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Spatial Analysis of Surface Runoff Using SCS-CN Technique Integrated with GIS and Remote Sensing

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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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Review Article

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ABSTRACT

The Soil Conservation Service (SCS) Curve Number (CN) method is a widely employed hydrological model for estimating surface runoff in watershed studies. This method utilizes land use, soil characteristics, and hydrologic soil grouping information to assign a CN that represents the

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potential for surface runoff of a specific area. The paper presents a comprehensive study on surface runoff estimation using the SCS Curve Number method integrated with Geographic Information System (GIS) and remote sensing technologies. The incorporation of GIS enhances the spatial representation and analysis of diverse influencing factors, contributing to more informed decision-making in water resource management. The Loose Coupling Model for Runoff Computation, combining GIS and simulation models, is appropriately employed. The study discusses the methodology, including the Thiessen polygon and the Improved Composite CN Computation Method, showcasing a meticulous approach. Results and discussions are supported by relevant studies, reinforcing the credibility of the research. Overall, the paper provides valuable insights for researchers and practitioners in the field of hydrology and water resource management. Future work in this field could focus on refining the SCS-CN method through improved data integration and model calibration. Additionally, exploring advanced machine learning techniques for enhancing the predictive capabilities of GIS-based surface runoff models could offer valuable insights for sustainable water resource management.

Keywords: SCS-CN; GIS; hydrologic soil group; runoff model.

1. INTRODUCTION

Surface runoff, a consequence of precipitation exceeding soil's infiltration capacity, is pivotal in water movement on Earth's surface and its interplay with soil. The fate of land water hinges on soil's physical and chemical makeup when precipitation occurs. This runoff occurs when rainfall or snowmelt surpasses soil infiltration, leading to water flow over soil. It's a critical component of the water cycle, shaping natural environments and human activities alike [1]. Soil attributes like texture, structure, and permeability profoundly affect water infiltration and subsequent runoff. High clay content or compaction reduces permeability, increasing runoff, while well-structured and permeable soils minimize it. Understanding these dynamics is crucial for managing water resources sustainably.

Surface runoff characteristics are shaped by a multitude of factors, including the:

Topography: The slope and shape of the land surface significantly impact the speed and direction of surface runoff. Steeper slopes generally result in faster runoff, while flat or gently sloping areas may allow water to spread out and move more slowly. **Land Cover and Land Use:** Different types of land cover, such as urban areas, forests, agricultural fields, and natural landscapes, affect surface runoff differently. Impermeable surfaces like pavement and buildings in urban areas can increase runoff by preventing water from infiltrating into the soil. **Soil Type and Porosity:** The type of soil and its porosity (ability to allow water to pass through) influence how much water can be absorbed and how quickly runoff occurs. Sandy soils typically allow for faster infiltration than clayey soils. **Vegetation:** Plants play a crucial role in controlling surface runoff. They help absorb and slow down water, reducing the risk of erosion. The density and type of vegetation cover impact runoff characteristics. **Climate and Precipitation Patterns:** The amount, intensity, and duration of precipitation events, as well as the overall climate of an area, influence surface runoff. Heavy rainfall or prolonged precipitation can lead to increased runoff. **Antecedent Soil Moisture:** Antecedent soil moisture, which refers to the soil's moisture content prior to rainfall, greatly influences surface runoff characteristics, influences how much water the soil can absorb. Saturated soil from previous rainfall can lead to increased surface runoff. **Geology:** The underlying geological features of an area can affect the permeability of the soil and influence how water moves over the surface. **Land Management Practices:** Agricultural practices, land development, and other land management activities can impact surface runoff by altering the natural characteristics of the land. Understanding these factors is crucial for managing and mitigating issues related to surface runoff, such as erosion, flooding, and water pollution. Effective land-use planning and sustainable water management practices take these factors into account to minimize the negative impacts of surface runoff.

