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ORIGINAL ARTICLE

Simplified sediment yield index incorporating parameter stream length

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Abstract
Sediment-Runoff process is highly variable and nonlinear in nature. In the present study an attempt has been made to develop a relationship between watershed stream length and Sediment Yield Index (SYI) and test it on Narmada watersheds, Madhya Pradesh, India. Area (A), Curve Number (CN) and stream length (SL) were utilized as input for model development. The three models (A model, CN model and simplified All India Soil and Land Use Survey (AISLUS) model including parameter SL) performed differently, with the coefficient of R^2 equal to 0.01, 0.02 and 0.71 (Shakkar watershed), 0.11, 0.23 and 0.91 (Bamhani watershed), 0.06, 0.001 and 0.80 (Manot watershed) and 0.40, 0.05 and 0.66 (Mohgaon watershed), respectively. The logarithmic simplified AISLUS model incorporating parameter SL resulted with the coefficient of R^2 as 0.76 (Shakkar watershed), 0.93 (Bamhani watershed), 0.84 (Manot watershed) and 0.66 (Mohgaon watershed). Therefore, the logarithm simplified AISLUS model was chosen as the best regression model for this study. It is observed that the simplified AISLUS model (logarithm form) incorporating parameter SL had a satisfactory efficiency as 76.35% (Shakkar watershed), 66.05% (Mohgaon watershed), 93.36% (Bamhani watershed), and 83.83% (Manot watershed) by Nash efficiency scale. The resulting higher Nash efficiency values support the versatility of the derived relationship and invoke assessment of SYI from the watershed stream length value. The prediction of SYI is important when adopting a suitable soil conservation measure in the watershed for minimizing soil erosion.

Keywords Sediment yield · Runoff · Narmada river · Modeling · Stream length

Introduction

Accurate estimation of the amount of runoff and sediment is important for management of the water resources (Gajbhiye et al. 2014). Surface runoff and sediment yield are two major hydrological response caused by precipitation (Gajbhiye et al. 2014). Water is the major agent responsible for soil erosion may be defined as detachment and then movement of soil particles from one place to another place. At many locations, wind and glacial runoff may also be the agent of soil erosion. To control soil erosion in any area by various soil and water management measures the developmental unit

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should be a hydrological unit i.e., watershed (Gajbhiye et al. 2013a b,c). Due to continuous erosion in the catchment of reservoir soil gets deposited in that reservoir which reduces the life of that reservoir. The soil erosion from the watershed and ultimate sediment coming to the outlet i.e., sediment yield are important factor which should be assessed in any land and fluvial region to manage the sustainability of watershed (Sharma et al. 2014). Due to unavailability of sediment yield data of watershed, prediction models are used to estimate the sediment yield or soil loss (Diodato and Grauso 2009).

One of the principal bases for prioritizing watersheds vulnerable to soil disintegration is the sediment yield from a catchment (Brahim et al. 2020). This includes continuous sediment sample observation at the outlet of the watershed. Continuous soil loss measurements are not, however, available for most watersheds, especially in developing countries, such as India (Meshram et al. 2020). As measurements of soil loss are costly, watersheds can be prioritized and measurements can be carried out to establish prediction models that can be applied to un-gauged watersheds.

In various part of the world different sediment yield prediction models are being used which are physical, conceptual and empirical in nature (Diodato and Grauso 2009). Moreover, conservation planning for erosion control mostly uses empirical models to estimate average annual soil loss. However, analysis of empirical models shows that large number of sediment yield models needs input parameters on spatial basis viz. drainage density, land use/land cover, topography and soil and, also runoff (Rao and Mahabaleswara 1990). To estimate sediment yield at actual and potential rate a sediment yield predictive equation (SYPE) developed by Flaxman (1971). Geomorphological parameters based models of empirical nature been developed to quantify sediment yield and their by prioritization of watersheds (Sarma and Saikia 2012; Patel et al. 2012). Although methods are in vogue depending on the need and possibility of available information so, in that situation a method developed by All India Soil and Land Use Survey (AISLUS 1977) i.e., sediment yield index (SYI) and another method proposed by Wischmeier and Smith (1978) i.e., Universal Soil Loss Equation (USLE) are very often used.

SYI method gives relative criteria of vulnerability to erosion of watersheds in low, medium and high erosion and does not provide an absolute sediment yield (AISLUS 1991). It is widely used, mainly because it is easy to use and has less data requirement. In addition, it can be applied to the larger area like sub watersheds, and so on. Delmas et al. (2009) developed a large-scale sediment yield index for European river basins with four indicators of mass movement, hill slope erosion, deposits, and drainage density. Naqvi et al. (2015); Yesuf et al. (2015); Dutta (2016); Zuo et al. (2016); Meshram et al. (2018a,b, 2019); Dahmardeh Ghaleno et al. (2020) and others tried in laboratory, at field level and some modeling methods to know the sediment yield dynamics and soil erosion in different part of the world.

AISLUS proposed an empirical relationship between SYI and area and delivery ratio (AISLUS 1991). A different approach proposed an empirical relationship between delivery ratio and morphological characteristics. These models are popularly employed because of their simplicity and simply available hydrological database. The common constraints with the models as discussed above includes local influence of climate and geomorphology which render the relationship unsuitable to other regions dissimilar then the region for which the model has been developed. Other approaches employed physical processes by taking in combination the surface excess water i.e., runoff and wearing away of soil erosion processes were also used.

The watershed susceptibility of soil erosion and sediment yield is displayed by utilizing the idea of SYI of AISLUS. It is understood that silt depends to a large extent on conditions of precipitation-runoff and watershed characterized i.e., stream length. The bigger the CN runoff, the higher the yield of sediment in agrarian watersheds and the other way around. Since CN speaks to the runoff delivering capability of a watershed and sediment yield index, the capability of residue yield, it is very legitimate that these two parameters, i.e., sediment yield index and curve number, should display some relation between them (Gajbhiye et al. 2014, 2015; Meshram and Powar 2017; Meshram et al. 2017). In this study a new regression model, i.e., simplified AISLUS model incorporating parameter SL (stream length) is proposed that bypasses the limitation observed in AISLUS model generally used.

Material and methods

Study area

River Narmada is one of the major rivers with 41 tributaries flowing through central parts of India. It rises from Amarkantak plateau of Maikala range in Shahdol district in Madhya Pradesh at an elevation of about 1059 m above mean sea level. The river travels a distance of 1312 km before it joins the Gulf of Cambay in the Arabian Sea near Bharuch in Gujarat. The three adjacent watersheds, namely Bamhani, Manot and Mohgaon, (Fig. 1) conjoin together to form an important southern sub-basin and one separate Shakkar watershed of Narmada basin in its upper reaches were used for the study (Meshram et al. 2017).

Derivation of SYI (Sediment Yield Index), runoff curve number (CN) and stream length (Sl)

As observed in the LANDSAT data, physiographic units were delineated in the sub watershed and were used for

