultural watersheds varying in area from 0.3 to 12,990 ha (Fig. 2). The rainfall–runoff data for 3–35 years are available at http://www.ars.usda.gov/arsdb.html as well as at http://hydrolab.arsusda.gov/arswater.html. The number of rainfall–runoff events varied from 8 to 979 (total = 38,169) for different watersheds.‘‘

Measures of model performance

The models' performance is evaluated using four widely accepted statistical indices: (1) root-mean-square error (RMSE) (Deshmukh et al. 2013) (2) coefficient of determination (R^2), (3) percent bias (PBIAS) (Moriasi et al. 2007) and (4) Nash–Sutcliffe efficiency (NSE) (Gupta et al. 1999; Nash and Sutcliffe 1970).These are expressed as:

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Q_{\mathrm{obs}} - Q_{\mathrm{comp}}\right)_i^2} \tag{32}$$

$$R^2 = \frac{\left(\sum_{i=1}^{N}\left(Q_{\mathrm{obs}} - \bar{Q}_{\mathrm{obs}}\right)_i\left(Q_{\mathrm{comp}} - \bar{Q}_{\mathrm{comp}}\right)_i\right)^2}{\sum_{i=1}^{N}\left(Q_{\mathrm{obs}} - \bar{Q}_{\mathrm{obs}}\right)_i^2 \sum_{i=1}^{N}\left(Q_{\mathrm{comp}} - \bar{Q}_{\mathrm{comp}}\right)_i^2} \tag{33}$$

$$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{N}\left(Q_{\mathrm{obs}} - Q_{\mathrm{comp}}\right)_i}{\sum_{i=1}^{N}\left(Q_{\mathrm{obs}}\right)_i}\right] \times 100 \tag{34}$$

$$\mathrm{NSE} = \left[1 - \frac{\sum_{i=1}^{N}\left(Q_{\mathrm{obs}} - Q_{\mathrm{comp}}\right)_i^2}{\sum_{i=1}^{N}\left(Q_{\mathrm{obs}} - \bar{Q}_{\mathrm{obs}}\right)_i^2}\right] \times 100 \tag{35}$$

where Q_{obs} is the observed storm runoff, Q_{comp} is the computed runoff, $\bar{Q}_{\mathrm{obs}}$ is the mean of observed runoff

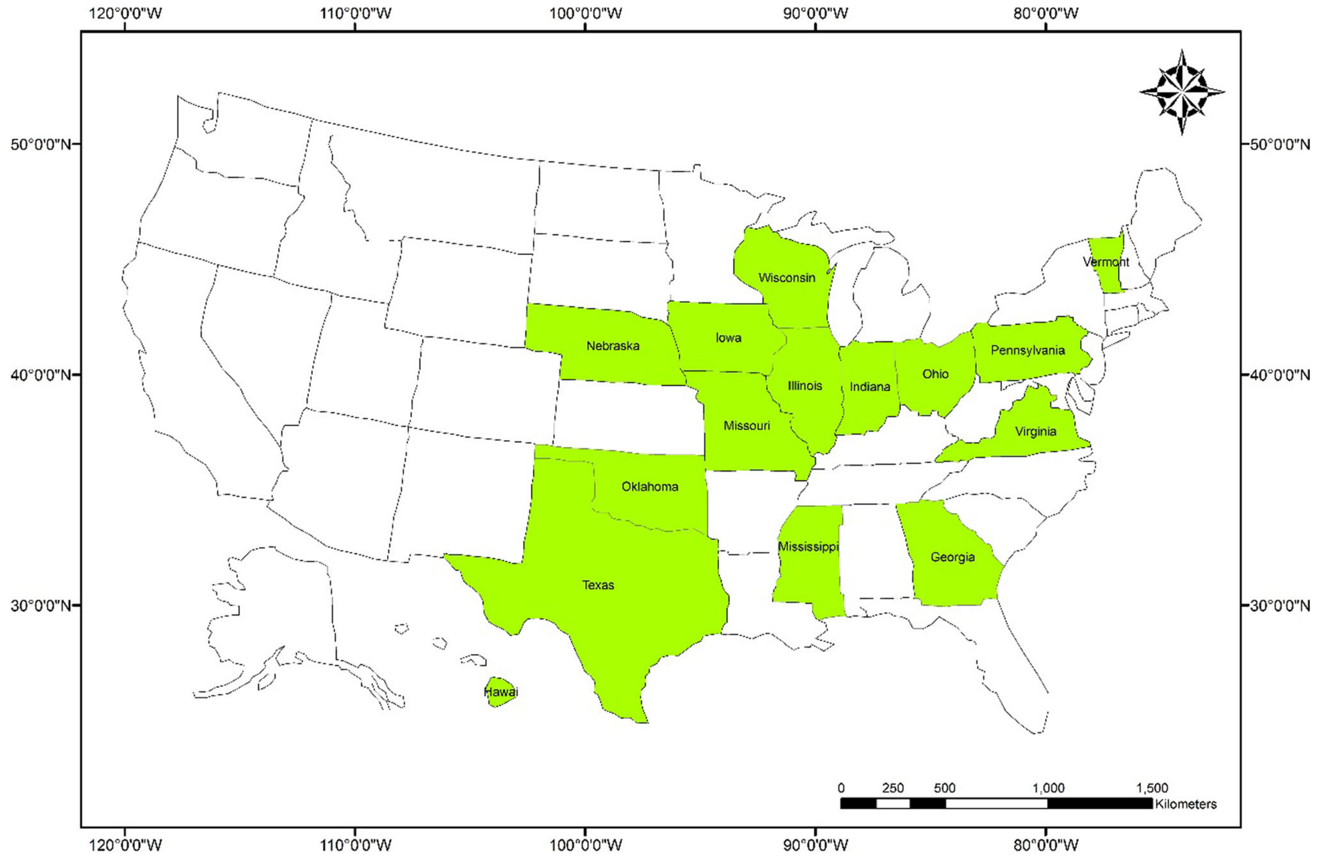

Fig. 2 Location of ARS experimental watersheds

values in a watershed, N is the total number of rainfall runoff events and i is an integer varying from 1 to N. The lower value of RMSE indicates better performance and vice versa. It means RMSE $= 0$ shows a perfect agreement between the observed and the predicted values. R^2 describes the proportion of the total variance explained by the model in the observed data. It is a meaningful indicator of the accuracy of predictions. It ranges from 0 to 1 with higher values indicating better agreement with the observed data. Published literature (Aitken 1973; Mishra and Singh 1999; Santhi et al. 2001; Garen and Moore 2005) indicates acceptable model performance if $R^2 > 0.6$. The PBIAS measures the model's average tendency to predict higher or lower values than the observed data. The ideal value is zero; however, negative value indicates over prediction, whereas a positive value indicates under prediction. According to Moriasi et al. (2007), the model performance for flow simulation can be interpreted as 'unsatisfactory' if PBIAS $> \pm 25\%$; 'satisfactory' if $\pm 15\% \leq$ PBIAS $\leq \pm 25\%$; 'good' if $\pm 10\% \leq$ PBIAS $< \pm 15\%$; and 'very good' if PBIAS $\leq \pm 10\%$. The NSE (%) $= 100$ indicates perfect agreement between observed and computed values, whereas poorer agreement is indicated by decreasing value (Fentie et al. 2002). NSE (%) $= 0$ indicates that the model predictions are as accurate as the mean of the observed data, implying that the model predictions are equal to the average of the observed data (Coffey et al. 2004). The negative value of NSE indicates that the average observed value is a better estimate than the model predicted value (Fentie et al. 2002; EI-Sadek et al. 2001). Deshmukh et al. (2013), Singh et al. (2015) among many others used this criterion for models comparison.

Parameter estimation

Model parameters were estimated using Marquardt (1963) algorithm of constrained least squares. In M1 and M2 applications, the initial estimate of CN is taken as 50 and it was allowed to vary in the range (0, 100). For models M3, M4 and M5, the initial estimate of parameter S was taken as 125 mm and was assumed to vary in the range (0, 2500) mm. For M3, V_0 and S_a parameters were allowed to vary in the range (0, 500) mm with its initial estimate of 100 mm. For the M4 and M5, α and β were allowed to vary in the range of (0, 1) with an initial estimate of 0.01. The statistics

Table 2 Range of parameters obtained from model application in 152 watersheds

Model	Parameters	Mean	Minimum	Maximum	Median	90% confidence level	
						Lower	Upper
M1	CN	81.89	30.80	94.93	87.62	79.67	84.11
M2	CN	75.79	42.13	89.57	77.98	74.32	77.27
M3	V_0	155.95	0.00	500.00	105.81	138.72	173.18
	S_a	152.04	1.62	500.00	100.35	133.71	170.36
	S	232.44	0.10	2451.61	124.50	178.42	286.47
M4	α	0.24	0.01	0.69	0.23	0.22	0.26
	β	0.15	0.00	0.98	0.12	0.13	0.18
	S	219.22	0.11	2500.00	127.72	172.39	266.05
M5	α	0.19	0.01	0.65	0.17	0.17	0.20
	β	0.12	0.00	0.94	0.09	0.10	0.15
	S	212.80	40.11	2500.00	123.61	167.58	258.03

of estimated values of model parameters are given in Table 2.

