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Estimation of Runoff Using USDA SCS-Curve Number and Autoregressive Time Series Model Parameters for Kachhinda Watershed, Morena District, Madhya Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Hydrological modeling is an influential method for examining hydrologic systems, serving as a valuable tool in investigating these systems for both present studies involving two hydrologic runoff models viz. Soil Conservation Service Two methods, namely the Soil Conservation Service-Curve Number (SCS-CN) method and the Autoregressive Time Series model, were utilized in the Kachhinda watershed to estimate surface runoff, CN, and AMC conditions. The study area covers 600 hectares and is sited in Morena district of M.P. in Chambal division. The SCS-CN technique was employed to determine the curve number and estimate surface runoff by using the potential maximum retention. The CN of the watershed was calculated and compared to observed and

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estimated surface runoff, which were found to be in close agreement with each other. Additionally, an Autoregressive Time Series model was developed to establish the correlation between observed and estimated runoff, resulting in a correlation coefficient of 0.974. Different orders of AR time series models (0, 1, and 2) were tested to predict annual stream flow, and the model goodness of fit was evaluated using the Box-Pierce Portmanteau test and the Akaike Informations Principle. The Akaike Information Criterions value for the Autoregressive (1) model for runoff was found to be 0.919158, which is within the range of the values obtained for Autoregressive (0) (0.207433) and Autoregressive (2) (5.9767) models.

Keywords: Rainfall; watershed; SCS curve number; autoregressive model; surface runoff.

1. INTRODUCTION

Water is an indispensable and highly valuable asset for the well-being of humanity. It is the basic requirement for of all forms of life on earth surface. Besides serving personal needs, It holds significant importance in the field of agriculture, industry, navigation, domestic purpose and the production of energy. Water is an essential resource that serves as the foundation for life on Earth. However, the growing population, rapid urbanization, and increased industrial and agricultural activities have intensified the strain on finite resources. Additionally, climate change is starting to impact global weather patterns, resulting in higher temperatures and reduced rainfall, particularly in tropical regions. Land deprivation caused by water and wind erosion is a significant contributing factor to this issue [1,2]. The assessment of storm-water run-off from small agricultural watershed traditionally relied on the Soil Conservation Service (SCS) Curve Number (CN) method, developed by the United States Department of Agriculture (USDA) and also known as the Natural Resources Conservation Service (NRCS)-CN method. This approach, which has expanded beyond storm runoff evaluation, now plays a crucial role in more complex, Long term simulation model [3]. The SCS-CN method utilizes a lumped conceptual approach to estimate the volume of direct surface runoff from rainfall storms based on a curve number (CN) [4-6]. In the words of Ponce and Hawkins [7]. While widely used, the realistics estimation of the CN parameter has been a subject of extensive discussion among hydrologists and the water resources community [8-13]. The SCS-CN method provides a straightforward and widely applicable means of predicting surface runoff from watersheds dominated by Torontonian overland flow. Its popularity can be attributed to its ability to account for critical watershed characteristics that contribute to runoff generation, including soil type, land use patterns, soil treatment, surface conditions, and antecedent moisture conditions (AMC) [14-17]. On a different note, the autoregressive time series model is a statistical and signal processing tool commonly employed for prediction purposes. It represents a random process and can be seen as the outcome of an all-pole infinite impulse response filter driven by white noise [18]. This suggests that past observed data may be indicative of present observed data. An autoregressive time series model is commonly referred to as an AR (p) model, where 'p' represents the degree or order of the model. The order of the autoregressive model, AR (p), can be determined using different methods, including the squares estimator of a threshold autoregressive time series model or a random coefficient autoregressive time series model. In addition to model selection, other important aspects of autoregressive time series modeling include statistical inference, power spectrum estimation, and model fitting for control purposes. These topics are crucial for understanding and analyzing autoregressive time series models. The order of an autoregressive time-series model can be determined using a generalized form of the Akaike criteria, considering certain properties and limitations.