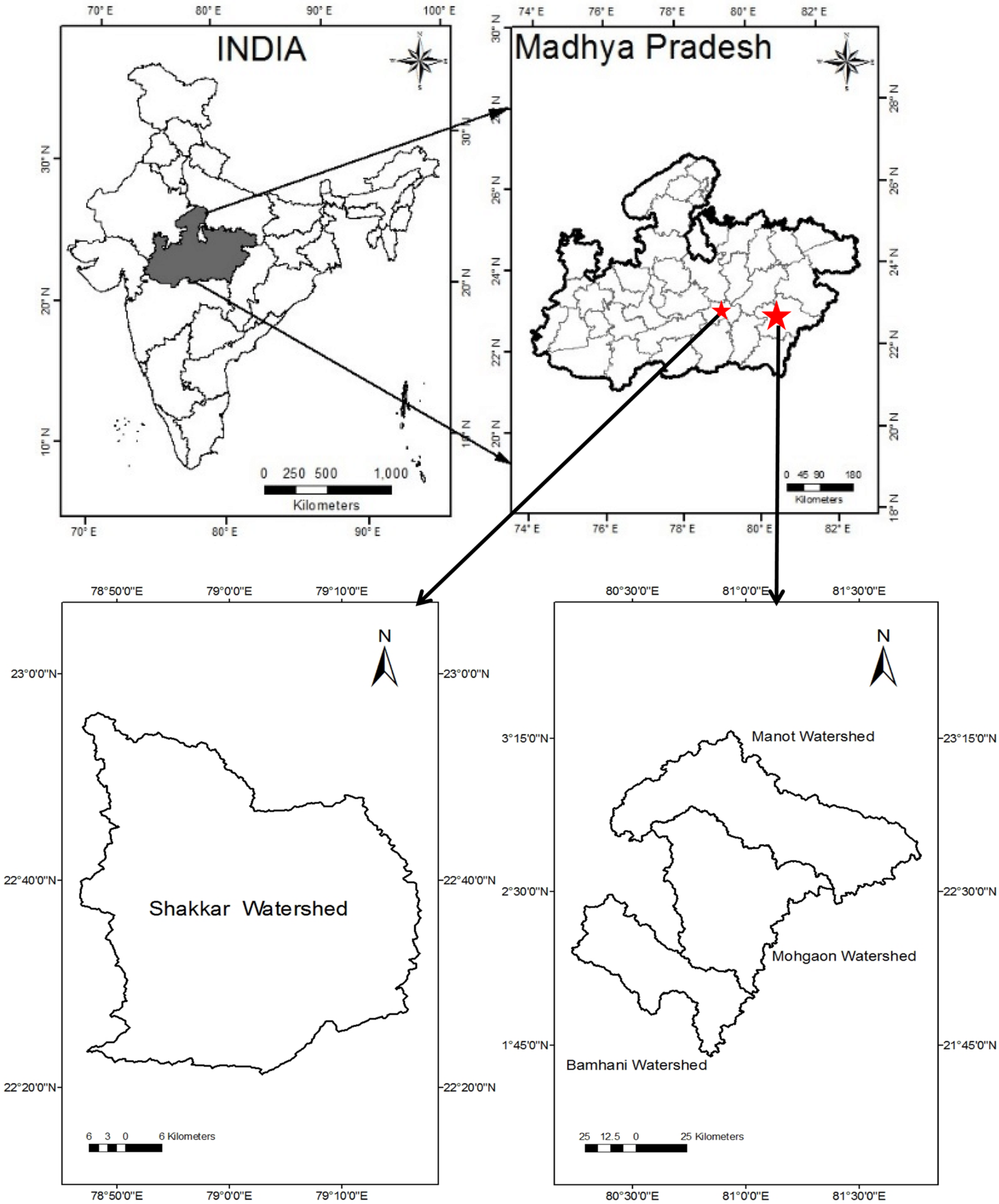

Fig. 1 Location Map of the study area

interpretation and image classification. The slope map was prepared via DEM. In this research, the soil map, prepared by NBSS and LUP (National Bureau of Soil Survey and Land Use Planning), was used. This basic information was transferred to a GIS-based map and was later used in combination with slope and forest cover information to designate/classify areas of varying soil erosion proneness. A composite intensity mapping unit (CIMU) map was prepared from the thematic slope, drainage, soil and land use maps, and the weightage value and delivery ratio were assigned to each physiographic unit according to the AISLUS guidelines (1991). Further, the various erosion intensity units were extracted using hierarchical querying. The composite erosion intensity unit map was then superimposed with sub-watershed boundaries on the drainage map, so that sub-watershed wise SYI value could be obtained. Sediment Yield Index (SYI) was calculated using the following empirical formula (AISLUS 1991):

$$SYI = \frac{\sum_{i=1}^{\backslash}(\mathcal{A}_i \times \mathcal{W}_i \times \mathcal{DR})}{\mathcal{A}_w} \times 100 \quad (1)$$

where, $\mathcal{A}_i$ = the area of the ith unit (CIMU) in km^2, $\mathcal{W}_i$ = the weight value of the ith mapping unit (dimensionless), $\backslash$ = the number of mapping units, $\mathcal{DR}$ = the sediment delivery ratio (dimensionless), and $\mathcal{A}_w$ = the total area of sub-watershed in km^2.

The hydrologic soil group and land use maps were overlaid on the Arc View platform to create a CN map. For generating the CN map, the Xtools extension of Arc View was used. For intersection, the hydrologic soil group field from the soil theme and the land use field from the land use map were chosen. A map with new polygons representing the combined soil hydrologic group and land use (soil-land map) was created after the intersection. The required CN value for each Soil-Land map polygon has been allocated. The weighted CN values for study watersheds were computed as:

$$CN = \frac{\sum(CN_i \times \mathcal{A}_i)}{\mathcal{A}} \quad (2)$$

where, CN = the weighted curve number; CN_i = the curve number of area i assigned on the basis of land use and land cover and hydrologic soil group conditions; varies from 0 to 100, $\mathcal{A}_i$= the area having CN_i, $\mathcal{A}$ = the total area of watershed.

The map layers of watershed, sub-watershed boundary, contours and drainage network besides the order of stream were set up utilizing the potential of GIS (Arc GIS 2004). The digital elevation model (DEM), generated using toposheets covering the study area of scale i.e., 1: 50,000. Drainage maps of watersheds are presented in Figs. 2 and 3. The stream length was calculated from the attribute table of drainage layer.

Model development

The sediment yield index (SYI) is defined as the sediment yield per unit area and SYI value was obtained by taking the weighted arithmetic mean of the products of erosion intensity weighted value and delivery ratio over the entire area of the hydrologic unit (Mishra et al. 2003a, b). Expressed mathematically,

$$SYI = f(DR)$$

Or

$$\text{SYI} = \varepsilon_0(\text{DR})^{\varepsilon_1} \quad (3)$$

where, DR is based on the assumed simple inverse relation from the basin size, which was primarily established by Vanoni (1975). Designating it as an area model, DR was related to area ($\mathcal{A}$) in the form of power function:

$$DR = \varphi(A)^{-k} \quad (4)$$

where, =area of the study area (km^2), φ and are two coefficient. For watersheds in Italy, coefficient , varying from − 0.69 to − 0.3 (Brath et al. 2002). From Eqs. 3 and 4,

$$\text{SYI} = \varepsilon_0(\mathcal{A})^{-\varepsilon_1} \quad (5)$$

Williams (1977) established the relation between DR with *CN*

$$\text{DR} = \text{f(CN)} \quad (6)$$

From Eqs. 3 and 6,

$$\text{SYI} = \varepsilon_0(\text{CN})^{\varepsilon_1} \quad (7)$$

where CN =Curve number (Dimensionless), ε_0 and ε_1 are the empirical coefficients.

Singh and Yadava (2003) found that the DR was correlated with the stream length (SL):

$$DR = f(SL) \quad (8)$$

From Eqs. 3 and 8,

$$\text{SYI} = \varepsilon_0(SL)^{\varepsilon_1} \quad (9)$$

Due to very uncertain and unpredictable nature of sediment generation, the sediment yield models are less efficient in predicting SYI. Therefore, with a view to develop a simplified SYI model incorporating parameter CN, which may be efficient in predicting *SYI*, is proposed here. To develop regression equation, at an initial stage, we assumed that a dependent (*SYI*) variable and independent (, *CN* and *SL*) variables have relationship in linear form. This implies a change in dependent variable will have a same effect on independent variables. So, in this research keeping hydro-geomorphological parameters regression model has been developed and calling it a simplified *SYI* model by incorporating a parameter *SL* which is given as under in subsequent text.

$$SYI = f(A, CN, SL) \quad (10)$$

where SYI = the sediment yield index (dimensionless), = the area (km^2), CN = curve number, (dimensionless), and SL = the stream length (km).

At initial stage of study to select or choose different multi regression equations types (Eq. 11). It was obtained by examining the potency of correlation between the SYI and area of catchment, curve number, stream length and the corresponding log-transformed values (Eq. 12). Thus, Eq. 10 in the linear form can be expressed as:

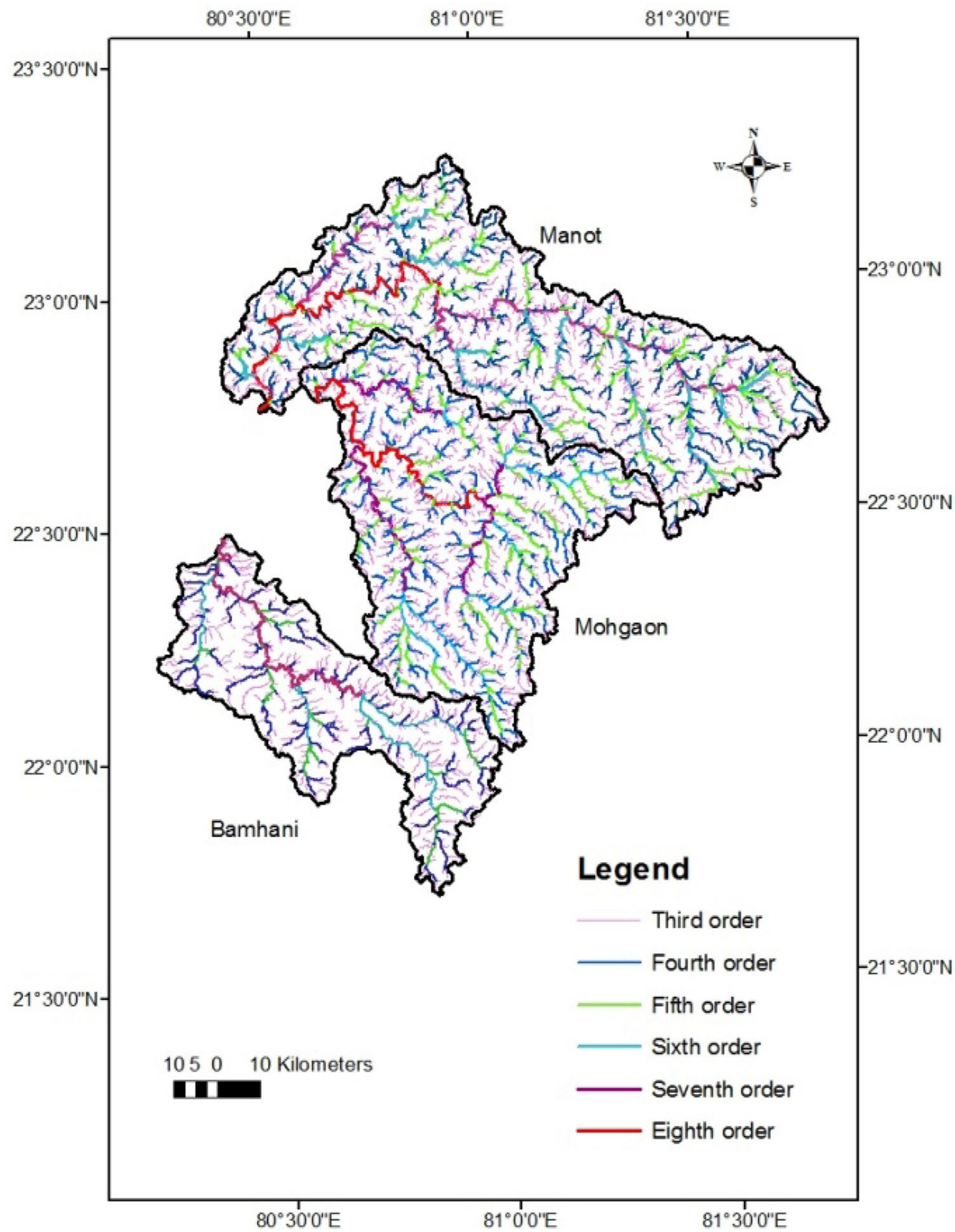

Fig. 2 Drainage map of the Combine watershed

$$\mathrm{SYI} = \varepsilon_0 + \varepsilon_1(A) + \varepsilon_2(\mathrm{CN}) + \varepsilon_3(\mathrm{SL}) \tag{11}$$

Or,

$$ln(\mathrm{SYI}) = \varepsilon_0 + \varepsilon_1 ln(A) + \varepsilon_2 ln(\mathrm{CN}) + \varepsilon_3 ln(\mathrm{SL}) \tag{12}$$

Where =watershed area (km^2); *CN* = Curve Number; SL = Stream length, ε_0, $\varepsilon_{1,}$ ε_2 and ε_3 are regression constants. For specified watershed parameters (or *SL*, *A*), the Sediment Yield Index (*SYI*) increases with the amount of the runoff curve, which is consistent with the general notion that the higher the runoff, the higher the sediment erosion and the higher the sediment yield index, and vice versa. The *CN* values vary from 0 to 100 but their practical limit ranges from 40 to 98 (Van Mullem 1989).

Model performance evaluation

The model's performance evaluation was performed using quantitative method. It was worked out by calculating the value of *RMSE*, *BIAS* and *NSE* by using the following relationship (Eqs. 13, 14, 15).

$$BIAS = \frac{1}{n}\sum_{i=1}^{n}(S_i - O_i) \tag{13}$$

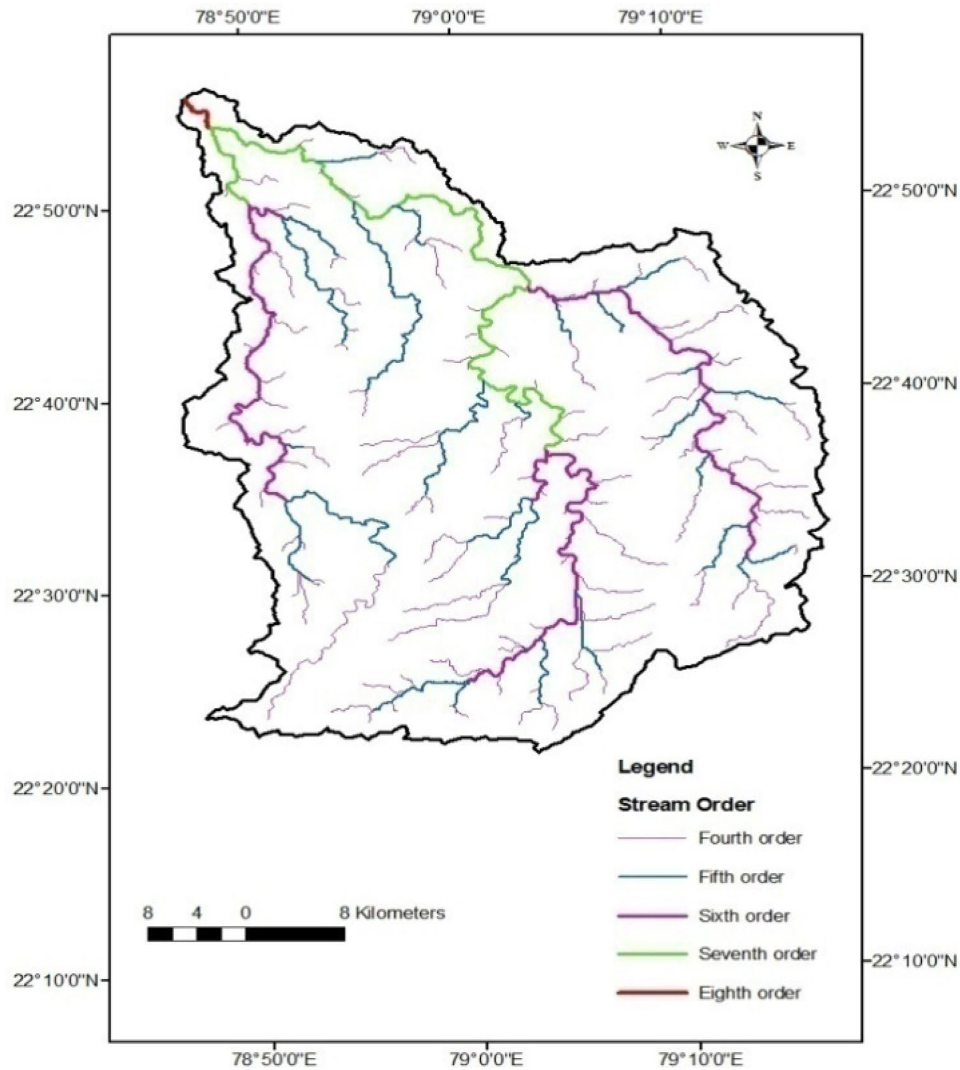

Fig. 3 Drainage map of the Shakkar watershed

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (lO_i - S_i)^2}{n}} \tag{14}$$

$$NSE = 1 - \left(\frac{\sum_{i=1}^{n} (S_i - O_i)^2}{\sum_{i=1}^{n} (S_i - \overline{O}_i)^2} \right) \tag{15}$$

In these relations S is the values simulated by the model, O the real values, i index the sub-watershed, and \ number of the watershed. The high values of NSE parameter, the low values of $RMSE$, and being close to zero for $BIAS$ index show the high performance of the model.