Results and discussion

The values of NSE (%), RMSE, R^2 and PBIAS resulting from model (M1–M5) applications to 152 USDA watersheds are summarized in Appendix I and II. A model can be ranked superior if it shows higher NSE (%) or R^2 values and vice versa. Conversely, lower values or RMSE and PBIAS (either positive or negative) also indicate better performance of models. Figure 3 shows the models' performance based on RMSE which shows that the proposed model (M5) has lowest RMSE for most of the watersheds. When the models' performance was evaluated on the basis of NSE (%), it is found that the model M1, M2, M3, M4 and M5 shows NSE (%) > 75 for 14, 40, 36, 59 and 62 watersheds, respectively. Figure 4 shows the models NSE (%) for all 152 watersheds. It is clear here that the model M5 shows significant improvement over M1, M2 and M3 and marginal improvement over model M4. Similar performance is observed from Fig. 5 depicting the models' performance on the basis of PBIAS. It shows that model M5 shows lowest PBIAS (either positive or negative) as compared to rest of the models. The models M1, M2 and M3 underestimate the runoff by showing positive value of PBIAS. According to the evaluation criteria set by Moriasi et al. (2007), M1, M2, M3, M4 and M5 models shows very good performance in 53, 29, 117, 129 and 134 watersheds, good in 17, 30, 13, 10 and 6, fair in 33, 41, 11, 9 and 10 and unsatisfactory in 49, 52, 11, 4 and 2 watersheds, respectively.