1.1 Study Area

The watershed lies on the North side of Chambal River and proposed code No. 2D1B2B2b is established in flood-prone area of Chambal River. This code comes in high priority. The Kachhinda watershed of Morena district is located between 250 10’ East to 330 15’ East longitude and 330 27’ North to 370 98’ North latitude. The total watershed area code is 600 ha. The shape of Kachhinda watershed is mostly rectangular. The total watershed area is 600 ha out of which 59 ha area is under agricultural use, 499 ha area is cultivable waste land and 42 ha area is non-cultivable west land. The project site is located in the Central Chambal river Alluvial Plain of Madhya Pradesh. This region is characterized by a flat terrain and a dense population. The majority of the land in this area is suitable for cultivation. The valleys of the major rivers in the region are not only significantly lower in elevation compared to the rest of the country but also wide in breadth. Consequently, there is a substantial expanse of low-lying land that experiences flooding during periods of high precipitation. The project area falls within a sub-tropical climate zone, with an average annual rainfall of 720 mm. The rainy season, occurring from July to September, accounts for approximately 80% of the total annual rainfall. During this period, the region experiences high-intensity storms and heavy rainfall.

2. MATERIALS AND METHODS

When plotting the data of accumulated rainfall and surface runoff for extended periods of intense rainfall in small drainage basins, it is observed that surface runoff begins only after all losses have been accounted for. Furthermore, the plotted curves gradually approach a straight line with a slope of 45 degrees, indicating a consistent pattern. These observations form the basis of the Curve Number method. The initial accumulation of rainfall in the plot represents processes such as interception, storage, and infiltration that occur before the onset of runoff, collectively referred to as initial abstraction. Subsequently, once the runoff commences, a portion of the additional rainfall is lost, primarily through infiltration, which is referred to as actual retention [19].

$$\frac{F}{S} = \frac{Q}{P-Ia} \quad (1)$$

After the commencement of surface runoff, any excess rainfall is divided into two categories: runoff and actual retention. Actual retention refers to the remaining rainfall after subtracting the initial ablation and surface runoff.

$$F = P - Ia - Q \quad (2)$$

Substituting eq. (2) in eq. (1) and by solving;

$$Q = \frac{(P-Ia)2}{(P-Ia-S)} \quad (3)$$

Where,

F = Cumulative infiltration excluding Ia, Q = Actual runoff (mm), P = Rainfall (mm), Ia = Initial analysis, which represents all the losses before the surface runoff begins, and is given by the empirical equation.

$$Ia = 0.2S \quad (4)$$

Substituting eq. (4) in eq. (3); the eq. (3) becomes

$$Q = \frac{(P-0.2S)2}{(P+0.8S)} \quad (5)$$

S = Potential infiltration after the surface runoff begins given by the following equation

$$CN = \frac{25400}{254+S} \quad (6)$$

The Curve Number (CN) is a unitless parameter ranging from 0 to 100, which is determined by considering factors such as land cover, Hydrologic Soil Group, and Antecedent Moisture Condition. The Hydrologic Soil Group categorizes soils into four groups (A, B, C, and D) based on their infiltration rates. Antecedent Moisture Condition is divided into three levels (I, II, and III) that correspond to certain rainfall limits during inactive and growing seasons. By using these factors, the Curve Number can be calculated to estimate the hydrological response of a watershed.

2.1 Estimation of Curve Number

Curve Number was estimated using observed runoff data and rainfall data on a year event basis. The equation of CN has been utilized to estimate the intensity of rainfall for each storm event, as well as the associated direct surface runoff. This approach, commonly referred to as the hydrological soil cover complex number method, relies on assessing the watershed's recharge capacity. The underlying principle of this technique is to determine the ratio between the actual retention and potential runoff, or rainfall excess.

$$\frac{P-Ia-Q}{S} = \frac{Q}{P-Ia} \quad (7)$$

Where,

Q = Storm runoff depth (mm), P = Storm rainfall depth (mm), S = Watershed storage index (mm) or potential maximum retention, and Ia = Initial abstraction

The relation between Initial abstraction and the Watershed storage index was developed utilizing rainfall and surface runoff data from the experimental watershed (SCS, USDA, 1964).