The understanding of surface runoff in soil science is crucial for assessing water availability for plants, managing soil erosion, and preserving water quality [2]. As runoff travels over the soil surface, it can carry sediments, nutrients and other substances, impacting both soil fertility and water quality. Soil scientists analyze the dynamics of surface runoff to develop effective soil and water conservation strategies, prevent erosion and optimize land management practices [3,4]. In essence, surface runoff serves as a key indicator for soil scientists, offering insights into the complex interplay between precipitation, soil properties and water movement within ecosystems. Adequate scientific planning and management of water harvesting structures necessitate a comprehensive dataset for accurate predictions regarding water availability [5]. Modern and quickly evolving technologies like Remote Sensing (RS) and Geographic Information System (GIS) offer significant potential in addressing the current challenges encountered by soil scientists.

Numerous empirical and semi-empirical formulas describe the relationship between rainfall and runoff volumes. Among various runoff assessment techniques, the USDA's Soil Conservation Service (SCS) curve number method, also termed the Curve Number (CN) method, stands out as widely acknowledged. It offers a straightforward, reliable, and consistent conceptual framework for analyzing rainfall-runoff dynamics.

2. SCS-CURVE NUMBER

In 1933, the Soil Erosion Service (SES) was established in the United States the agency underwent a transformation with the Soil Conservation Act of 1935, leading to its renaming as the Soil Conservation Service (SCS). Recognizing the necessity for hydrological data and a straightforward method to estimate runoff rates/potential, SCS took initiative. The passage of the Flood Control Act of 1936 (Public Law 74-738) then authorized the Department of Agriculture to conduct watershed surveys and investigations. These efforts aimed to implement measures that would slow down runoff and water flow while preventing soil erosion.

The assumption is made that the ratio of direct runoff (Q) to rainfall (P) minus the initial loss (P – Ia) equals the ratio of actual retention to storage capacity (S).

$$\frac{Q}{P-1_a} = \frac{P-Q-1_a}{S} \qquad \ldots\ldots\ldots\ldots (1)$$

By assuming that the initial abstraction (Ia) is a fraction of the storage capacity (S), typically represented as Ia = 0.2S on average, equation (1) is transformed into

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

With knowledge of both P (precipitation) and S (storage capacity), one can calculate the value of Q (direct runoff), which shares the same units as P and is commonly expressed in millimeters.

The Soil Conservation Department (1972) made modifications and put forward specific equations tailored for various regions across India:

❖Rainfall runoff equations have been developed for India. The equations are as follows:

$$Q = \frac{(P-0.3S)^2}{P+0.7S} \qquad \ldots\ldots\ldots\ldots\ldots (3)$$

The Soil Conservation Department in 1972 provided a convenient method to evaluate antecedent rainfall, soil conditions, and land use practices through the curve number:

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

SCD in 1972 established curve numbers representing the recharge capacity (S) of watersheds, categorized into various groups. These values are based on average antecedent rainfall conditions.

Antecedent Soil Moisture: It refers to the water content present in the soil at a given time. Antecedent soil moisture conditions play a crucial role in determining the curve number [6,7].

The antecedent moisture condition is divided into three categories:

1. **Antecedent Moisture Condition I (AMC I):** Dry soil conditions. This occurs when the soil is dry and little or no moisture is present. AMC I is associated with lower curve numbers.
2. **Antecedent Moisture Condition II (AMC II):** Average or typical soil moisture conditions. This is considered a moderate state, with some moisture present in the soil. AMC II has **moderate curve numbers.**
3. **Antecedent Moisture Condition III (AMC III):** Wet soil conditions. This occurs when the soil is saturated, and significant moisture is present. AMC III is associated with higher curve numbers.

Thiessen polygon: Thiessen polygon is a geometric method used in hydrology and meteorology to estimate rainfall distribution across a given area based on a network of rainfall measurement stations. This method assumes that the influence of each rainfall station extends equally in all directions until it meets the influence of neighbouring stations, creating polygons that cover the entire area of interest.