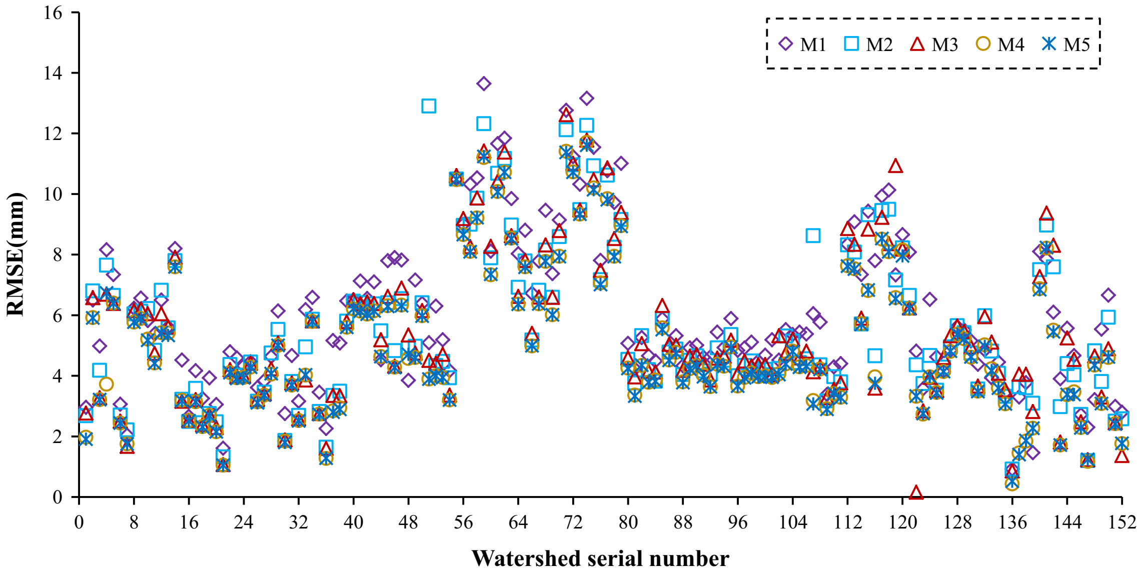

Fig. 3 Models' performance on the basis of RMSE for 152 watersheds

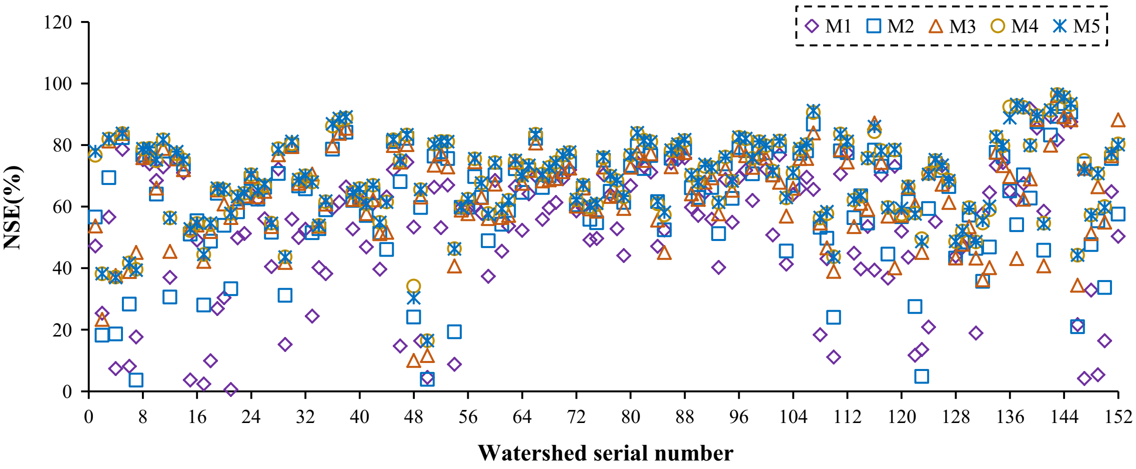

Fig. 4 Models' performance on the basis of NSE (%) for 152 watersheds

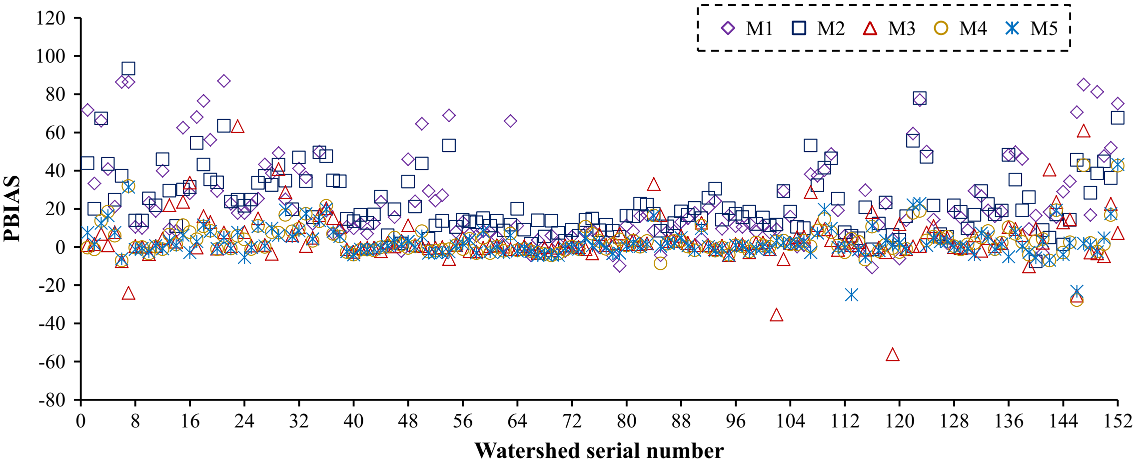

Fig. 5 Models' performance on the basis of PBIAS for 152 watersheds

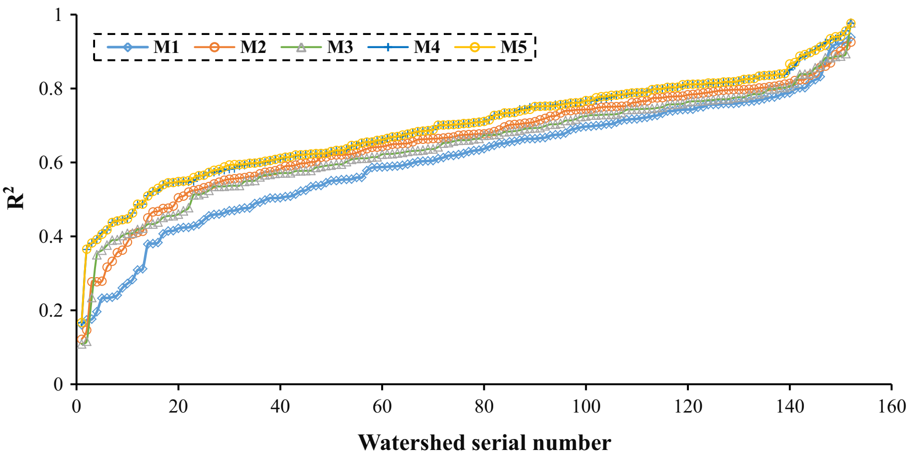

Fig. 6 Models' performance on the basis of R^2 for 152 watersheds

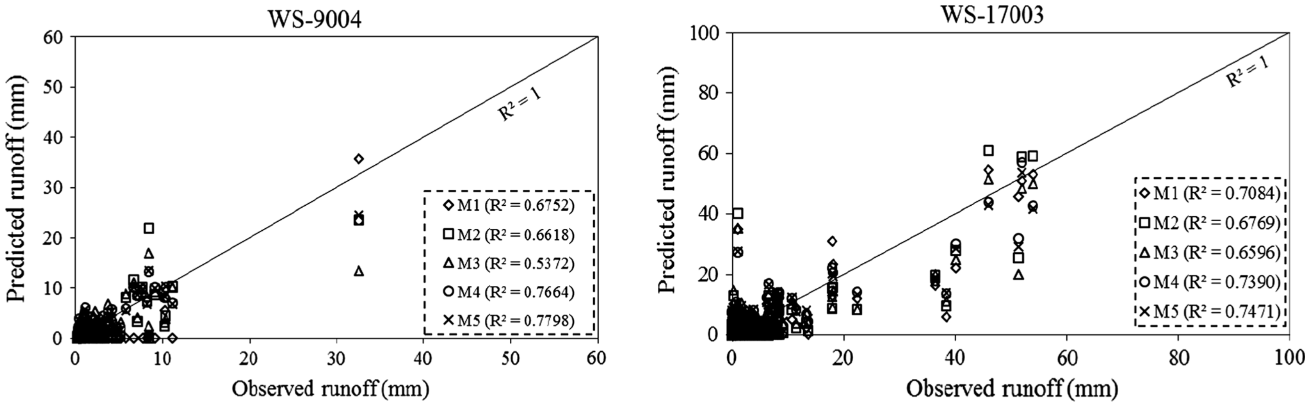

Fig. 7 Scatter plot of models (M1–M5) under study

Table 3 Evaluation of models rank based on NSE (%) and RGS

S. no.	WS ID	Rank based on NSE (%)					Grade based on NSE (%)				
		M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
1	9004	V	III	IV	II	I	1	3	2	4	5
2	10001	IV	V	III	II	I	2	1	3	4	5
3	13008	V	IV	III	II	I	1	2	3	4	5
4	13009	V	IV	II	I	III	1	2	4	5	3
5	13014	V	IV	II	III	I	1	2	4	3	5
6	16010	V	IV	III	I	II	1	2	3	5	4
7	16020	IV	V	I	II	III	2	1	5	4	3
8	17001	V	III	IV	II	I	1	3	2	4	5
9	17002	V	III	IV	II	I	1	3	2	4	5
10	17003	III	V	IV	II	I	3	1	2	4	5
11	17004	V	IV	III	II	I	1	2	3	4	5
12	19004	IV	V	III	I	II	2	1	3	5	4
13	19005	IV	III	V	II	I	2	3	1	4	5
14	25001	V	III	IV	I	II	1	3	2	5	4
15	26001	V	IV	I	III	II	1	2	5	3	4
16	26002	V	I	IV	III	II	1	5	2	3	4
17	26003	V	IV	III	II	I	1	2	3	4	5
18	26004	V	IV	III	II	I	1	2	3	4	5
19	26005	V	IV	III	II	I	1	2	3	4	5
20	26006	V	IV	III	II	I	1	2	3	4	5
21	26007	V	IV	III	II	I	1	2	3	4	5
22	26010	V	IV	III	I	II	1	2	3	5	4
23	26011	V	IV	III	II	I	1	2	3	4	5
24	26012	V	IV	III	II	I	1	2	3	4	5
25	26014	V	IV	III	I	II	1	2	3	5	4
26	26015	V	III	IV	II	I	1	3	2	4	5
27	26016	V	IV	III	I	II	1	2	3	5	4
28	26018	IV	V	III	I	II	2	1	3	5	4
29	26021	V	IV	III	I	II	1	2	3	5	4
30	26023	V	III	IV	II	I	1	3	2	4	5
31	26024	V	IV	III	II	I	1	2	3	4	5
32	26025	V	IV	III	II	I	1	2	3	4	5
33	26035	V	IV	I	II	III	1	2	5	4	3
34	26036	V	IV	III	II	I	1	2	3	4	5
35	26828	V	IV	III	II	I	1	2	3	4	5

Table 3 continued

S. no.	WS ID	Rank based on NSE (%)					Grade based on NSE (%)				
		M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
36	31001	V	IV	III	II	I	1	2	3	4	5
37	31003	V	III	IV	II	I	1	3	2	4	5
38	31004	V	IV	III	II	I	1	2	3	4	5
39	34001	V	IV	III	I	II	1	2	3	5	4
40	34002	V	III	IV	I	II	1	3	2	5	4
41	34006	V	IV	III	II	I	1	2	3	4	5
42	34007	V	III	IV	I	II	1	3	2	5	4
43	34008	V	III	IV	II	I	1	3	2	4	5
44	34013	I	V	IV	II	III	5	1	2	4	3
45	35001	V	III	IV	II	I	1	3	2	4	5
46	35002	V	IV	III	II	I	1	2	3	4	5
47	35003	V	III	IV	II	I	1	3	2	4	5
48	35004	I	IV	V	II	III	5	2	1	4	3
49	35005	V	IV	III	II	I	1	2	3	4	5
50	35006	IV	V	III	II	I	2	1	3	4	5
51	35008	V	III	IV	I	II	1	3	2	5	4
52	35009	V	III	IV	I	II	1	3	2	5	4
53	35010	V	III	IV	II	I	1	3	2	4	5
54	35011	V	IV	III	I	II	1	2	3	5	4
55	37001	IV	III	V	I	II	2	3	1	5	4
56	37002	IV	III	V	II	I	2	3	1	4	5
57	42002	V	IV	III	II	I	1	2	3	4	5
58	42003	V	III	IV	I	II	1	3	2	5	4
59	42004	V	IV	III	I	II	1	2	3	5	4
60	42006	IV	III	V	I	II	2	3	1	5	4
61	42007	V	IV	III	II	I	1	2	3	4	5
62	42008	V	III	IV	I	II	1	3	2	5	4
63	42010	V	IV	III	II	I	1	2	3	4	5
64	42011	V	IV	III	I	II	1	2	3	5	4
65	42012	V	III	IV	II	I	1	3	2	4	5
66	42013	V	III	IV	I	II	1	3	2	5	4
67	42014	V	IV	III	I	II	1	2	3	5	4
68	42015	V	III	IV	I	II	1	3	2	5	4
69	42016	V	III	IV	I	II	1	3	2	5	4
70	42017	V	III	IV	II	I	1	3	2	5	4
71	42023	V	III	IV	II	I	1	3	2	4	5
72	42024	V	III	IV	II	I	1	3	2	4	5
73	42028	V	IV	III	II	I	1	2	3	4	5
74	42035	V	IV	III	II	I	1	2	3	4	5
75	42036	V	IV	III	II	I	1	2	3	4	5
76	42037	V	III	IV	II	I	1	3	2	4	5
77	42038	IV	III	V	II	I	2	3	1	4	5
78	42039	V	III	IV	II	I	1	3	2	4	5
79	42040	V	III	IV	II	I	1	3	2	4	5
80	44001	V	III	IV	II	I	1	3	2	4	5
81	44002	V	III	IV	II	I	1	3	2	4	5
82	44003	IV	V	III	I	II	2	1	3	5	4
83	44004	V	IV	III	I	II	1	2	3	5	4
84	44005	V	II	IV	III	I	1	4	2	3	5
85	44006	IV	III	V	II	I	2	3	1	4	5
86	44007	IV	III	V	II	I	2	3	1	4	5
87	44008	V	III	IV	II	I	1	3	2	4	5
88	44009	V	III	IV	II	I	1	3	2	4	5
89	44010	V	III	IV	II	I	1	3	2	4	5