Ia = 0.2S (8)

Where

The Soil Conservation Service presented the relationship between S and the Curve Number method.

$$\mathrm{CN} = \frac{1000}{\mathrm{S}+10} \quad (9)$$

The retention parameter S was calculated using the Antecedent Moisture Condition (AMC), which was determined by considering the cumulative rainfall over a five-day period. In this context, AMC I, AMC II, and AMC III represent three levels of AMC that are used to characterize the wetness of the watershed area.

Upon solving equation (5), the outcomes can be obtained using the following equation:

S = 5(P+2Q-(4Q2+5PQ)1/2 (10)

Where

P, Q, and S in mm
P = Total annual rainfall,
Q = Total annual runoff,
S = Potential maximum retention.

2.2 Antecedent Moisture Condition (AMC)

Antecedent moisture-condition has been calculated for Kachhinda watershed of Morena district by taking five days preceding rainfall data of a storm event. Antecedent Moisture Condition (AMC) is utilized as a metric for assessing the wetness of a watershed. Table 1 illustrates the implementation of a three-level AMC classification. AMC I - Lowest runoff potential. The Kachhinda watershed has dry soil enough for satisfactory cultivation to take place (less than 35 mm)

AMCII - Average condition (35 to 52.5 mm)

AMCIII - The Kachhinda watershed exhibits a high runoff potential due to saturation caused by previous rainfall. The determination of the Antecedent Moisture Condition (AMC) group involves considering a five-day period of antecedent rainfall, specifically rainfall exceeding 52.5 mm.

2.3 Converting the Value of CN I and CN III to CNII

To convert Curve Number II and Curve Number III into Curve Number II, Chow et al. (1988) proposed the Curve Number method. This study utilized the same approach to convert Curve Number I and Curve Number III into Curve Number II. The specific methods of conversion are described as follows.

CNI = 4.2CNII / (10-0.058CNII)

CNIII = 23CNII / (10+0.13CNII)

Table 1. Antecedent Moisture Condition (AMC)

AMC type	Total rainfall in past 5 days	
	Dormant Season	**Growing Season**
I	Less than 13mm	Less than 36mm
II	13-28mm	36-53mm
III	More than 28mm	More than 53mm

2.4 Autoregressive Time Series (AR) Model

The Autoregressive time series model, denoted as AR(p), represents the current value of a variable as a weighted sum of a predetermined number of lagged values and a random component based on the previous values of the process. This model equation is commonly expressed as:

$$Y_t = \bar{Y}\Phi_1(Y_{t-1}-\bar{Y}) + \Phi_2(Y_{t-2}-\bar{Y}) + ... + \Phi_p(Y_{t-p}-\bar{Y}) + \varepsilon_t \quad (11)$$

$$Y_t = \bar{Y} + \sum_{j=1}^{p} \Phi_j (Y_{t-j} - \bar{Y}) + \varepsilon_t \quad (12)$$

Where,

Y_t = The time dependent series (variable)
ε_t = The time independent series which is independent of Y_t and is normally distributed with mean zero and variance σ^2
Ȳ = Mean value rainfall and runoff data
$\Phi_1, \Phi_2 .... \Phi_p$ = Autoregressive parameter

2.5 Estimation of Autoregressive Parameter (Φ) Maximum Likelihood Estimate

For estimation of the model parameter by the method of maximum likelihood will be used [20]. Consider the sum of cross-products,