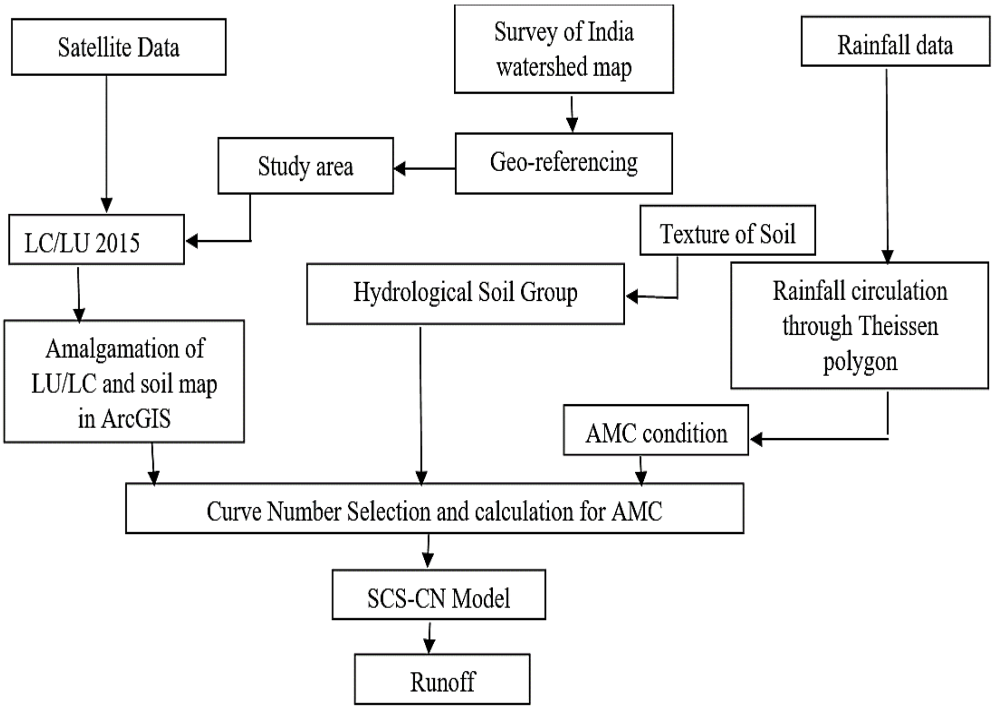

Fig. 1. General chart of methodology for surface runoff

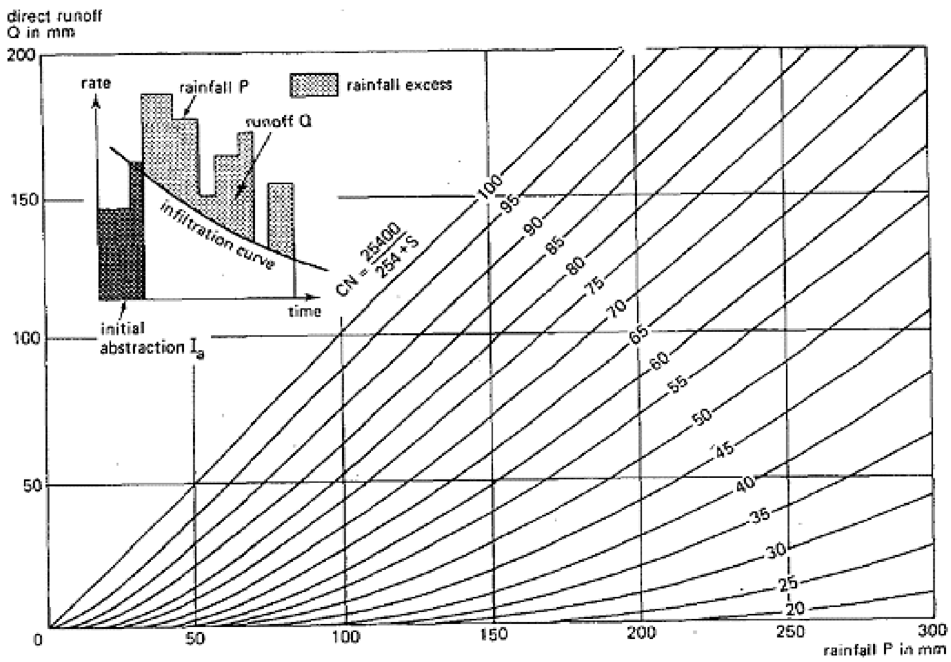

Fig. 2. SCS-Curve number

❖ The curve number is a dimensionless parameter ranging from 0 to 100

Table 1. USDA-SCS Soil classification

HSG	Types of Soil	Soil Textures	Runoff Potential	Minimum Rate of Infiltration (mm/hr)	Water transmission
A	Deep, well-drained soils	Sand, loamy sand or sandy loam	Low	7.62-11.43	High rate (0.30 in/hr)
B	Soil is moderately deep, well-drained, and exhibits textures ranging from moderately fine to coarse.	Silt loam or loam	Moderate-low	3.81-7.62	Moderate rate (0.15-0.30 in/hr)
C	Moderately fine to fine textures	Sandy clay loam	Moderate	1.27-3.81	Low rate (0.05-0.15 in/hr)
D	Soil expands considerably when wet, has a dense, plastic texture, and maintains a consistently high water table.	Silty clay loam, sandy clay, silty clay, clay, clay loam	High	0-1.27	Very low rate (0-0.05 in/hr)

Table 2. Runoff curve numbers for hydrologic soil cover

Sl. No	Land use	Hydrologic Soil Group			
		A	B	C	D
1	**Agriculture**	72	81	88	91
2	**Double Crop**	62	71	88	91
3	**Plantation**	45	53	67	72
4	**Commercial**	89	92	94	95