F test: an *F* test is any statistical test in which the test statistic has an *F* distribution under the null hypothesis. It is most often used when comparing statistical models that have been fitted to a data set, in order to identify the model that best fits the population from which the data were sampled. Exact "*F* tests" mainly arise when the models have been fitted to the data using least squares. The *F* test in one-way analysis of variance is used to assess whether the expected values of a quantitative variable within several pre-defined groups differ from each other.

$$F = \frac{\sum_{i=1}^{k} n_i \left(\overline{Y}_i - \overline{Y} \right)^2 / (K-1)}{\sum_{i=1}^{K} \sum_{j=1}^{n_i} (Y_{ij} - \overline{Y}_i)^2 / (N-K)} \tag{16}$$

where, $\overline{Y}_i$= Sample mean in the ith group; n_i is the no. of observation; $\overline{Y}$ is the overall mean of the data; K is the no. of groups; Y_{ij} is the jth observation in the ith out of K group; N is the overall sample size.

t test: The *t* test is any statistical hypothesis test in which the test statistic follows a Student's *t* distribution under the null hypothesis. A *t* test is the most commonly applied when the test statistic would follow a normal distribution if the value of a scaling term in the test statistic were known. When the scaling term is unknown and is replaced by an estimate based on the data, the test statistics (under certain conditions) follow a Student's *t* distribution. The *t* test can be used, for example, to determine if the means of two sets of data are significantly different from each other.

$$t = \frac{\overline{X} - \mu}{\sigma/\sqrt{n}} \quad (17)$$

where, $\overline{X}$ is the sample mean from a sample X_1, X_2, …, X_n, of size n, σ is the estimate of the standard deviation of the population, and μ is the population mean.

Result and discussion

The method for soil erosion developed by AISLUS i.e., sediment yield index has effects of catchment characteristics which are highly variable in nature. This changes with soil of the area, land use pattern and cover, rainfall- runoff factor, area of drainage basin, topography specially slope and relief and length ratio. The present research tried to link SYI and SL. The area, CN, SL, and SYI for each sub-watershed are listed in Table 1. The description of notations is the same as those given in Table 1. Bamhani, Manot, Mohgaon, and Shakkar watershed is signified by BM, MN, MG, and SH correspondingly.

Model calibration

The area, CN and simplified AISLUS model (Eqs. 5, 7 and 11) have been calibrated using the data of four watersheds of Narmada basin. The weighted value of CN for the sub-watersheds was estimated from the land use cover and soil cover data. Making use of the corresponding , CN and SL, SYI (Table 1) was calculated by the above three models (Eqs. 5, 7 and 11). Parameters ε_0, ε_1, ε_2 and ε_3 for each of the watersheds were determined by the least square optimization technique. The estimated values of ε_0, ε_1, ε_2 and ε_3 along with R^2 of the dependent and independent variable are given in Table 2.

For the area model, the estimated coefficients were $\varepsilon_0 = 1034.74$ and $\varepsilon_1 = 0.07$ for the Shakkar watershed, $\varepsilon_0 = 1125.54$ and $\varepsilon_1 = -0.18$ for Manot watershed, $\varepsilon_0 = 1225.69$ and $\varepsilon_1 = -0.58$ for Mohgaon watershed, and $\varepsilon_0 = 1089.21$ and $\varepsilon_1 = -0.34$ for Bamhani watershed. It may be noted that the power function exponent ε_1 here appears with a negative sign, implication that the SYI holds an inverse relationship with the area for all watersheds except Shakkar watershed. The common notion that DR, at the same rate with sediment yield (SY), shows an inverse relationship with the catchment area has been observed in different parts of the world (Krasa et al. 2005; Verstraeten 2006; Kasai et al. 2001; Lu et al. 2006; Zhou and Wu 2008).

For the curve number model, parameter estimates were: $\varepsilon_0 = 892.63$, $\varepsilon_1 = 2.17$ for Shakkar watershed, $\varepsilon_0 = 1111.19$, $\varepsilon_1 = -0.66$ for Manot watershed, $\varepsilon_0 = 1360.64$, $\varepsilon_1 = -4.58$ for Mohgaon watershed, and $\varepsilon_0 = 1357.78$, $\varepsilon_1 = -4.86$ for Bamhani watershed. The higher the volume of runoff, the higher the sediment erosion and its transport and hence higher the sediments yield and vice versa (Caroni et al. 1984; Gajbhiye et al. 2014).

The values of parameters for the simplified AISLUS model incorporating parameter SL were: ε_0 ranged from 1282.99 to 1829.05, ε_1 from 0.09 to 1.12, ε_2 from − 8.48 to 0.66 and ε_3 from − 20.14 to − 9.85. However, for the logarithm form of the simplified AISLUS model, ε_0 ranged from 3.23 to 3.80, ε_1 from − 0.02 to 0.23, ε_2 from − 0.33 to 0.02 and ε_3 from − 0.39 to − 0.14. The coefficient values, estimated from the data, generally matched the Sediment Yield Index (SYI) data of both the calibration (Figs. 4, 5, 6, 7a–d) and the validation (Figs. 4, 5, 6, 7a1–d1) data set. In calibration, the three models (model, CN model and simplified AISLUS model incorporating parameter SL) performed differently, with the coefficient of R^2 equal to 0.01, 0.02 and 0.71 (Shakkar watershed), 0.11, 0.23 and 0.91 (Bamhani watershed), 0.06, 0.001 and 0.80 (Manot watershed) and 0.41, 0.05 and 0.66 (Mohgaon watershed), respectively. The logarithm simplified AISLUS model incorporating parameter SL resulted with the coefficient of R^2 as 0.76 (Shakkar watershed), 0.93 (Bamhani watershed), 0.84 (Manot watershed) and 0.66 (Mohgaon watershed). Therefore, the logarithm simplified AISLUS model was selected as the better regression model for this analysis. It can be seen from the scatter plots (Figs. 4, 5, 6, 7a–d) that the strength of correlation increases significantly with log-transformation of selected data set, i.e., from R^2equal to 0.71–0.76 (Shakkar watershed), 0.91 to 0.93 (Bamhani watershed), 0.80–0.84 (Manot watershed) and 0.41–0.47 (Mohgaon watershed).

To compare the performance of the simplified AISLUS model incorporating parameter SL, the responses of the simplified AISLUS model incorporating parameter SL (Eq. 15) for 1, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 were generated. Utilizing the area and curve number of all sub watersheds, SYI for each SL profile was estimated using Eq. 15, the parameters ε_0, $\varepsilon_{1,}$ ε_2 and ε_3 of the respective model for each of the SL dataset were estimated by the least square optimization. The estimated value of ε_0, $\varepsilon_{1,}$ ε_2 and ε_3 of the modified AISLUS model incorporating parameters SL for different SL values are given in Table 3 and Fig. 8. It can be seen from Fig. 8 that the parameters ε_0 and ε_3 consistently increased as SL increased, whereas ε_1 and $\varepsilon_2$were found constant i.e., − 0.28 and 1.50 for all SL profiles (Table 4).

Table 1 Derivation of model inputs for various sub-watersheds

Watersheds	Sub-watershed	Area (km^2)	SYI (Dimensionless)	CN (Dimensionless)	Stream length (km)
Bamhani	BM 1	91.15	1070.47	36.41	15.05
	BM 2	23.38	1159.31	76.97	5.00
	BM 3	40.56	1107.11	59.63	8.33
	BM 4	155.74	1279.04	43.95	2.59
	BM 5	83.48	1094.39	63.96	7.68
	BM 6	337.16	914.97	54.08	30.10
	BM 7	111.52	796.42	86.73	40.05
	BM 8	38.08	969.15	79.57	15.10
	BM 9	31.93	1062.07	58.11	15.05
	BM 10	101.02	1013.29	61.22	15.06
	BM 11	533.29	923.82	58.09	30.06
	BM 12	71.73	971.02	69.97	15.20
	BM 13	137.52	1154.44	64.21	5.05
	BM 14	31.76	1177.68	72.75	5.06
	BM 15	267.03	1032.71	77.10	15.08
	BM 16	98.15	1115.03	45.54	10.35
	BM 17	81.42	1264.42	56.00	5.00
	BM 18	97.70	840.95	78.15	30.10
	BM 19	43.68	1054.24	57.55	13.16
	BM 20	165.86	901.41	73.61	30.10
Manot	MN 1	260.89	991.61	73.87	41.53
	MN 2	522.51	987.42	77.73	46.21
	MN 3	478.65	986.82	72.03	46.51
	MN 4	263.12	1032.24	84.95	30.22
	MN 5	371.85	1173.33	79.51	29.37
	MN 6	268.94	1088.42	78.23	22.93
	MN 7	161.73	1031.08	64.75	35.44
	MN 8	96.10	1099.92	59.36	17.34
	MN 9	381.26	940.97	76.71	42.85
	MN 10	291.04	1030.19	66.42	39.40
	MN 11	432.56	1347.60	76.71	14.80
	MN 12	170.57	1238.36	67.84	13.40
	MN 13	707.85	1007.85	73.76	37.24
	MN 14	477.77	925.38	74.15	45.84
Mohgaon	MG 1	51.27	1252.84	61.65	8.56
	MG 2	383.94	973.76	68.04	41.64
	MG 3	98.15	1109.84	56.65	15.13
	MG 4	135.36	965.63	65.64	13.89
	MG 5	631.75	943.09	73.51	45.15
	MG 6	431.72	1054.65	55.28	30.08
	MG 7	193.96	1322.99	62.48	5.00
	MG 8	502.33	938.59	74.96	36.57
	MG 9	149.53	1259.42	56.17	20.74
	MG 10	58.39	1148.61	78.28	8.20
	MG 11	333.72	846.58	62.68	42.52
	MG 12	106.98	1337.36	59.38	17.33
	MG 13	238.33	956.43	54.49	32.53
	MG 14	328.37	915.91	61.47	44.15
	MG 15	334.13	1052.09	54.35	26.58