Table 3 continued

S. no.	WS ID	Rank based on NSE (%)					Grade based on NSE (%)				
		M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
90	44011	V	III	IV	II	I	1	3	2	4	5
91	44012	V	III	IV	II	I	1	3	2	4	5
92	44013	V	IV	III	II	I	1	2	3	4	5
93	44014	V	IV	III	II	I	1	2	3	4	5
94	44015	V	III	IV	II	I	1	3	2	4	5
95	44016	V	IV	III	II	I	1	2	3	4	5
96	44017	V	III	IV	II	I	1	3	2	4	5
97	44018	V	III	IV	II	I	1	3	2	4	5
98	44019	V	IV	III	II	I	1	2	3	4	5
99	44020	V	III	IV	II	I	1	3	2	4	5
100	44021	V	III	IV	II	I	1	3	2	4	5
101	44022	V	IV	III	I	II	1	2	3	5	4
102	44023	IV	III	V	II	I	2	3	1	4	5
103	44024	V	IV	III	II	I	1	2	3	4	5
104	44025	V	III	IV	II	I	1	3	2	4	5
105	44026	V	III	IV	II	I	1	3	2	4	5
106	44028	V	III	IV	II	I	1	3	2	4	5
107	44029	V	III	IV	II	I	1	3	2	4	5
108	61002	V	IV	III	II	I	1	2	3	4	5
109	61003	V	III	IV	II	I	1	3	2	4	5
110	61004	V	IV	III	I	II	1	2	3	5	4
111	62001	V	IV	III	II	I	1	2	3	4	5
112	62002	IV	III	V	II	I	2	3	1	4	5
113	62003	V	III	IV	II	I	1	3	2	4	5
114	62004	V	II	IV	III	I	1	4	2	3	5
115	62005	V	IV	III	I	II	1	2	3	5	4
116	62008	V	IV	I	III	II	1	2	5	3	4
117	62010	V	IV	III	I	II	1	2	3	5	4
118	62012	V	IV	III	I	II	1	2	3	5	4
119	62014	IV	III	V	II	I	2	3	1	4	5
120	62017	V	IV	III	II	I	1	2	3	4	5
121	62018	V	IV	III	II	I	1	2	3	4	5
122	67003	V	IV	I	II	III	1	2	5	4	3
123	67005	IV	V	III	I	II	2	1	3	5	4
124	67009	V	IV	I	II	III	1	2	5	4	3
125	69030	V	IV	III	II	I	1	2	3	4	5
126	69032	II	IV	V	III	I	4	2	1	3	5
127	69033	III	IV	V	I	II	3	2	1	5	4
128	69034	III	V	IV	II	I	3	1	2	4	5
129	69035	V	III	IV	II	I	1	3	2	4	5
130	69036	V	III	IV	I	II	1	3	2	5	4
131	69037	V	III	IV	II	I	1	3	2	4	5
132	69042	I	V	IV	III	II	5	1	2	3	4
133	69043	I	IV	V	III	II	5	2	1	3	4
134	69044	V	IV	III	I	II	1	2	3	5	4
135	69045	IV	III	V	I	II	2	3	1	5	4
136	70002	V	IV	III	I	II	1	2	3	5	4
137	70003	III	IV	V	II	I	3	2	1	4	5
138	70004	IV	III	V	I	II	2	3	1	5	4
139	70006	I	V	IV	III	II	5	1	2	3	4
140	70007	V	IV	III	II	I	1	2	3	4	5
141	70008	I	IV	V	II	III	5	2	1	4	3
142	70009	III	IV	V	II	I	3	2	1	4	5
143	70010	V	IV	III	II	I	1	2	3	4	5

Table 3 continued

S. no.	WS ID	Rank based on NSE (%)					Grade based on NSE (%)				
		M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
144	70011	V	III	IV	I	II	1	3	2	5	4
145	70012	V	III	IV	II	I	1	3	2	4	5
146	71001	IV	V	III	II	I	2	1	3	4	5
147	71005	V	II	III	I	IV	1	4	3	5	2
148	74003	V	IV	III	II	I	1	2	3	4	5
149	74008	V	IV	III	I	II	1	2	3	5	4
150	74009	V	IV	III	I	II	1	2	3	5	4
151	77003	V	IV	III	II	I	1	2	3	4	5
152	77006	V	IV	I	II	III	1	2	5	4	3
Total score							209	362	376	642	691
Overall rank							V	IV	III	II	I

The models' performance based on R^2 indicates that model M1, M2, M3, M4 and M5 shows acceptable performance ($R^2 > 0.6$) for 86, 107, 100, 116 and 117 watersheds, respectively. Figure 6 shows the R^2 of all models indicating the significant improvement as compared to M1, M2 and M3 and marginal improvement over M4.

The models' performances are also evaluated using scatter plots (Fig. 7a, b for WS-ID 9004 and 17003, respectively), which compare the predicted runoff with the observed runoff for all the five models.

The models' performance were further assessed using RGS based on efficiency suggested by Mishra and Singh (1999) and Singh et al. (2015), by assigning ranks (I)–(V) to the above five models in the order of their merit in applications to the dataset of a watershed. The rank (I) shows the highest NSE and rank (V) the lowest NSE. The ranks of models in each application and their overall ranks (I–V) from the overall score of each model are shown in Table 3. This table shows that M5 scores the highest (= 691) marks with overall rank I followed by M4 with 642 marks and overall rank II, M3 with 376 marks with overall rank III, M2 with 362 marks with overall rank IV and M1 with 209 marks, and overall rank V out of the maximum 2280 marks. Therefore, based on the overall results obtained here, it can be clearly deduced that M5 is rated as the best model followed by M4, M3, M2 and M1 models.

Conclusions

An enhanced SMA-based SCS-CN-inspired model was proposed and tested for its suitability using the large dataset of 152 US watersheds. Based on RMSE, R^2, PBIAS and NSE (%), the proposed model (M5) was found to perform marginally better than Singh et al. (M4) model and significantly better than both Mishra and Singh (2002) (M2) and Michel et al. (2005) (M3) models as well as the original method (M1). It was also supported by ranking and grading systems, which show M5 to have scored the highest marks/rank.

Appendix 1

See Table 4.

Table 4 NSE (%) and RMSE resulted by applications of models in 152 watersheds

S. no.	WS ID	Area (ha)	Number of storms	NSE (%)					RMSE (mm)				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
1	9004	24	94	47.18	56.58	53.7	76.63	77.91	2.96	2.68	2.77	1.97	1.91
2	10001	7.8	32	25.34	18.21	23.35	38.12	38.17	6.5	6.8	6.58	5.92	5.91
3	13008	361.4	169	56.6	69.4	81.27	81.95	81.96	4.98	4.18	3.27	3.21	3.21
4	13009	73.7	202	7.37	18.59	37.59	37.07	36.95	8.16	7.65	6.69	3.72	6.73
5	13014	157.4	89	78.57	82.38	83.73	83.68	83.77	7.34	6.65	6.39	6.4	6.39
6	16010	40.5	325	8.09	28.29	38.88	41.67	41.63	3.06	2.7	2.5	2.44	2.44
7	16020	56.7	325	17.67	3.61	45.09	39.57	39.33	2.04	2.21	1.67	1.75	1.75
8	17001	11	586	75.25	76.74	75.88	78.75	78.77	6.23	6.04	6.15	5.77	5.77
9	17002	20.2	546	73.86	77.14	76.61	78.9	78.92	6.56	6.13	6.2	5.89	5.89
10	17003	5.1	137	68.5	64.05	65.97	74.82	75.19	5.82	6.22	6.05	5.21	5.17
11	17004	117.3	608	72.9	78	78.89	81.7	81.74	5.38	4.84	4.74	4.42	4.41
12	19004	1.2	109	37	30.59	45.46	56.3	56.29	6.5	6.82	6.05	5.42	5.42
13	19005	1.1	59	75.48	75.71	75.46	77.13	77.83	5.61	5.58	5.61	5.41	5.33
14	25001	62.32	672	71	73.77	71.98	75.13	75.11	8.2	7.8	7.91	7.59	7.59
15	26001	0.5	329	3.64	51.06	52.95	52.2	52.72	4.52	3.22	3.16	3.19	3.17
16	26002	0.5	273	49.09	55.39	54.01	54.48	54.61	2.66	2.49	2.53	2.52	2.51
17	26003	1.1	850	2.37	27.98	42.17	44.41	44.45	4.17	3.58	3.21	3.14	3.14
18	26004	1.1	338	9.89	48.76	51.9	54.14	54.62	3.25	2.45	2.38	2.32	2.31
19	26005	0.7	202	26.86	64.28	65.39	65.72	65.97	3.93	2.75	2.7	2.69	2.68
20	26006	1	220	30.41	53.91	60.82	65.46	65.49	3.05	2.48	2.29	2.15	2.15
21	26007	0.9	106	0.53	33.27	56.45	57.76	57.8	1.61	1.32	1.07	1.05	1.05
22	26010	0.6	879	49.84	58.31	61.41	63.26	63.25	4.79	4.37	4.2	4.1	4.1
23	26011	0.7	721	51.23	62.84	63.46	64.29	64.54	4.59	4.01	3.97	3.93	3.91
24	26012	0.7	584	64.13	69.1	69.76	70.35	70.44	4.33	4.02	3.98	3.94	3.93
25	26014	0.3	695	62.4	62.41	63.17	65.24	65.22	4.46	4.45	4.41	4.28	4.28
26	26015	0.5	706	56.02	66.24	64.95	66.74	67.24	3.61	3.16	3.22	3.14	3.11
27	26016	0.6	358	40.51	51.64	53.47	54.58	54.54	3.84	3.46	3.4	3.36	3.36
28	26018	0.5	106	72.22	70.75	76.84	78.78	78.57	4.63	4.75	4.23	4.05	4.07
29	26021	0.8	311	15.19	31.14	41.83	43.62	43.6	6.14	5.53	5.08	5	5
30	26023	3	504	55.9	79.96	79.5	80.39	81.16	2.75	1.86	1.88	1.84	1.8
31	26024	2.9	521	49.94	66.71	67.56	68.74	68.75	4.67	3.81	3.76	3.69	3.69
32	26025	3.1	622	52.62	65.73	68.35	69.97	70.16	3.16	2.69	2.58	2.52	2.51
33	26035	1040	65	24.42	51.48	70.55	67.95	67.94	6.18	4.95	3.86	4.02	4.03
34	26036	1853.5	138	40.18	52.78	53.6	53.82	53.88	6.59	5.86	5.81	5.79	5.79
35	26828	1.08	577	38.17	58.94	60.8	61.53	61.78	3.46	2.82	2.75	2.73	2.72
36	31001	133.55	724	59.38	78.62	79.75	86.11	86.9	2.26	1.64	1.6	1.27	1.28
37	31003	21.25	80	61.51	83.81	83.76	88.17	88.64	5.16	3.35	3.35	2.84	2.8
38	31004	69.2	114	66.37	84.13	85.44	88.7	89.12	5.08	3.49	3.34	2.94	2.89
39	34001	0.9	258	52.75	61.98	62.28	64.6	64.56	6.47	5.8	5.78	5.6	5.6
40	34002	2	247	62.4	62.96	62.47	65.86	65.8	6.51	6.46	6.5	6.2	6.21
41	34006	0.7	275	46.89	57.07	57.68	60.8	60.81	7.13	6.41	6.37	6.13	6.13
42	34007	0.8	262	60.97	64.44	62.19	66.9	66.89	6.55	6.25	6.44	6.03	6.03
43	34008	1.9	231	39.63	51.43	51.18	54.8	54.83	7.1	6.37	6.39	6.14	6.14
44	34013	0.8	52	63.14	46.03	51.64	61.48	61.46	4.53	5.48	5.19	4.63	4.63
45	35001	13.5	158	71.99	81.09	79.83	81.7	81.78	7.8	6.41	6.62	6.31	6.29
46	35002	1.3	151	14.72	68.07	74.45	74.95	75.1	7.9	4.83	4.32	4.28	4.27
47	35003	1.3	107	74.43	82.12	80.15	83.22	83.34	7.82	6.54	6.89	6.33	6.31