5	**Industrial**	81	88	91	93
6	**Urban**	89	92	94	95
7	**Village**	72	82	87	91
8	**Land with scrub**	36	60	73	79
9	**Land without scrub**	45	66	77	83
10	**Scrub forest**	33	47	64	67
11	**Canal**	100	100	100	100
12	**River**	97	97	97	97
13	**Reservoir**	100	100	100	100
14	**Quarry**	71	87	89	91

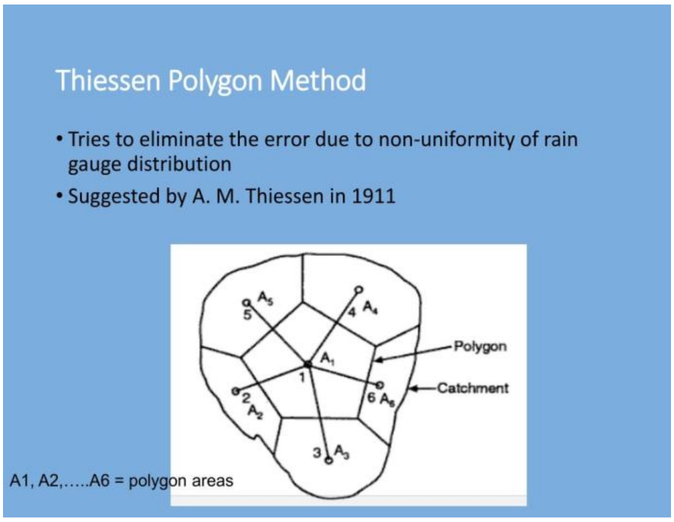

Fig. 3. Thiessen polygon method

3. METHODOLOGY USED IN THIS STUDY

3.1 Integrated RS-GIS Approach to Surface Runoff Modeling

Integrated RS-GIS approaches are utilized for surface runoff modeling, involving three main components: (a) land class derivation of the study area using remote sensing (RS), (b) determination of hydrological parameters using GIS and (c) runoff modeling with GIS. The land class type and soil data provided the hydrological curve number, a crucial parameter for hydrologic models [8]. Hydrological parameters, such as maximum storage, which are directly related to runoff calculation, were determined using the curve number. Land-use types were employed as independent variables in the proposed methodology. Finally, runoff was calculated using precipitation data and the maximum storage dataset.