Table 1 (continued)

Watersheds	Sub-watershed	Area (km^2)	SYI (Dimensionless)	CN (Dimensionless)	Stream length (km)
Shakkar	SH 1	9.23	666.52	79.05	3.41
	SH 2	37.87	917.39	89.84	9.00
	SH 3	114.00	1125.26	69.10	18.01
	SH 4	538.22	881.72	63.36	50.01
	SH 5	158.35	1387.25	79.11	15.00
	SH 6	581.45	1023.86	70.29	40.02
	SH 7	383.43	1090.04	62.83	30.01
	SH 8	397.96	1341.51	83.31	14.27

Table 2 Estimated values of $\mathcal{A}$ (Area Model), Curve Number (CN Model) and Simplified AISLUS model incorporating SL parameter, coefficient of determination (R^2) for the dependent and independent variables

Watersheds	Regression parameters	Sediment yield index model							
		Area model		CN model		Simplified AISLUS model incorporating parameter SL			
		$SYI = \varepsilon_0 (Area)^{\varepsilon 1}$	R^2	$SYI = \varepsilon_0 (CN)^{\varepsilon 1}$	R^2	$SYI = \varepsilon_0 + \varepsilon_1(\mathcal{A}) + \varepsilon_2(CN) + \varepsilon_3 (SL)$	R^2	$\log(SYI) = \varepsilon_0 + \varepsilon_1 \log(\mathcal{A}) + \varepsilon_2 \log(CN) + \varepsilon_3 \log(SL)$	R^2
Shakkar	ε_0	1034.75	0.01	892.64	0.02	1829.05	0.71	3.62	0.76
	ε_1	0.07		2.17		1.12		0.23	
	ε_2					− 8.48		− 0.33	
	ε_3					− 20.14		− 0.39	
Bamhani	ε_0	1089.21	0.11	1357.79	0.23	1313.59	0.91	3.43	0.93
	ε_1	− 0.35		− 4.86		0.09		− 0.02	
	ε_2					− 1.54		− 0.13	
	ε_3					− 11.41		− 0.14	
Manot	ε_0	1125.55	0.06	1111.20	0.001	1282.99	0.80	3.23	0.84
	ε_1	− 0.18		− 0.66		0.16		0.05	
	ε_2					0.66		0.02	
	ε_3					− 9.85		− 0.25	
Mohgaon	ε_0	1225.70	0.40	1360.64	0.05	1522.57	0.66	3.80	0.66
	ε_1	− 0.58		− 4.58		0.14		− 0.02	
	ε_2					− 3.59		− 0.30	
	ε_3					− 10.13		− 0.15	

Model validation

For validation, the above optimized parameters,$\mathcal{A}$, CN and SL were used as a part of (Eqs. 9, 11, 15) for determining the SYI. This calculated SYI, named as (SYI_c), was compared with the conventionally derived SYI of AISLUS termed as (SYI_O), for all the three models. The computed SYI values for all sub-watershed datasets (Table 1) were plotted against the corresponding observed SYI as shown in Figs. 4a1–d1, 5a1–d1, 6a1–d1 and 7a1–d1 for Shakkar, Bamhani, Manot and Mohgaon watersheds, respectively.

The resulting Nash–Sutcliffe efficiency, Bias, RMSE is shown in Table 5. Both SYI-computed and SYI-observed (for three models) values were compared through the line of perfect fit. It is observed that the simplified AISLUS model (logarithm form) incorporating parameter SL had a satisfactory performance, with Nash efficiency as 76.35% (Shakkar watershed), 66.05% (Mohgaon watershed), 93.36% (Bamhani watershed), and 83.83% (Manot watershed). It is observed that RMSE was 72.70 (Shakkar), 39.35 (Bamhani), 43.94 (Manot) and 89.79 (Mohgaon) which showed better fitting of the modified AISLUS model incorporating parameter SL. Moreover, the Bias value for Mohgaon (− 0.0038),

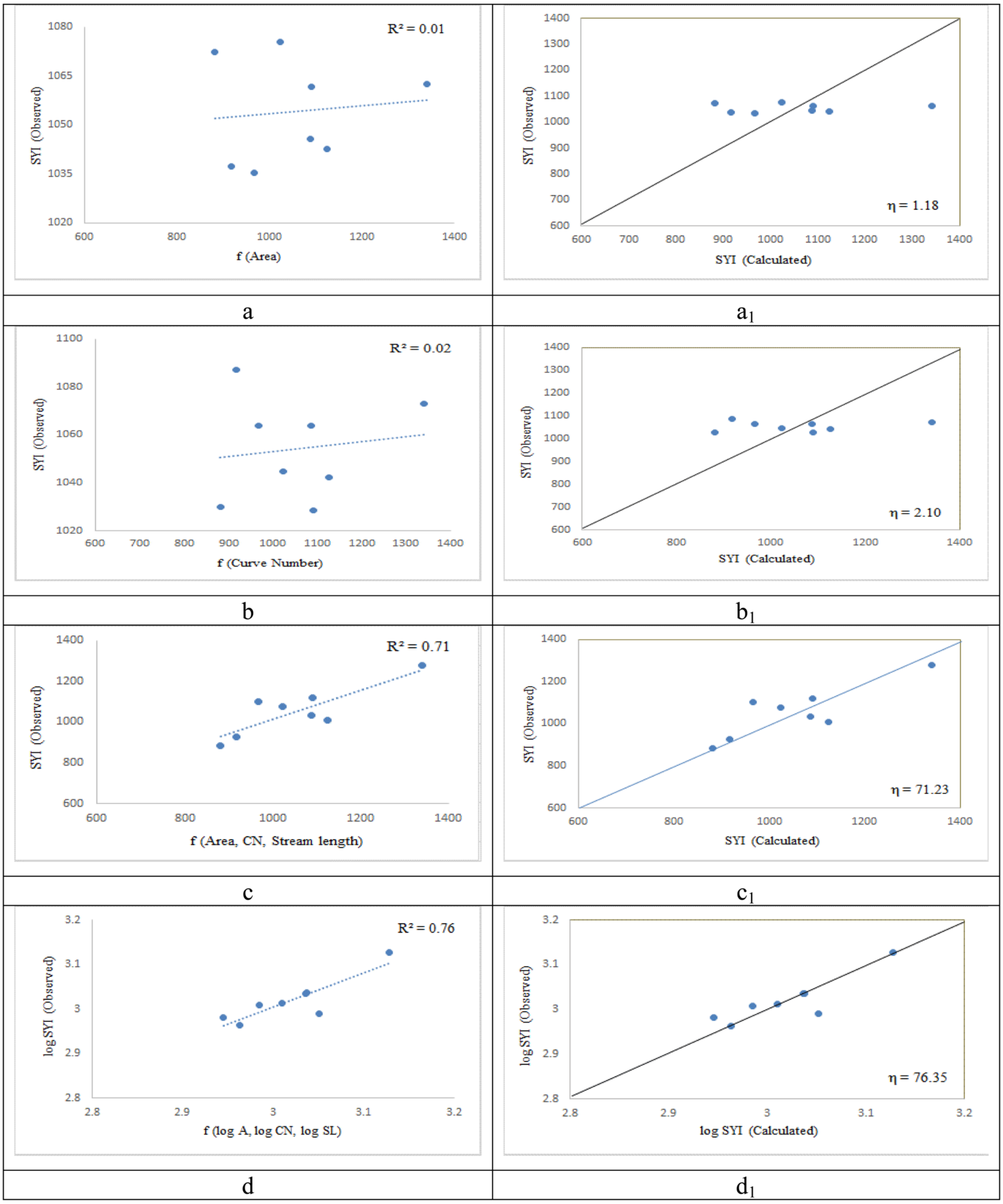

Fig. 4 Fitting of **a** Area Model, **b** CN Model, and **c** Simplified AISLUS model incorporating parameter SL **d** logarithm simplified AISLUS model using calibration dataset and respective scatter plots (a_1–d_1) between predicted and actual SYI for Shakkar watershed