Table 4 continued

S. no.	WS ID	Area (ha)	Number of storms	NSE (%)					RMSE (mm)				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
48	35004	2.3	26	53.34	24.09	10	34.16	30.33	3.85	4.91	5.35	4.57	4.71
49	35005	2.1	128	16.34	59.7	63.1	65.5	65.54	7.16	4.97	4.75	4.6	4.59
50	35006	1	31	4.49	3.83	11.58	16.38	16.46	6.39	6.41	6.15	5.98	5.97
51	35008	3.7	129	66.28	76.38	73.44	80.28	80.27	5.09	6.53	4.51	3.89	3.89
52	35009	5.4	120	53.14	77.78	77.09	81.12	81.11	6.3	4.34	4.41	4	4
53	35010	6.4	113	67.01	75.57	72.87	81.02	81.06	5.19	4.47	4.71	3.94	3.94
54	35011	38.4	99	8.76	19.32	40.7	46.29	46.25	4.17	3.93	3.36	3.2	3.2
55	37001	6.8	195	59.63	59.75	58.84	59.87	59.81	10.5	10.49	10.61	10.47	10.48
56	37002	37.2	388	59.41	59.78	57.7	62.4	62.46	9	8.96	9.19	8.66	8.66
57	42002	234.3	195	60.2	69.73	74.52	75.5	75.52	10.32	9	8.26	8.1	8.09
58	42003	449.2	487	57.86	63.01	62.92	67.71	67.63	10.53	9.86	9.87	9.21	9.22
59	42004	1772.5	125	37.33	48.89	56.07	57.74	57.51	13.64	12.32	11.42	11.2	11.24
60	42006	70.4	819	68.51	70.21	67.3	74.29	74.16	8.11	7.89	8.27	7.33	7.35
61	42007	52.6	148	45.48	54.22	56.46	59.25	59.3	11.66	10.68	10.42	10.08	10.07
62	42008	17.1	162	53.64	58.76	57.13	62.02	62.01	11.84	11.17	11.38	10.72	10.72
63	42010	8	224	66.55	72.29	74.38	74.88	74.97	9.85	8.97	8.62	8.54	8.52
64	42011	125	287	52.27	64.59	67.52	70.08	70.07	8.03	6.92	6.62	6.36	6.36
65	42012	53.4	277	64.14	71.87	71.71	73.35	73.37	8.8	7.79	7.81	7.59	7.58
66	42013	32.3	36	69.93	82.15	80.61	83.49	83.45	6.72	5.18	5.4	4.98	4.99
67	42014	6.6	273	55.86	66.21	68.33	70.53	70.48	7.79	6.82	6.6	6.37	6.37
68	42015	16.2	128	59.57	69.96	68.7	72.72	72.65	9.46	8.15	8.32	7.77	7.78
69	42016	8.4	293	61.35	69.08	69.07	74.32	74.3	7.37	6.59	6.59	6.01	6.01
70	42017	7.5	237	69.05	72.66	71.35	76.65	76.69	9.14	8.59	8.79	7.94	7.93
71	42023	1.31	80	71.92	74.64	72.5	77.54	77.69	12.76	12.12	12.62	11.41	11.37
72	42024	1.2	252	58.6	60.52	60.15	62.2	62.27	11.23	10.96	11.01	10.73	10.72
73	42028	1.2	263	59.64	65.97	66.03	66.98	67	10.32	9.48	9.47	9.33	9.33
74	42035	1.3	163	49.12	55.84	59.23	59.78	60.41	13.16	12.26	11.78	11.7	11.61
75	42036	1.3	197	49.62	54.75	58.51	60.58	61.09	11.54	10.93	10.47	10.2	10.14
76	42037	4.6	181	70.37	75.04	72.82	75.82	76.17	7.81	7.17	7.48	7.06	7.01
77	42038	2.3	158	63.91	64.94	63.29	69.87	70.04	10.77	10.62	10.86	9.84	9.81
78	42039	4	237	52.79	66.05	63.6	68.45	68.54	9.72	8.24	8.53	7.94	7.93
79	42040	4.6	226	44.11	61.36	59.38	63.11	63.25	11.01	9.16	9.39	8.95	8.93
80	44001	194.7	407	66.8	73.33	72.78	76.68	76.72	5.07	4.54	4.59	4.25	4.24
81	44002	166.3	482	74.26	79.64	77.44	83.73	84	4.23	3.76	3.96	3.36	3.33
82	44003	844.2	235	72.92	72.31	74.96	81.54	81.46	5.26	5.32	5.06	4.34	4.35
83	44004	1412.4	349	71.19	76.59	77.14	81.06	81.01	4.66	4.2	4.15	3.78	3.78
84	44005	1.5	135	47.11	61.61	55.57	60.87	61.72	4.49	3.82	4.12	3.86	3.82
85	44006	1.4	149	52.41	52.42	45.11	57.22	58.14	5.88	5.88	6.32	5.58	5.52
86	44007	1.5	524	74.19	75.68	72.94	78.22	78.31	4.92	4.78	5.04	4.52	4.51
87	44008	1.5	515	75.32	79.23	78.11	80.18	80.3	5.32	4.88	5.01	4.77	4.75
88	44009	1.6	537	75.82	78.98	77.55	81.41	81.73	4.33	4.04	4.18	3.8	3.77
89	44010	1.6	537	59.72	66.08	64.16	70.22	70.31	4.92	4.51	4.64	4.23	4.22
90	44011	1.7	486	57.14	62.96	62.32	67.97	68	5.01	4.66	4.7	4.33	4.33
91	44012	1.59	355	64.6	71.13	67.96	73.05	73.73	4.61	4.16	4.38	4.02	3.97
92	44013	1.5	248	55.91	66.19	69.31	72.7	72.73	4.62	4.05	3.86	3.64	3.64
93	44014	1.6	262	40.24	51.17	57.66	61.27	61.39	5.44	4.92	4.58	4.38	4.37
94	44015	1.6	295	68.78	73.83	72.33	76.1	76.12	4.93	4.51	4.64	4.31	4.31