$z_i z_j + z_{i+1} z_{j+1} + ... + z_{n+1-j}\, z_{n+1-1}$

and define

$$D_{ij} = D_{ji} = \frac{N}{N+2-i-j} \sum_{l=0}^{N+1-(i+j)} z_{i+l}\, z_{l+i}$$

Where,

D=difference operator,
N=sample size
i,j=maximum possible order

The maximum likelihood estimates of the parameters $\Phi_1, \ldots\ldots\ldots\ldots, \Phi_p$ are found by solving the system of equations

$D_{ij} = \Phi_1 \; D_{j2} = \Phi_2 \; D_{j3} + \ldots\ldots\ldots\ldots\ldots + \Phi_p \; D_{j,p+1},$

j=2, ..., p+1 for $\Phi_1 \ldots\ldots\ldots\ldots, \; \Phi_p$

AR (1) : $\Phi_1 = \dfrac{D_{1,2}}{D_{2,2}}$

AR (2) : $\Phi_1 = \dfrac{D_{1,2}D_{3,3} - D_{1,3}D_{2,3}}{D_{2,2}D_{3,3} - D_{2,3^2}}$

$$\Phi_2 = \frac{D_{1,3}D_{2,2} - D_{1,2}D_{2,3}}{D_{2,2}D_{3,3} - D_{2,3^2}}$$

2.6 Land Use and Land Cover Classification Map

The land use and land cover classification map of the study area was generated using unsupervised classification methodology, primarily because there was a scarcity of ground-level truth data for accurate classification. The unsupervised classification procedure was carried out using ArcGIS software, as illustrated in the analysis Fig. 1. This category encompasses land that is deteriorating due to insufficient water resources and soil quality issues caused by natural factors. Approximately 42 hectares of the total mapped area fall into this category, including subcategories such as salt-affected land, gullied/ravaged land, and scrubland.

2.7 Hydrologic Soil-Group Conditions (HSG)

The classification of hydrological soil groups is presented in Table 2. The determination of Curve Number values for the watershed was based on both the hydrological soil group and the antecedent moisture conditions. In particular, the Curve Number values for antecedent moisture conditions -I and antecedent moisture conditions -III were derived from the values corresponding to antecedent moisture conditions -II.