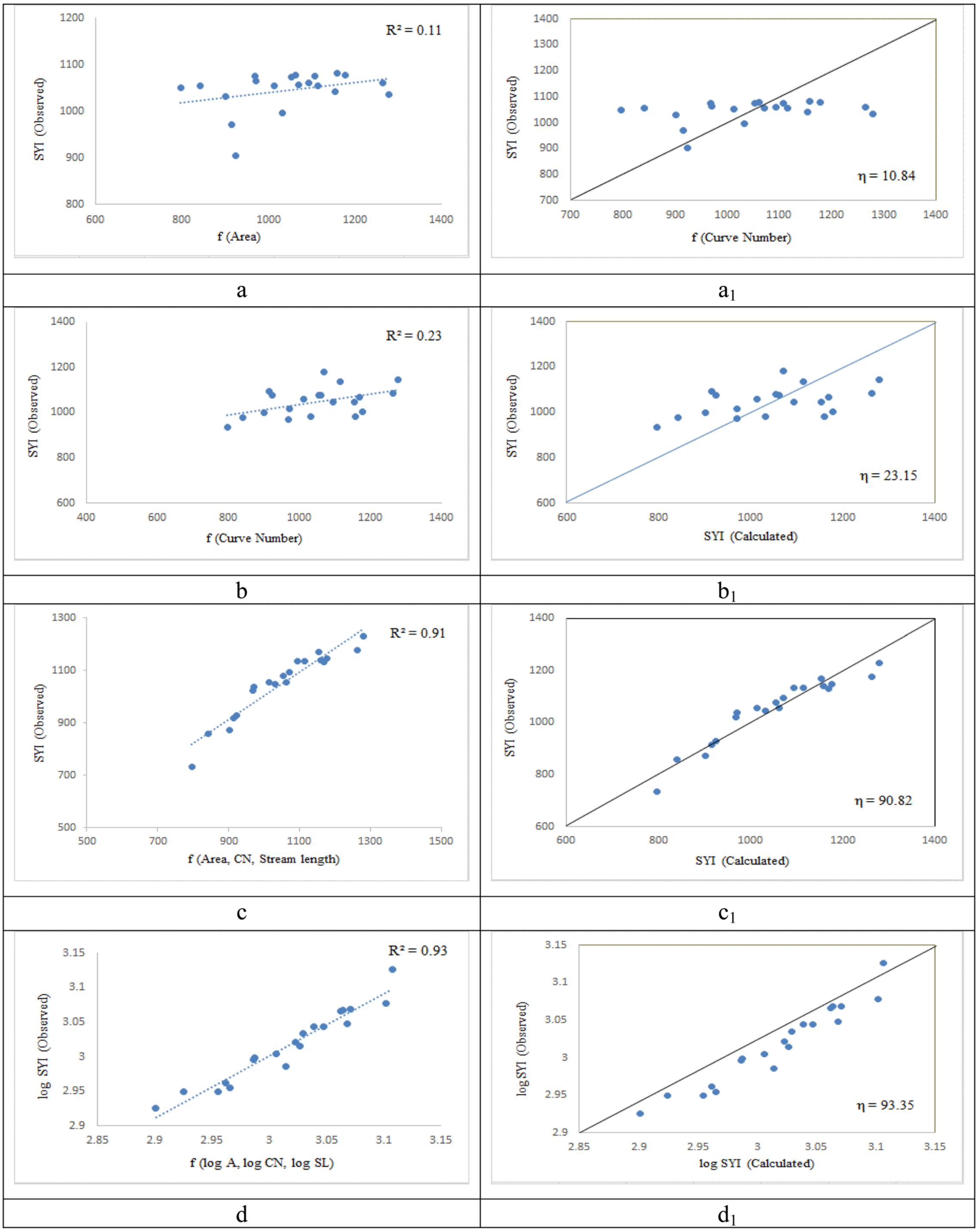

Fig. 5 Fitting of **a** Area Model, **b** CN Model, and **c** Simplified AISLUS model incorporating parameter SL **d** logarithm simplified AISLUS model using calibration dataset and respective scatter plots (a_1–d_1) between predicted and actual SYI for Bamhani watershed

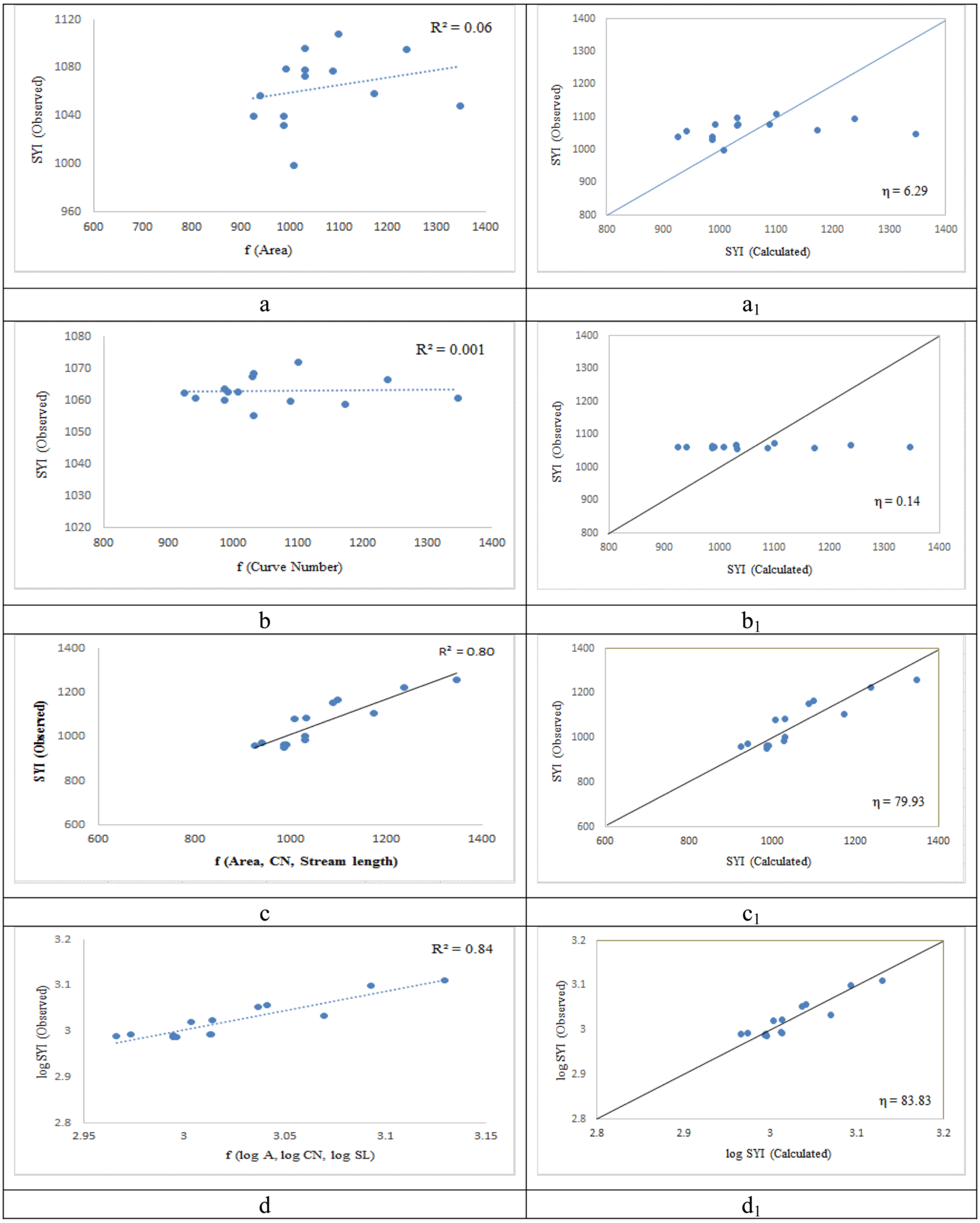

Fig. 6 Fitting of **a** Area Model, **b** CN Model, and **c** Simplified AISLUS model incorporating parameter SL **d** logarithm simplified AISLUS model using calibration dataset and respective scatter plots (a_1–d_1) between predicted and actual SYI for Manot watershed