Table 4 continued

S. no.	WS ID	Area (ha)	Number of storms	NSE (%)					RMSE (mm)				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
95	44016	1.5	309	54.91	62.62	65.28	68.21	68.28	5.89	5.36	5.17	4.95	4.94
96	44017	1.4	276	69.44	79.17	78.45	82.48	82.54	4.84	4	4.06	3.66	3.66
97	44018	1.4	274	71.77	78.11	76.55	81.96	82.06	4.92	4.34	4.49	3.94	3.93
98	44019	1.5	303	61.97	70.65	72.75	75.63	75.73	5.11	4.49	4.32	4.09	4.08
99	44020	1.4	281	75.95	79.06	77.07	81.09	81.15	4.48	4.18	4.37	3.97	3.97
100	44021	1.6	321	72.13	77.41	75.73	79.75	79.86	4.68	4.21	4.37	3.99	3.98
101	44022	1.5	320	50.78	70.28	70.29	71.53	71.45	5.19	4.03	4.03	3.94	3.95
102	44023	1.7	258	76.77	79.64	67.91	81.26	81.43	4.52	4.24	5.32	4.06	4.04
103	44024	1.6	264	41.28	45.56	56.91	62.79	62.93	5.52	5.31	4.73	4.39	4.39
104	44025	1.6	238	63.94	66.84	65.96	70.96	71.05	5.36	5.14	5.21	4.81	4.8
105	44026	1.5	241	65.78	77.24	75.56	78.65	78.83	5.44	4.43	4.59	4.29	4.28
106	44028	1.8	269	69.51	78.07	75.64	80.14	80.34	5.38	4.56	4.81	4.34	4.32
107	44029	0.9	16	65.61	86.78	83.94	90.51	91.17	6.05	8.62	4.13	3.18	3.07
108	61002	18.4	386	18.35	53.24	54.62	56.26	56.44	5.77	4.36	4.3	4.22	4.21
109	61003	157.8	463	43.06	49.7	46.6	57.62	58.36	3.38	3.17	3.27	2.91	2.89
110	61004	25.5	342	11.11	24.01	38.92	43.69	43.58	4.29	3.97	3.55	3.41	3.42
111	62001	809.37	236	70.59	78.09	78.44	83.58	83.6	4.4	3.8	3.76	3.29	3.28
112	62002	404.7	136	77.42	77.5	74.49	81.11	81.16	8.34	8.32	8.86	7.63	7.62
113	62003	2237.9	28	44.84	56.41	53.48	62.08	62.23	9.08	8.08	8.34	7.53	7.52
114	62004	9226.9	22	39.74	63.48	61.02	63.41	63.65	7.34	5.71	5.9	5.72	5.7
115	62005	12,990.5	92	53.52	54.65	59.1	75.72	75.64	9.43	9.31	8.84	6.81	6.83
116	62008	437.1	19	39.32	78.31	87.14	84.34	85.99	7.8	4.66	3.59	3.96	3.75
117	62010	8093.7	104	70.26	73.07	74.32	78.18	78.07	9.93	9.45	9.23	8.51	8.53
118	62012	3055.4	35	36.75	44.55	56.91	59.67	59.66	10.13	9.49	8.36	8.09	8.09
119	62014	0.6	134	73.08	74.34	40.1	78.35	78.57	7.33	7.16	10.94	6.58	6.54
120	62017	1295	26	51.99	56.67	57.15	57.49	59.39	8.66	8.22	8.18	8.15	7.96
121	62018	441.1	59	43.55	61.66	66.31	66.48	66.48	8.08	6.65	6.24	6.22	6.22
122	67003	836.5	125	11.69	27.5	60.51	57.91	57.61	4.81	4.36	0.16	3.32	3.33
123	67005	11,116.4	247	13.54	4.8	45.08	49.52	48.63	3.57	3.74	2.84	2.73	2.75
124	67009	46.9	58	20.84	59.34	70.97	70.71	70.42	6.52	4.67	3.95	3.96	3.98
125	69030	7.2	161	55.15	73.98	74.09	74.93	75.22	4.62	3.52	3.51	3.45	3.43
126	69032	17.9	198	73.34	71.66	67.24	73.44	73.44	4.15	4.28	4.6	4.14	4.14
127	69033	12.1	156	67.95	66.47	61.33	68.52	68.41	4.84	4.95	5.32	4.8	4.81
128	69034	5.2	94	43.87	43.22	43.28	48.71	48.71	5.62	5.65	5.64	5.37	5.37
129	69035	5.26	116	46.74	48.45	47.72	52.15	52.15	5.51	5.42	5.46	5.22	5.22
130	69036	10.7	113	49.58	57.19	53.45	59.65	59.39	5.15	4.75	4.95	4.61	4.62
131	69037	11	123	18.89	46.4	43.23	48.49	48.59	4.38	3.56	3.66	3.49	3.48
132	69042	9.6	85	57.64	35.68	36.21	54.63	55.45	4.85	5.98	5.95	5.02	4.97
133	69043	11	127	64.54	46.84	40.14	58.94	60.1	3.93	4.81	5.11	4.23	4.17
134	69044	7.8	225	73.38	77.62	77.62	82.68	82.64	4.45	4.08	4.08	3.59	3.59
135	69045	11.1	250	74.27	76.34	73.26	79.74	79.71	3.46	3.32	3.53	3.07	3.07
136	70002	717.9	8	65.09	65.09	69.73	92.4	88.81	0.92	0.92	0.86	0.43	0.52
137	70003	2182.1	9	62.23	54.11	43.08	92.71	93.17	3.3	3.64	4.05	1.45	1.4
138	70004	4365.4	12	67.51	70.27	62.39	92.23	92.09	3.77	3.6	4.05	1.84	1.86
139	70006	277.6	14	91.74	62.72	68.99	79.88	79.89	1.46	3.09	2.82	2.27	2.27
140	70007	4.1	25	85.49	87.55	88.3	89.54	89.64	8.1	7.5	7.27	6.87	6.84
141	70008	3.5	23	58.48	45.8	40.75	54.59	54.33	7.85	8.97	9.37	8.21	8.23

Table 4 continued

S. no.	WS ID	Area (ha)	Number of storms	NSE (%)					RMSE (mm)				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
142	70009	2.7	18	89.2	83.25	79.94	91.23	91.38	6.1	7.59	8.31	5.5	5.45
143	70010	1.8	9	81.66	89.27	96.04	96.48	96.48	3.9	2.98	1.81	1.71	1.71
144	70011	2.9	41	87.83	92.42	89.18	95.54	95.53	5.57	4.4	5.25	3.37	3.38
145	70012	2.8	15	87.52	90.69	88.18	93.11	93.45	4.67	4.03	4.54	3.47	3.38
146	71001	30.1	979	21.65	20.95	34.46	44.2	44.26	2.71	2.72	2.48	2.29	2.28
147	71005	157.43	375	4.17	73.84	72.43	74.98	71.89	2.3	1.2	1.23	1.17	1.24
148	74003	1566.94	284	32.82	47.64	51.21	57.26	57.29	3.21	4.82	4.65	4.35	4.35
149	74008	1665.28	349	5.33	55.32	66.42	70.72	70.71	5.54	3.81	3.3	3.08	3.08
150	74009	261.43	202	16.39	33.67	54.95	60	59.67	6.66	5.93	4.89	4.6	4.62
151	77003	2.8	248	64.84	75.56	76.49	77.08	77.29	2.99	2.5	2.45	2.42	2.41
152	77006	2.9	118	50.34	57.56	88.16	80.32	80.09	2.8	2.58	1.37	1.76	1.77

Appendix 2

See Table 5.

Table 5 PBIAS and R^2 resulted by applications of models in 152 watersheds

S. no.	WS ID	Area (ha)	Number of storms	PBIAS					R2				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
1	9004	24	94	71.73	43.88	0.95	−0.39	7.53	0.6752	0.6618	0.5372	0.7664	0.7815
2	10001	7.8	32	33.24	19.92	1.59	−1.24	1.4	0.4239	0.2769	0.2341	0.3812	0.382
3	13008	361.4	169	66.07	67.27	6.85	13.6	12.4	0.7254	0.8244	0.8141	0.8247	0.8246
4	13009	73.7	202	40.75	43.43	0.81	18.42	16.4	0.3122	0.3627	0.3761	0.3925	0.3913
5	13014	157.4	89	21.13	24.67	7.68	5.85	7.55	0.8016	0.8413	0.8388	0.838	0.8392
6	16010	40.5	325	86.36	37.21	−7.45	−7.16	−6.25	0.1606	0.3324	0.3894	0.4172	0.4175
7	16020	56.7	325	86.37	93.42	−24.02	31.86	31.34	0.2722	0.1463	0.4598	0.4085	0.4058
8	17001	11	586	10.51	13.87	0.46	−0.44	−1.3	0.7684	0.7743	0.7588	0.7878	0.7878
9	17002	20.2	546	9.95	13.82	0.14	−0.11	−0.7	0.7562	0.7782	0.7662	0.7891	0.7892
10	17003	5.1	137	23.15	25.42	−3.74	−3.47	−2.52	0.7084	0.6769	0.66	0.749	0.7522
11	17004	117.3	608	18.81	21.74	0.58	0.1	0.61	0.7658	0.7985	0.789	0.8171	0.8175
12	19004	1.2	109	39.86	45.93	4.44	−1.16	−0.96	0.4635	0.4498	0.4557	0.564	0.5638
13	19005	1.1	59	9.39	29.47	21.83	6.46	3.09	0.7565	0.7739	0.7637	0.7729	0.7786
14	25001	62.32	672	8.5	10.92	2.79	1.33	0.88	0.7218	0.7422	0.7307	0.752	0.7515
15	26001	0.5	329	62.46	30.04	23.69	11.41	6.13	0.1739	0.5242	0.537	0.5237	0.5298
16	26002	0.5	273	28.07	31.36	33.73	7.72	−2.91	0.5035	0.5623	0.5498	0.5454	0.5507
17	26003	1.1	850	67.98	54.45	−0.31	4	2.81	0.2353	0.3844	0.4218	0.4449	0.4448
18	26004	1.1	338	76.47	43.17	16.12	10.76	11.5	0.2326	0.5348	0.5242	0.5437	0.5492
19	26005	0.7	202	56.16	35.33	13.09	8.46	8.15	0.4142	0.6732	0.6571	0.6585	0.6611
20	26006	1	220	29.37	33.77	−0.91	−1.18	−0.89	0.4281	0.5978	0.6081	0.6548	0.655
21	26007	0.9	106	86.9	63.39	7.58	5.73	4.91	0.196	0.4675	0.5658	0.5787	0.5788
22	26010	0.6	879	22.64	23.75	0.55	−0.89	−0.75	0.5875	0.6227	0.6142	0.6327	0.6325
23	26011	0.7	721	17.76	24.73	63.22	5.75	7.68	0.5505	0.6407	0.6363	0.6435	0.6462
24	26012	0.7	584	17.72	21.56	7.81	3.95	−5.46	0.6671	0.7015	0.6986	0.7038	0.7049
25	26014	0.3	695	21.68	24.76	0.71	−1.08	−0.28	0.6555	0.6492	0.6318	0.6524	0.6522
26	26015	0.5	706	25.31	33.52	14.92	10.97	10.6	0.5949	0.6761	0.652	0.6687	0.6738