“Various hydrologic models exist to assess the quantity of direct runoff resulting from rainfall in a river basin. These models range from complex to straightforward, with varying structures and data input requirements. Nonetheless, simple empirical equations linked to basin properties, as well as intricate physical models, are available to estimate basin runoff” [9]. “The SCS-CN (Soil Conservation Service Curve Number) method is a widely used approach for estimating direct surface runoff from rainfall, favored by hydrologists, environmentalists, and irrigation engineers” [10,11,12,13,14,15]. “The SCS model is primarily employed for direct runoff assessment. The initial step in measuring runoff involves demarcating and calculating the river basin's stream or drainage area. The SCS-CN method is the most commonly used empirical technique to determine direct runoff from a watershed or river basin [16]. The SCS-CN equation relates runoff volume to rainfall volume, explaining the water balance equation as articulated by Soulis and Valiantzas (2012).

3.2 Loose Coupling Model for Runoff Computation

- In the loose coupling model, GIS and simulation models are treated as separate software packages, with data transferred between them by storing data in one system and then reading it from the other [17].
- Accordingly, loose coupling (linked to GIS) model was used, after developing the curve number in the GIS environment.

Various thematic maps were created using ERDAS Imagine 9.1 and ArcGIS 9.3, including contour maps, drainage maps, DEMs, slope maps, and land use/land cover maps. Initially, the base map was derived from Survey of India (SOI) toposheets at a scale of 1:50,000 [8].