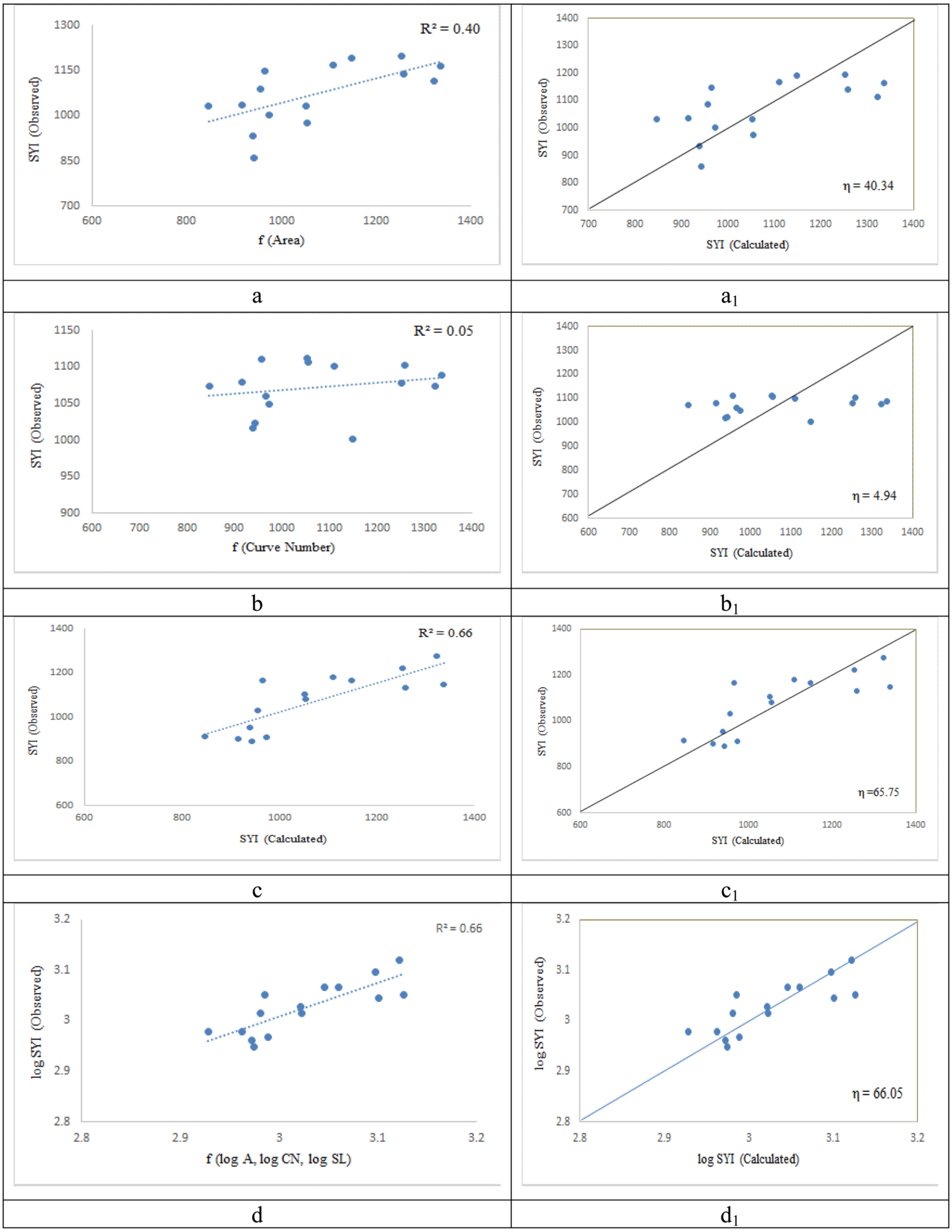

Fig. 7 Fitting of **a** Area Model, **b** CN Model, and **c** Simplified AISLUS model incorporating parameter SL **d** logarithm simplified AISLUS model using calibration dataset and respective scatter plots (a_1–d_1) between predicted and actual SYI for Mohgaon watershed

Table 3 Estimated values of coefficient ε_0, ε_1, ε_2 and ε_3 of the Simplified AISLUS model incorporating parameter SL (Eq. 9) for different SL profiles

Stream length (km)	Regression coefficient			
	ε_0	ε_1	ε_2	ε_3
1	1034.24	− 0.28	1.50	− 9.26
5	1071.22	− 0.28	1.50	− 9.24
10	1117.05	− 0.28	1.50	− 9.20
15	1162.27	− 0.28	1.50	− 9.15
20	1206.74	− 0.28	1.50	− 9.09
25	1250.35	− 0.28	1.50	− 9.01
30	1293.02	− 0.28	1.50	− 8.93
35	1334.70	− 0.28	1.50	− 8.85
40	1375.35	− 0.28	1.50	− 8.76
45	1414.96	− 0.28	1.50	− 8.67
50	1453.52	− 0.28	1.50	− 8.57

Bamhani (− 0.00271), Manot (− 0.0688) and Shakkar (− 0.00567) was close to a better fitted model. Therefore, on the basis of this performance test it can be said that the simplified AISLUS model incorporating parameter SL was the best fit model.

Goodness of fit

The research hypothesis for the F test claims that there is some predictive relationship between the independent variables (A, CN, SL) and dependent variable (SYI). Thus, SYI is more than just pure randomness and must depend on at least one of the independent variables. Thus, the research hypothesis claims that at least one of the regression coefficients is not 0. Note that it is not necessary for every independent variable to affect SYI; it is enough for there to be just one.

The easiest way to perform the *F* test is to look for the appropriate *p* value in the computer analysis and to interpret the resulting significance level. If the *p* value is more than 0.05, then the result is not significant. If the *p* value is less than 0.05, then the result is significant. The *F* test value are 53.35 (BM), 13.27 (MN), 7.04 (MG), 5.34 (SH). The result is significant for the entire watershed (Tables 6, 7, 8, 9).

If the *F* test is significant, you know that one or more of the independent variables is helpful in predicting SYI, and you may proceed with statistical inference using *t* tests for individual regression coefficients to find out which one (or more) of the independent variables is useful. These t tests show you whether an independent variable has a significant impact on SYI, holding all other independent variables fixed. All independent variables (A, CN, SL) are significant because their *p* values are less than 0.05 (Tables 6, 7, 8, 9). If the *F* test is not significant, then you are not permitted to use *t* tests on the regression coefficients.

The problem of multi-collinearity arises when some of your explanatory (independent) variables are too similar. Although they do a good job of explaining and predicting SYI (as indicated by a high R^2 and a significant *F* test), the individual regression coefficients are poorly estimated. The regression (*F* test) is significant, and the t test for assets is also significant now that the strong multi-collinearity has been eliminated.

The easiest way to perform the *t* test (for regression coefficient) is to compare the *t* statistic and *t* critical value and to interpret the resulting significance level. If the *t* statistic value is more than *t* critical value, then the result is not significant. If the *t* statistic value is less than *t* critical value, then the result is significant (Nbina, 2012). The *t* statistic value are 0.818 (BM), 0.987 (MN), 0.991 (MG), 0.980 (SH). The regression coefficient is significant for the entire watershed (Table 10).

Conclusion

The efforts made by many researchers to develop a general model for reliable estimation of Sediment Yield Index (SYI) have produced a number of different kinds of models, mainly on the basis of actual data availability. The Sediment Yield Index (SYI) model proposed here provides a simple method based on easily available catchment parameters. The simplified form of AISLUS model including parameter SL has four number of parameters (coefficient) particular to the watershed and requires area, stream length, curve number as input to calculate the SYI. The parameters were estimated using least square optimization technique. The Simplified AISLUS model (logarithm form) incorporating parameter SL has a satisfactory performance, with Nash efficiency as 76.35% (Shakkar watershed), 66.05% (Mohgaon watershed), 93.36% (Bamhani watershed), and 83.83% (Manot watershed). The proposed simplified AISLUS model shows a good match with SYI (AISLUS) model. Simplified AISLUS model saves the time in comparison to AISLUS model. Present research gives an opportunity/useful procedure which can be utilized in the agricultural catchments lacking with long periods of hydrological data (sediment data).