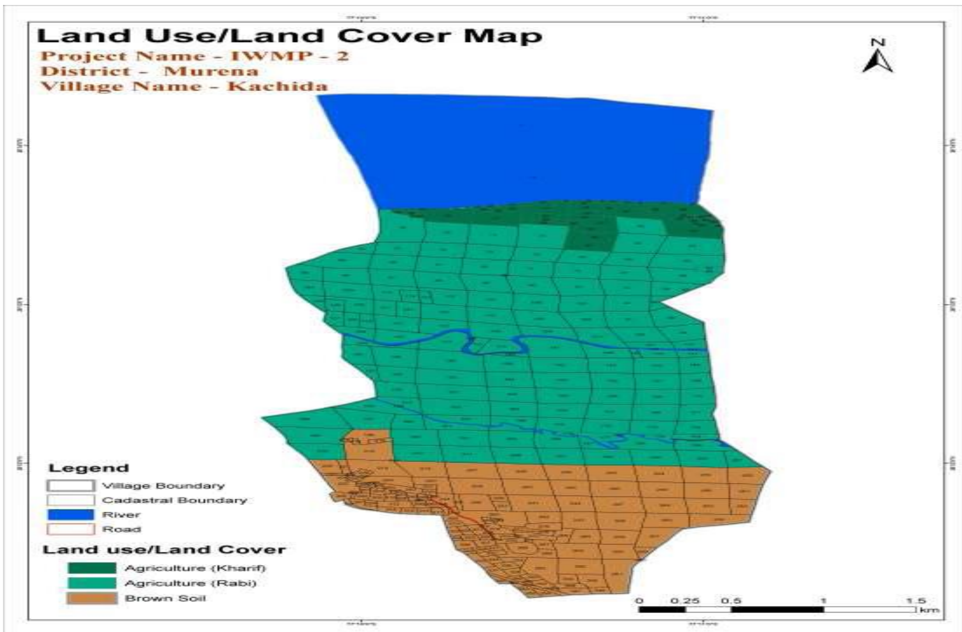

Fig. 1. Land use map of study area

Table 2. Tentative hydrological classes of different types of soils

S. No.	Soil Types	Tentative hydrological grouping
1.	Alluvial Soil riverine (non-saline) non calcareous to moderately calcareous	B
2.	Alluvial soil, riverine (highly calcareous)	B
3.	Alluvial soil, developed on cost as alluvial soil (occasionally saline soil)	A
4.	Alluvial soil, developed on deltaic as alluvial (occasionally saline soil)	B
5.	Alluvial soil riverine affected by salinity and alkalinity	C
6.	Pedocal sierozem of alluvial origin	C
7.	pedicle brown soil of alluvial parent	C
8.	Grey and brown soil (sands) soil	D
9.	Desert soil	A
10.	Deep black soil	D
11.	Medium black soil	D
12.	Shallow black soil	D
13.	Black soil affected by salinity and alkalinity factors	D
14.	Black soil undifferentiated	D
15.	Mixed red and black soil	C
16.	Ferraugious red soil	B
17.	Ferraugious red gravelly	B
18.	Red and yellow soil	C
19.	Laterite	B
20	Laterite and black soil	D
21.	Brown soil under deciduous forest	B
22.	Forest soil	B
23.	Podsolic soil	B
24.	Foothill (tarai) soil	C
25.	Mountain and hill soil	B
26.	Mountain meadow soil	B
27.	Peat	B
28.	Glaciers and eternal snow	B

3. RESULTS AND DISCUSSION

3.1 SCS-Curve Number Method

Potential maximum retention values (S) were estimated and the findings are presented in Table 3. The table illustrates a range of potential maximum retention values from 1062.464 mm to 1865 mm, indicating higher surface runoff as indicated in Table 3. The Soil Conservation Services (1964; 1972) introduced the Curve Number, which suggests that the initial abstraction corresponds to 20 percent of the potential maximum retention value S. This value is considered an average estimate due to significant variations observed in the data plots. However, several researchers [21] have reported lower initial abstraction values than 20 percent of the potential maximum retention value, with percentages of 15, 10, or even lower. In addition, [22] proposed modifying the Soil Conservation Services Curve Number (SCS-CN) method (SCS, 1956) to include the static portion of infiltration and antecedent moisture condition.

A statistical model was created to analyze the correlation between measured surface runoff and estimated surface runoff in the Kachhinda watershed of Morena district, Madhya Pradesh. The results, presented in Table 4 and Fig. 2, indicated a significant relationship between the observed and estimated values of surface runoff, with a coefficient of determination (R2) of 0.9748, indicating a strong association.

3.2 Statistical Parameters of Autoregressive Time Series (AR) Models for Surface Runoff

Statistical Parameters of Autoregressive time series (AR) Models for surface runoff are AIC value for AR (1) model is (0.919158) which is lying between AR (0) is (0.207433) and AR (2) is (5.9767), White Noise, Akaike Information Criterion, AIC (P), Value of Porte Moniteau statistics, Q and Degree of freedom up to 5 large as shown in Table 5.