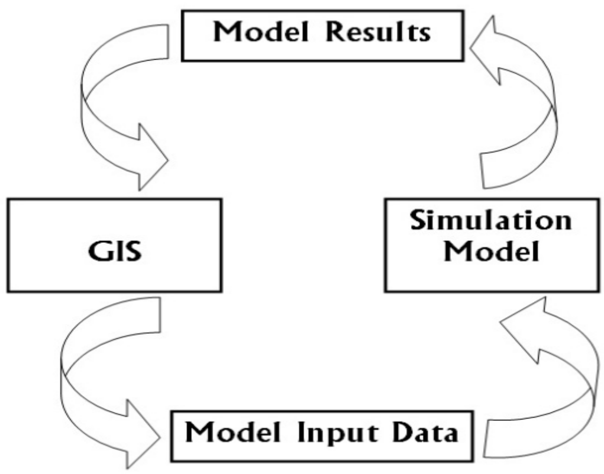

Fig. 4. Loose coupling model

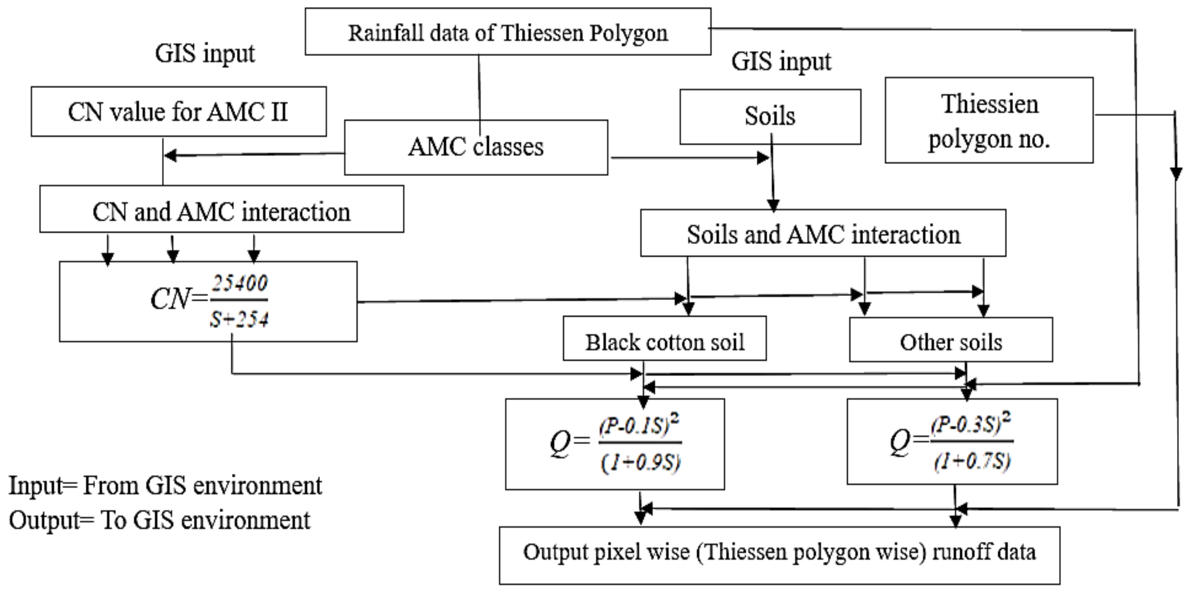

Fig. 5. Flow diagram used for developing program for calculating runoff from GIS input data

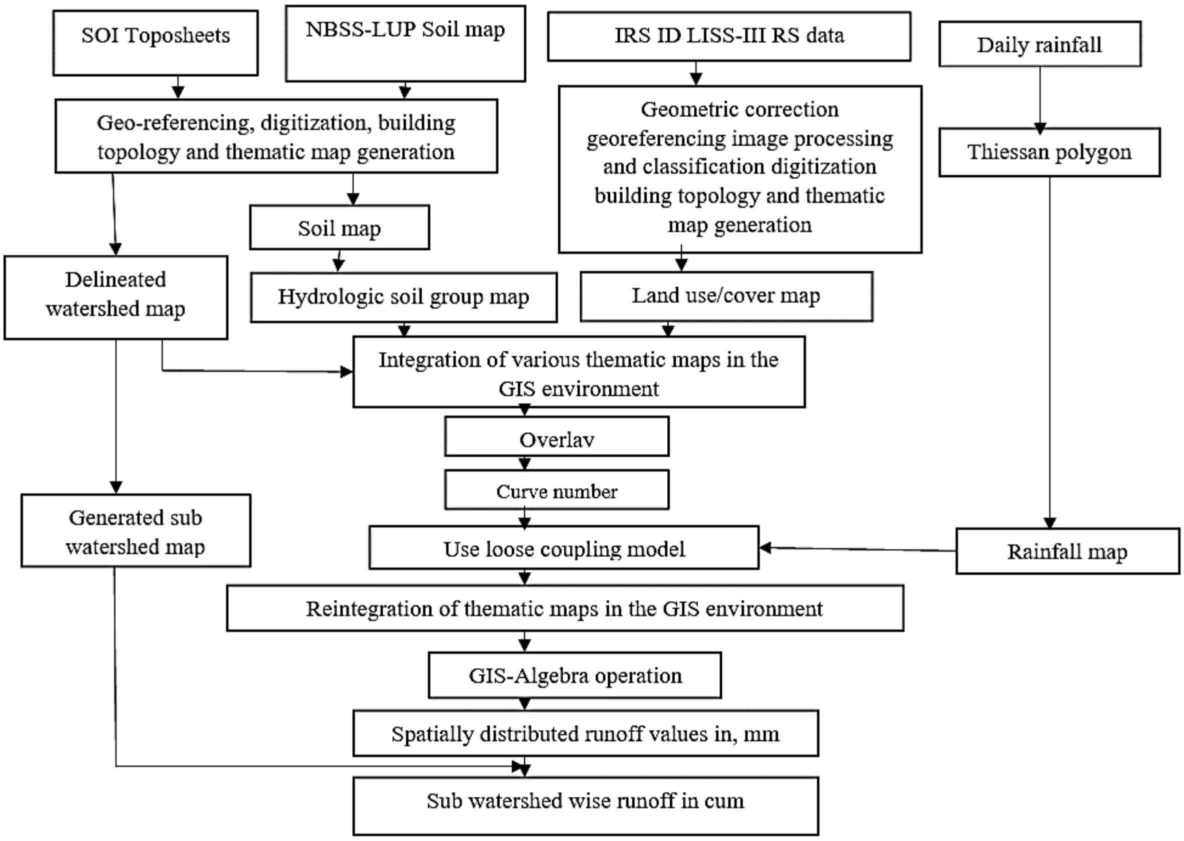

Fig. 6. Flow chart depicting the detailed procedure of calculating runoff under the GIS environment