Table 4 Nash -Sutcliffe efficiency (η) between observed and computed SYI of the watersheds

Watersheds	SYIo	SYIc			Nash–Sutcliffe efficiency (η) (%)
		Area model	CN model	Simplified AISLUS model	
Shakkar	966.5222	1035.396	1063.813	1100.57	1.18 (Area model) 2.10 (CN model) 71.23 (Simplified AISLUS model) 76.35 (Simplified AISLUS model-logarithm)
	917.393	1037.402	1087.166	928.5386	
	1125.256	1042.735	1042.259	1007.908	
	881.7209	1072.453	1029.824	886.0004	
	1087.246	1045.842	1063.947	1033.197	
	1023.862	1075.482	1044.846	1076.754	
	1090.041	1061.61	1028.68	1120.413	
	1341.506	1062.627	1073.025	1280.122	
Bamhani	1070.47	1057.578	1180.803	1093.937	10.84 (Area model) 23.15 (CN model) 90.82 (Simplified AISLUS model) 93.35 (Simplified AISLUS model-logarithm)
	1159.31	1081.098	983.6436	1140.385	
	1107.11	1075.136	1067.932	1130.527	
	1279.04	1035.16	1144.152	1230.095	
	1094.39	1060.238	1046.884	1135.024	
	914.97	972.193	1094.91	916.5336	
	796.42	1050.508	936.2009	733.2779	
	969.15	1075.996	971.0052	1022.469	
	1062.07	1078.13	1075.321	1055.462	
	1013.29	1054.153	1060.203	1056.58	
	923.82	904.1236	1075.418	927.8872	
	971.02	1064.317	1017.67	1038.998	
	1154.44	1041.482	1045.669	1169.338	
	1177.68	1078.188	1004.157	1146.911	
	1032.71	996.5329	983.0117	1046.401	
	1115.03	1055.147	1136.423	1134.134	
	1264.42	1060.953	1085.577	1177.638	
	840.95	1055.303	977.9077	858.7435	
	1054.24	1074.053	1078.043	1078.901	
	901.41	1031.649	999.9763	871.6428	
Manot	991.6133	1078.736	1062.562	965.639	6.29 (Area model) 0.14 (CN model) 79.93 (Simplified AISLUS model) 83.83 (Simplified AISLUS model-logarithm)
	987.4233	1031.796	1060.019	964.9254	
	986.8179	1039.666	1063.769	951.0028	
	1032.243	1078.337	1055.268	1084.795	
	1173.328	1058.828	1058.848	1107.356	
	1088.416	1077.291	1059.689	1153.11	
	1031.078	1096.528	1068.563	1003.349	
	1099.923	1108.303	1072.114	1167.346	
	940.97	1057.14	1060.692	974.2261	
	1030.187	1073.327	1067.463	986.6119	
	1347.601	1047.935	1060.692	1258.981	
	1238.361	1094.942	1066.532	1223.989	
	1007.853	998.5421	1062.635	1080.999	
	925.3817	1039.824	1062.378	958.8646	

Table 4 (continued)

Watersheds	SYIo	SYIc			Nash–Sutcliffe efficiency (η) (%)
		Area model	CN model	Simplified AISLUS model	
Mohgaon	1252.84	1195.951	1078.054	1221.75	40.34 (Area model) 4.94 (CN model) 65.75 (Simplified AISLUS model) 66.05 (Simplified AISLUS model-logarithm)
	973.7584	1002.964	1048.752	910.83	
	1109.844	1168.756	1100.973	1179.78	
	965.6294	1147.173	1059.768	1165.35	
	943.0908	859.2121	1023.709	890.83	
	1054.647	975.2512	1107.228	1080.55	
	1322.99	1113.178	1074.267	1275.11	
	938.5886	934.2896	1017.05	954.18	
	1259.422	1138.952	1103.149	1131.94	
	1148.61	1191.825	1001.799	1166.67	
	846.5804	1032.103	1073.352	914.05	
	1337.364	1163.635	1088.459	1148.94	
	956.4297	1087.436	1110.893	1031.14	
	915.9131	1035.206	1078.854	901.08	
	1052.089	1031.864	1111.517	1105.52	

SYIo observed sediment yield index, *SYIc* computed sediment yield index

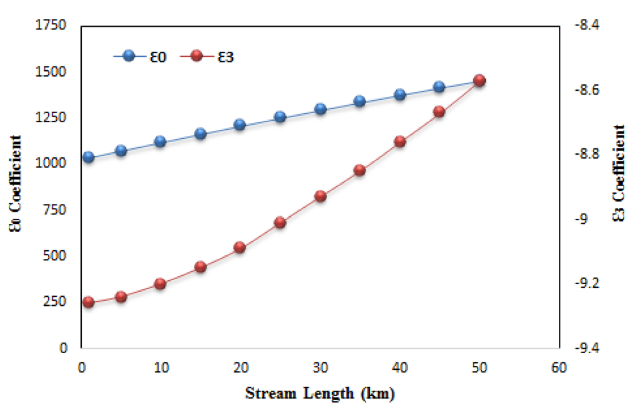

Fig. 8 Variation of coefficients ε_0 and ε_3 with stream length (SL)

Table 5 Performance evaluation of Modified AISLUS model incorporating parameter SL

Watersheds	BIAS	RMSE	NSE
Shakkar	− 0.00567	72.70	71.23
Bamhani	− 0.00271	39.35	93.14
Manot	− 0.0688	43.94	85.18
Mohgaon	− 0.0038	89.79	65.88

Table 6 Analysis of variance (ANOVA) for Bamhani watershed

(a) *F* test	Sum of squares	df	Mean square	*F*	Sig
Regression	296,205.468	3	98,735.156	53.351	0.000a
Residual	29,610.513	16	1850.657		
Total	325,815.982	19			

(b) *t* test and multi-collinearity	Unstandardized coefficients	Std. error	Standardized coefficients (beta)	*t*	Sig	Collinearity statistics tolerance	VIF
(Constant)	1302.542	53.187		24.49	0		
A	0.103	0.097	0.097	1.058	0.002	0.670	1.492
CN	− 1.466	0.855	− 0.148	− 1.715	0.006	0.767	1.305
SL	− 11.313	1.182	− 0.931	− 9.57	0	0.601	1.665

Table 7 Analysis of variance (ANOVA) for Manot watershed

(a) *F* test	Sum of squares	df	Mean square	*F*	Sig
Regression	145,840.281	3	48,613.427	13.277	0.001a
Residual	36,615.863	10	3661.586		
Total	182,456.143	13			

(b) *t* test and multi-collinearity	Unstandardized coefficients	Std. error	Standardized coefficients (beta)	*t*	Sig	Collinearity statistics tolerance	VIF
(Constant)	1283.173	195.681		6.557	0		
A	0.164	0.129	0.229	1.269	0.033	0.617	1.621
CN	0.662	2.791	0.038	0.237	0.017	0.798	1.253
SL	− 9.852	1.634	− 0.989	− 6.029	0	0.746	1.341

Table 8 Analysis of variance (ANOVA) for Mohgaon watershed

(a) *F* test	Sum of squares	df	Mean square	*F*	Sig
Regression	232,227.845	3	77,409.282	7.041	0.007a
Residual	120,927.87	11	10,993.443		
Total	353,155.714	14			

(b) *t* test and multi-collinearity	Unstandardized coefficients	Std. error	Standardized coefficients (beta)	*t*	Sig	Collinearity statistics tolerance	VIF
(Constant)	1522.737	243.56		6.252	0		
A	0.142	0.3	0.156	0.474	0.045	0.289	3.465
CN	− 3.593	3.843	− 0.174	− 0.935	0.007	0.896	1.116
SL	− 10.134	3.575	− 0.905	− 2.835	0.016	0.306	3.272

Table 9 Analysis of Variance (ANOVA) for Shakkar watershed

(a) *F* test	Sum of squares	df	Mean square	*F*	Sig
Regression	81,714.282	3	27,238.094	5.343	0.006a
Residual	317,771.71	4	79,442.927		
Total	399,485.992	7			

(b) *t* test and multi-collinearity	Unstandardized coefficients	Std. error	Standardized coefficients (beta)	*t*	Sig	Collinearity statistics tolerance	VIF
(Constant)	1221.042	1552.745		0.786	0.046		
A	1.022	1.036	0.966	0.987	0.009	0.408	3.811
CN	− 1.837	18.131	− 0.075	− 0.101	0.024	0.365	2.739
SL	− 13.955	18.584	− 0.94	− 0.751	0.004	0.227	2.873

Table 10 Verification of regression coefficients (*t* test)

Watershed	$t_{statistic}$	$t_{critical}$ (5% significance)
Shakkar	0.980	2.353
Bamhani	0.818	
Manot	0.987	
Mohgaon	0.991	

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Declarations

Conflict of interest None.

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