Table 3. Potential maximum retention values (S)

Year	Observed rainfall (mm)	Observed runoff (mm)	Potential maximum retention (S) (mm)	Initial abstraction (0.2S) (mm)
2001	715	112.8	1333.44	266.688
2002	722	146.9	1152.718	230.5436
2003	790	76.2	1865	373
2004	810	115.4	1596.23	319.246
2005	785	153.3	1287.550	257.51
2006	698	113.2	1281.622	256.3244
2007	735	140.1	1224.44	244.888
2008	585	96.7	1062.464	212.492
2009	732	125.4	1301.990	260.398
2010	636	110.6	1121.20	224.24

Table 4. Relationship between measured and estimated surface runoff by curve number method

Year	Rainfall (mm)	Observed runoff (mm)	Estimated runoff (mm)
2001	715	112.8	176.652
2002	722	146.9	209.224
2003	790	76.2	147.543
2004	810	115.4	188.279
2005	785	153.3	221.554
2006	698	113.2	175.383
2007	735	140.1	204.60
2008	585	96.7	148.716
2009	732	125.4	190.233
2010	636	110.6	166.830

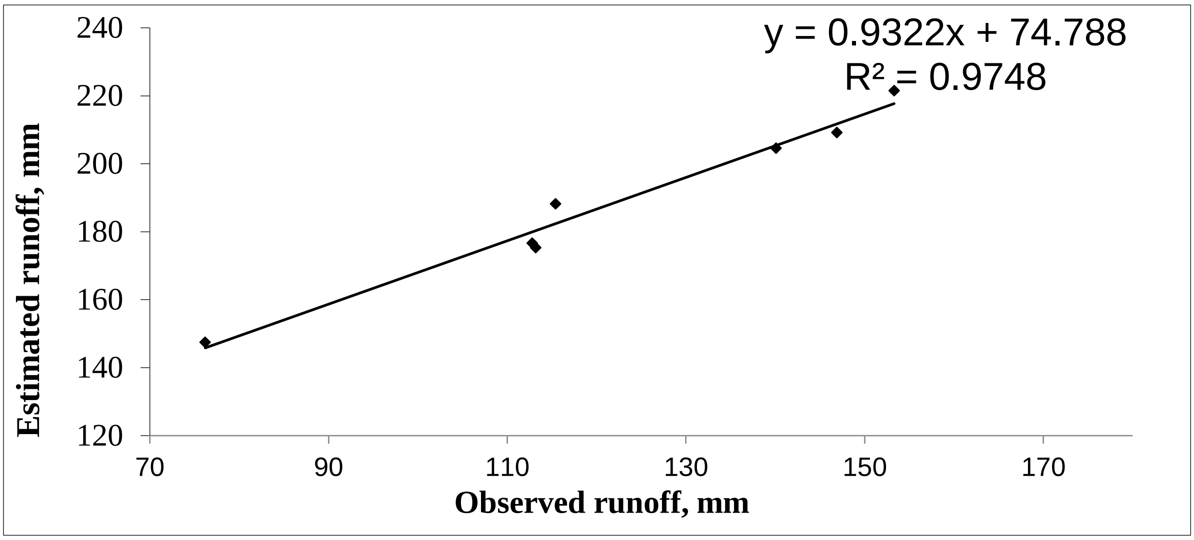

Fig. 2. Relationship between observed and estimated runoff

A statistical model was created to analyze the relationship between the observed and estimated surface runoff values of the Kachhinda watershed in Morena district, Madhya Pradesh. This relationship was illustrated in Table 6 and Fig. 3. The coefficient of determination (R2) was determined to be 0.9956, indicating a robust correlation between the measured and estimated surface runoff values.

Table 5. Statistical parameters of autoregressive time series (AR) models for surface runoff

Modle	AR (0)	AR(1)	AR (2)
Autoregressive Parameters		$\Phi_1 = 0.91918$	$\Phi_1 = 5.9767$ $\Phi_2 = 0.207433$
White Noise	85.9493	52.6283	3.5862
Akaike Information criterion, AIC (P)	151.42	136.750	68.6987
Value of Porte Moniteau statistics, Q	91.9493	75.6283	16.5862
Degree of freedom upto 5 lage	5	4	3