Table 5 continued

S. no.	WS ID	Area (ha)	Number of storms	PBIAS					R2				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
27	26016	0.6	358	43.25	37.13	1.12	−0.03	0.53	0.4922	0.5519	0.5348	0.5458	0.5455
28	26018	0.5	106	38.64	32.42	−3.57	7.78	9.83	0.8167	0.7874	0.7689	0.791	0.789
29	26021	0.8	311	49.17	42.99	40.74	7.43	6.05	0.3089	0.4059	0.4184	0.4376	0.4374
30	26023	3	504	24.92	34.67	28.75	16.8	19.34	0.6317	0.8116	0.8022	0.8064	0.8149
31	26024	2.9	521	19.31	19.74	6.1	8.13	5.45	0.5593	0.6753	0.6761	0.6883	0.6881
32	26025	3.1	622	41.1	46.82	10.45	9.47	8.4	0.59	0.6878	0.6847	0.7008	0.7024
33	26035	1040	65	36.44	34.4	0.56	17.33	17.39	0.4886	0.6645	0.7055	0.7014	0.7016
34	26036	1853.5	138	12.21	15.62	4.84	3.15	4.15	0.4553	0.542	0.5368	0.5386	0.5395
35	26828	1.08	577	49.93	49.46	16.73	13.43	13.73	0.459	0.6202	0.6112	0.6174	0.62
36	31001	133.55	724	19	47.52	20.28	21.54	19.8	0.6243	0.795	0.7987	0.8625	0.8701
37	31003	21.25	80	6.93	34.86	15.14	6.84	7.93	0.6638	0.8577	0.841	0.8823	0.8874
38	31004	69.2	114	8.31	34.32	10.17	5.44	5.51	0.6971	0.8603	0.8557	0.8874	0.8916
39	34001	0.9	258	10.62	14.66	−1.3	−2.7	−2.44	0.5881	0.6413	0.6228	0.6464	0.6459
40	34002	2	247	9.73	13.48	−2.51	−4.04	−4.1	0.6638	0.6497	0.625	0.6595	0.6595
41	34006	0.7	275	12.25	16.8	−0.53	−1.49	−1.21	0.5341	0.5898	0.5769	0.6081	0.6081
42	34007	0.8	262	6.94	12.57	−0.6	−1.44	−1.38	0.6458	0.6556	0.6219	0.6691	0.669
43	34008	1.9	231	12.28	17.03	−0.34	−1.84	−1.1	0.4598	0.5315	0.5118	0.5484	0.5483
44	34013	0.8	52	23.69	26.24	−2.3	−0.13	−0.52	0.6793	0.5464	0.5169	0.6147	0.615
45	35001	13.5	158	0.63	6.07	2.27	0.35	0.65	0.7588	0.8137	0.7985	0.817	0.8179
46	35002	1.3	151	15.59	19.72	0.21	4.94	2.74	0.4768	0.7258	0.7445	0.7509	0.7513
47	35003	1.3	107	−2.11	1.82	3.23	1.06	1.44	0.7647	0.8215	0.802	0.8323	0.8335
48	35004	2.3	26	45.94	34.22	11.32	−0.56	2.95	0.6031	0.2787	0.1088	0.3643	0.3654
49	35005	2.1	128	23.93	21.1	0.92	0.38	−0.01	0.3831	0.6262	0.631	0.655	0.6554
50	35006	1	31	64.49	43.72	0.42	8.21	5.74	0.1759	0.1215	0.1162	0.1663	0.1667
51	35008	3.7	129	29.25	4.26	−0.72	−2.43	−3.27	0.7326	0.7751	0.7344	0.803	0.8029
52	35009	5.4	120	24.32	11.22	−0.42	−1.95	−2.85	0.6513	0.7911	0.7709	0.8113	0.8113
53	35010	6.4	113	27.05	13.6	−0.12	−1.47	−3.07	0.7271	0.7662	0.7288	0.8107	0.811
54	35011	38.4	99	68.89	53.14	−6.3	−1.22	−2.64	0.2407	0.3169	0.4084	0.463	0.4628
55	37001	6.8	195	7.91	10.47	1.1	0.89	0.52	0.6022	0.6013	0.5885	0.5988	0.5981
56	37002	37.2	388	12.89	14.13	4.59	−1.09	1.63	0.6047	0.6022	0.5774	0.6247	0.6249
57	42002	234.3	195	6.74	13.35	−2.22	4.18	3.61	0.6637	0.7396	0.7456	0.756	0.7561
58	42003	449.2	487	5.81	12.93	−2.38	−3.27	−3.1	0.6131	0.6508	0.6295	0.6776	0.6768
59	42004	1772.5	125	8.31	15.04	−0.45	4.65	8.24	0.4696	0.5576	0.5607	0.5818	0.5811
60	42006	70.4	819	7.67	11.15	0.49	−3.25	−2.4	0.6995	0.7072	0.673	0.7433	0.7419
61	42007	52.6	148	5.29	13.58	0.87	0.18	0.03	0.5035	0.575	0.5674	0.5925	0.593
62	42008	17.1	162	1.1	8.61	0.12	−2.09	−2.95	0.5546	0.5972	0.5713	0.6207	0.6205
63	42010	8	224	65.93	11.6	−1.09	7.06	6.04	0.7035	0.7432	0.744	0.7523	0.7522
64	42011	125	287	11.12	19.96	−1.09	−1.72	−2.13	0.5859	0.6743	0.6752	0.7011	0.7009
65	42012	53.4	277	−0.1	9.03	0.37	−1.08	−0.91	0.6601	0.7247	0.7172	0.7336	0.7338
66	42013	32.3	36	−4.47	1.62	−1.05	−2.22	−2.37	0.7153	0.8235	0.8063	0.8352	0.8348
67	42014	6.6	273	3.59	13.96	−3.07	−3.12	−4.48	0.592	0.6794	0.6835	0.7055	0.7055
68	42015	16.2	128	−1.4	5.42	−0.24	−3.74	−3.66	0.6287	0.7038	0.687	0.7296	0.7285
69	42016	8.4	293	6.01	13.68	−1.62	−4.41	−3.95	0.6425	0.706	0.6908	0.7439	0.7435
70	42017	7.5	237	1.82	7.34	−0.43	−3.48	−4.37	0.7036	0.7334	0.7135	0.7672	0.7677
71	42023	1.31	80	−2.14	3.15	0.79	−1.56	−0.61	0.7204	0.7472	0.7251	0.7763	0.7778
72	42024	1.2	252	5.4	8.83	0.71	0.15	−0.06	0.5985	0.6136	0.6016	0.622	0.6227
73	42028	1.2	263	−0.77	5.86	−0.14	−1.08	−1.23	0.61	0.6642	0.6603	0.6699	0.6701