Table 6. Given the two models can be compared as observed and estimated runoff

Year	Rainfall (mm)	Observed runoff (mm)	AR (estimated) runoff (mm)
2001	715	112.8	115.42
2002	722	146.9	151.31
2003	790	76.2	80.37
2004	810	115.4	116.6
2005	785	153.3	157.27
2006	698	113.2	113.91
2007	735	140.1	141.14
2008	585	96.7	98.147
2009	732	125.4	130.51
2010	636	110.6	114.07

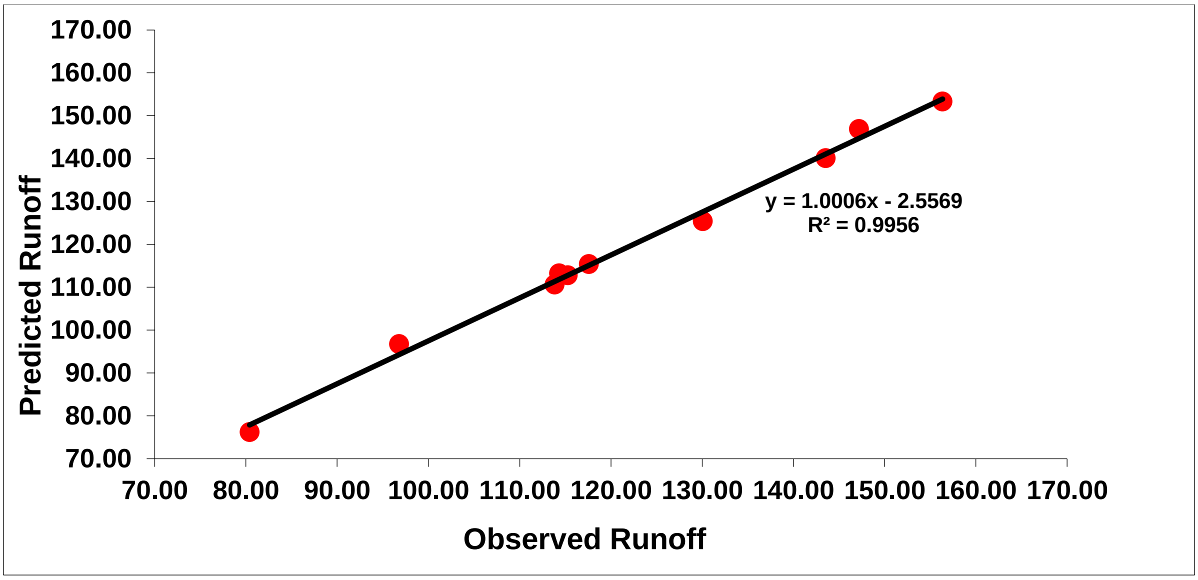

Fig. 3.Relationship between observed and predicted surface runoff

4. CONCLUSION

The initial model mentioned in your statement pertains to the Soil Conservation Service Curve Number (SCS-CN) method, widely employed in hydrology and environmental engineering to assess surface runoff resulting from rainfall. This technique employs the concept of potential maximum retention and assigns a Curve Number to a watershed, aiding in the estimation of runoff. In the case of the Kachhinda watershed, the SCS-CN method was utilized to estimate the Curve Number specifically for that area. A comparison between the estimated Curve Number and the observed surface runoff revealed a close agreement, indicating the accuracy of the estimated runoff derived from the Curve Number. Subsequently, a regression model was developed to establish a relationship between the observed and estimated surface runoff. The correlation coefficient, which measures the strength and direction of this relationship, was determined to be 0.974 and 0.995 for the Curve Number and Autoregressive models, respectively. This suggests a strong correlation between both models and the observed surface runoff, with the Autoregressive model demonstrating slightly better performance in terms of the correlation coefficient. Thus, based on the available information, it appears that the Autoregressive model outperformed the Curve Number model in estimating surface runoff. However, it is crucial to consider the specific characteristics of the study area and the limitations associated with each model before drawing definitive conclusions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Banasik K. Model sedymentogramu wezbrania opadowego w małej zlewni rolniczej [Sediment graph model of a rainfall event in a small agricultural watershed]. Publication of Warsaw Agricultural University – SGGW. 1994;15:120.
2. Deshmukh DS, Chaube UC, Hailu AE, Gudeta DA, Kassa MT. Estimation and comparison of curve numbers based on dynamic land use land cover change, observed rainfall-runoff data and land slope. Journal of Hydrology. 2013;492:89–101.
3. Chauhan MS, Kumar V, Rahul AK. Modelling and quantifying water use efficiency for irrigation project and water supply at large scale. Int. J. Adv. Sci. Tech. Res. 2013;2(3):617–639.
4. Ignar S. The SCS method and its application for effective rainfall determination. Rev. Geophys. 1988;32:451–455.