Table 5 continued

S. no.	WS ID	Area (ha)	Number of storms	PBIAS					R2				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
74	42035	1.3	163	7.39	14.12	− 1.08	10.61	4.79	0.5376	0.5927	0.5924	0.6039	0.6052
75	42036	1.3	197	8.78	14.89	− 3.41	6.85	0.62	0.5533	0.5902	0.5859	0.6085	0.6112
76	42037	4.6	181	− 0.2	8.74	6.69	3.06	2.2	0.7138	0.7526	0.7293	0.7585	0.7618
77	42038	2.3	158	3.15	11.57	0.98	− 1.04	− 0.49	0.6513	0.6625	0.633	0.6992	0.7007
78	42039	4	237	− 4.54	8.56	1.95	1.38	− 3.53	0.5504	0.6633	0.6361	0.6846	0.6859
79	42040	4.6	226	− 9.88	5.31	7.05	3.94	− 3.25	0.469	0.6143	0.5949	0.6315	0.6329
80	44001	194.7	407	11.21	16.35	1.33	0.7	0.31	0.7	0.7506	0.7278	0.7668	0.7673
81	44002	166.3	482	8.16	16.15	3.62	3.24	1.94	0.7588	0.8048	0.7746	0.8375	0.8401
82	44003	844.2	235	16.21	22.66	1.42	0.04	0.23	0.7767	0.7852	0.7497	0.8154	0.8147
83	44004	1412.4	349	16.83	22.15	1.91	3.09	1.51	0.7388	0.789	0.7715	0.8108	0.8102
84	44005	1.5	135	8.43	17.32	33.03	16.42	16.32	0.4982	0.6202	0.5709	0.6216	0.6211
85	44006	1.4	149	− 4.37	8.43	16.54	− 8.61	0.36	0.5244	0.5264	0.4551	0.5733	0.5878
86	44007	1.5	524	8.04	10.77	2.9	1.64	2.05	0.7503	0.7611	0.7296	0.7823	0.7833
87	44008	1.5	515	8.18	12.46	3	3.11	1.89	0.7603	0.7967	0.7816	0.8022	0.8032
88	44009	1.6	537	13.06	18.61	5.89	3.27	4.81	0.7642	0.7967	0.7765	0.8146	0.8181
89	44010	1.6	537	15.05	16.7	2.04	0.15	0.53	0.6367	0.6772	0.6417	0.7022	0.7031
90	44011	1.7	486	17.89	20.34	0.84	− 1.77	− 1.75	0.6184	0.6514	0.6232	0.6798	0.6801
91	44012	1.59	355	4.16	15	12.72	11.2	9.73	0.657	0.715	0.6822	0.7325	0.739
92	44013	1.5	248	20.47	25.72	0.78	0.02	0.24	0.6185	0.7026	0.6931	0.7271	0.7273
93	44014	1.6	262	23.97	30.47	− 1.24	− 2.02	− 1.97	0.5083	0.5778	0.5765	0.6129	0.6141
94	44015	1.6	295	9.52	14.27	0.65	− 0.26	− 0.62	0.7171	0.752	0.7233	0.7611	0.7613
95	44016	1.5	309	16.43	20.26	− 4.18	− 4.1	− 4.37	0.621	0.6687	0.6533	0.6827	0.6833
96	44017	1.4	276	10.81	17.36	1.5	0.84	0.92	0.7489	0.8088	0.7845	0.8249	0.8254
97	44018	1.4	274	10.44	15.6	1.32	0.22	0.5	0.7588	0.7959	0.7656	0.8196	0.8206
98	44019	1.5	303	12.25	18.48	− 2.87	− 2.37	− 2.37	0.6975	0.7424	0.7278	0.7565	0.7575
99	44020	1.4	281	7.98	12.01	2.13	2.3	− 0.81	0.7715	0.7967	0.7709	0.8111	0.8116
100	44021	1.6	321	11.34	15.45	2.33	0.87	0.18	0.7414	0.7829	0.7576	0.7978	0.7987
101	44022	1.5	320	7.57	11.23	− 1.14	0.09	− 1.43	0.5895	0.71	0.7029	0.7154	0.7146
102	44023	1.7	258	9.28	11.68	− 35.37	2.96	3.28	0.7818	0.8022	0.7653	0.8129	0.8147
103	44024	1.6	264	29.34	29.21	− 6.35	3.29	2.17	0.5592	0.562	0.5715	0.6283	0.6295
104	44025	1.6	238	15.91	18.51	2.03	1.32	1.92	0.6747	0.6833	0.6597	0.7096	0.7106
105	44026	1.5	241	0.16	10.53	5.1	1.33	1.67	0.6914	0.7773	0.7562	0.7865	0.7884
106	44028	1.8	269	0.95	9.84	5.36	3.34	2.74	0.7176	0.7841	0.757	0.8016	0.8035
107	44029	0.9	16	38.04	53.14	28.82	0.28	− 2.95	0.7384	0.8688	0.8628	0.9051	0.9122
108	61002	18.4	386	37.29	32.33	11.28	8.63	7.27	0.38	0.559	0.5482	0.5638	0.5654
109	61003	157.8	463	40.1	41.51	9.18	14.59	19.62	0.537	0.5547	0.4687	0.5835	0.5952
110	61004	25.5	342	48.66	46.41	3.61	7.76	9.75	0.3788	0.4105	0.3906	0.4422	0.4416
111	62001	809.37	236	19.19	25.23	− 1.5	0.68	− 0.18	0.7565	0.7982	0.7845	0.8358	0.836
112	62002	404.7	136	5.83	7.71	2.21	− 2.74	− 0.17	0.788	0.7794	0.7452	0.812	0.8118
113	62003	2237.9	28	4.05	5.83	0.91	4.29	− 25	0.4765	0.5734	0.5351	0.6229	0.6239
114	62004	9226.9	22	− 2.25	4.53	2.54	2.69	− 1.49	0.4214	0.6368	0.6111	0.635	0.6369
115	62005	12,990.5	92	29.69	20.7	− 1.42	− 6.64	− 5.2	0.6951	0.6317	0.5911	0.7634	0.7605
116	62008	437.1	19	− 10.77	− 1.24	18.21	10.6	11.03	0.415	0.7937	0.8825	0.8499	0.8663
117	62010	8093.7	104	11.53	12.3	− 0.27	− 2.2	− 1.92	0.7431	0.7624	0.7431	0.7826	0.7813
118	62012	3055.4	35	22.74	23.24	− 2.8	1.18	3.35	0.4737	0.5559	0.5698	0.5968	0.6002
119	62014	0.6	134	4.04	6.19	− 56.15	− 0.67	0.97	0.7425	0.7493	0.6921	0.7837	0.7858
120	62017	1295	26	− 6.07	3.78	11.84	− 2.71	2.09	0.5222	0.5693	0.5779	0.5755	0.5943

Table 5 continued

S. no.	WS ID	Area (ha)	Number of storms	PBIAS					R2				
				M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
121	62018	441.1	59	13.89	16.08	−1.17	−1.06	−0.84	0.5071	0.6429	0.6631	0.6648	0.6648
122	67003	836.5	125	59.33	55.6	0.29	17.83	21.98	0.5539	0.6456	0.6101	0.6241	0.6243
123	67005	11,116.4	247	76.9	77.89	0.53	18.86	22.69	0.4067	0.3558	0.451	0.5099	0.509
124	67009	46.9	58	49.93	47.18	7.63	3.38	0.76	0.4444	0.7399	0.713	0.7103	0.7087
125	69030	7.2	161	14.33	21.67	10.89	5.36	4.78	0.5776	0.751	0.7427	0.7498	0.7526
126	69032	17.9	198	4.04	6.65	5.49	4.53	2.74	0.7436	0.719	0.6739	0.7353	0.7348
127	69033	12.1	156	1.96	5.3	4.93	5.32	2.87	0.6879	0.6661	0.6147	0.6865	0.6847
128	69034	5.2	94	18.04	21.79	−0.01	0.4	0.07	0.5041	0.4752	0.4329	0.487	0.4871
129	69035	5.26	116	15.32	18.3	−0.64	−1.39	0.1	0.5137	0.5089	0.4772	0.5215	0.5216
130	69036	10.7	113	8.87	9.65	−0.3	1.35	−0.81	0.5448	0.5821	0.5348	0.5967	0.594
131	69037	11	123	29.36	16.75	6.03	1.95	−3.93	0.2829	0.4762	0.4331	0.4851	0.4871
132	69042	9.6	85	26.62	29.21	−2.01	4.86	7.16	0.6331	0.4133	0.3622	0.5477	0.559
133	69043	11	127	19.13	22.36	4.65	8.27	5.36	0.6658	0.4818	0.4018	0.5907	0.6031
134	69044	7.8	225	16.05	17.04	0.3	−1.23	−1.22	0.7975	0.8062	0.7763	0.8268	0.8265
135	69045	11.1	250	18.69	19.05	1.89	2.32	1.57	0.7864	0.7789	0.5949	0.7976	0.7972
136	70002	717.9	8	48.19	48.19	10.34	10.34	−5.12	0.8014	0.8014	0.7031	0.9427	0.9413
137	70003	2182.1	9	49.6	35.25	9.4	6.81	7.69	0.7755	0.6194	0.4386	0.9338	0.9397
138	70004	4365.4	12	46.05	19.19	6.09	2.57	0.41	0.8319	0.7435	0.6267	0.923	0.9029
139	70006	277.6	14	9.4	26.03	−10.25	−4.1	−2.8	0.9383	0.6961	0.6938	0.7993	0.7992
140	70007	4.1	25	16.48	−7.64	9.47	3.02	−5.71	0.8701	0.8913	0.8863	0.8982	0.897
141	70008	3.5	23	−3.26	8.78	2.2	4.12	3.1	0.5869	0.4659	0.4079	0.5473	0.5449
142	70009	2.7	18	18.26	4.91	40.54	−7.1	−6.88	0.9244	0.8356	0.838	0.9148	0.916
143	70010	1.8	9	15.67	16.93	23.54	19.26	19.26	0.8236	0.9012	0.9771	0.9762	0.9762
144	70011	2.9	41	28.95	1.24	12.83	−2.93	−3.98	0.9221	0.925	0.8939	0.9556	0.9557
145	70012	2.8	15	34.37	14.19	14.44	2.42	2.07	0.9075	0.9136	0.8873	0.9312	0.9345
146	71001	30.1	979	70.49	45.6	−25.53	−27.89	−23.19	0.2603	0.277	0.3499	0.4487	0.4472
147	71005	157.43	375	85	42.7	60.98	42.8	1.8	0.919	0.7503	0.7475	0.7612	0.7337
148	74003	1566.94	284	16.69	28.32	−2.94	2.02	1.03	0.4242	0.5199	0.5124	0.5727	0.573
149	74008	1665.28	349	81.24	38.44	−3.38	−2.35	−2.51	0.2331	0.6209	0.6645	0.7074	0.7073
150	74009	261.43	202	47.56	44.79	−4.85	1.4	4.74	0.4326	0.5045	0.5508	0.6002	0.6
151	77003	2.8	248	51.9	36.08	22.58	16.72	17.37	0.6723	0.7661	0.7684	0.7727	0.775
152	77006	2.9	118	75.02	67.59	7.37	42.51	43.18	0.604	0.6675	0.8828	0.8367	0.8355

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