5. Ignar S, Banasik K, Ignar A. Random variability of curve number values for SCS runoff procedure. In Proceedings of the International Conference on Hydrological Processes in the Catchment, Cracow. 1995:127–130.
6. Washington DC, USA. USDA Natural Resources Conservation Service. Hydrology. In National Engineering Handbook; USDA Soil Conservation Service: Chapter 21; 1972.
7. Ponce VM, Hawkins RH. Runoff curve number, has it reached maturity? J. Hydrol. Eng. 1996;1:11–19.
8. Hawkins RH. Runoff curve numbers with varying site moisture. J. Irrig. Drain. Div. 1978;104:389–398.
9. Simanton JR, Hawkins RH, Mohseni-Saravi M, Renard KG. Runoff curve number variation with drainage area, Walnut Gulch, Arizona, Soil and Conservation Division. Trans. ASAE. 1996;39:1391–1394.
10. Steenhuis TS, Winchell M, Rossing J, et al. SCS runoff equation revisited for variable-source runoff areas. J. Irrig. Drain. Eng. 1995;121:234–238.
11. Bonta JV. Determination of watershed curve number using derived distribution. J. Irrig. Drain. Eng. 1997;123:28–36.
12. Sahu RK, Mishra SK, Eldho TI, Jain MK. An advanced soil moisture accounting procedure for SCS curve number method. J. Hydrol. Proc. 2007;21:2872–2881.
13. Mishra SK, Singh VP. A re-look at NEH-4 curve number data and antecedent moisture condition criteria. Hydrol. Process. 2006;18:3323–3354.
14. Mishra SK, Singh VP. SCS-CN-based hydrologic simulation package. In Mathematical Models in Small Catchment Hydrology and Applications; Singh VP, Frevert DK, Eds.; Water Resources Publications: Littleton, CO, USA. 2002:391–464.
15. Mishra SK, Singh VP. Soil Conservation Service Curve Number (SCS-CN) Methodology; Kluwer Academic Publishers: Dordrecht, The Netherlands; 2003.
16. Mishra SK, Singh VP. Derivation of the SCS-CN parameter S from linearized Fokker-Planck equation. Acta Geophys. Polon. 2003;51:179–202.
17. Merz R, Blöschl G. A regional analysis of event runoff coefficients with respect to climate and catchment characteristics in Austria. Water Resour. Res. 2009; 45.
    DOI: 10.1029/2008WR007163
18. Wang N, Chu X. A Modified SCS curve number method for temporally varying rainfall excess simulation. Water. 2023;15(13):2374.
19. Handbook of Hydrology. Soil Conservation Department, Ministry of Agriculture, New Delhi; 1972.

20. Box GEP, Jenkins GM. Time-series analysis, forecasting and control: Holden day, San Francisco, USA; 1970.
21. Springer EP, McGurk BJ, Hawkins RH, Coltharp GB. Determination of direct runoff with the 'curve number method' in the coastal area of Tanzania/East Africa. Wasser und Boden, I. 1980:13-16.
22. Blaszczynski J. Agricultural Research Service, Channel and Watershed Processes Research Unit, National Sedimentation Laboratory, Oxford; 2003.

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