3.3 Extracting Vegetation, Impervious Surface and Soil Fractions

The composite Curve Number (CN) is determined using impervious surface data obtained through Linear Spectral Mixture Analysis (LSMA), a method known for its physically based approach to image processing, ensuring consistent and precise extraction of quantitative sub-pixel details [18].

The assumption is that the sensor's spectrum measurement is a linear amalgamation of all the component spectra within the pixel.

The mathematical model of LSMA can be expressed as:

$$R_i = \sum_{k=1}^{n} f_k R_{ik} + ER_i$$

Here, 'i' ranges from 1 to m (the number of spectral bands), and 'k' ranges from 1 to n (the number of end members). 'Ri' represents the spectral reflectance of band i containing end members, 'fk' denotes the proportion of end member k within the pixel, 'Rik' stands for the known spectral reflectance of end member k within the pixel on band i, and 'ERi' indicates the error associated with band i.

The accuracy of the un-mixing results is assessed by calculating the Root Mean Square Error (RMSE), which can be expressed as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (\hat{X}_i - X_i)}{N}}$$

In this context, "$\hat{X}_i$" represents the estimated percentage of impervious surface for sample i derived from Landsat data, while 'Xi' represents the corresponding ground reference percentage from high spatial resolution imagery for the same sample i. 'N' denotes the total number of samples used for evaluation.

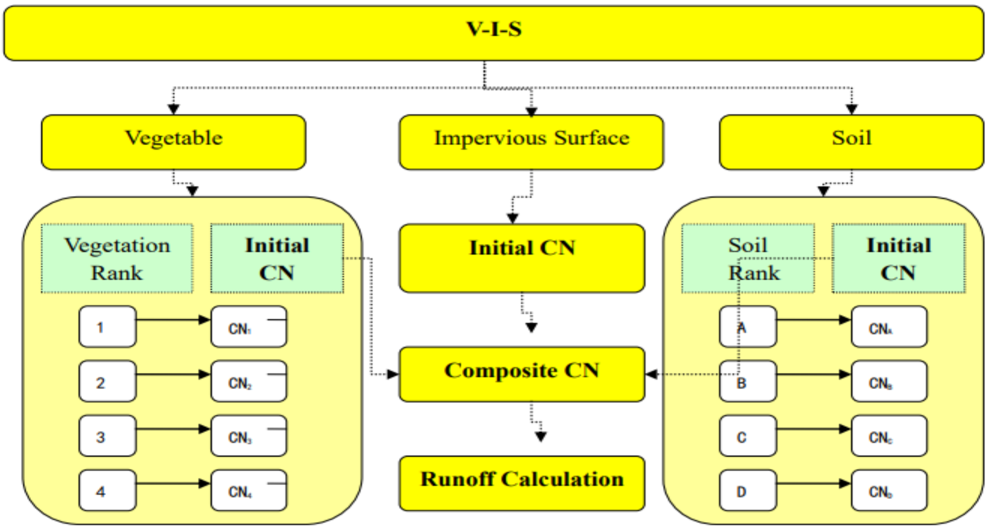

Fig. 7. Procedure for computing composite CN

3.4 Improved Composite CN Computation Method

To derive the composite Curve Number (CN) for Guangzhou, each 30 m × 30 m pixel is treated as a standalone drainage area, comprising impervious surfaces, vegetation, and soil exclusively. This analysis assumes all soil types, vegetation types, and impervious surfaces to fall under AMC-II conditions, necessitating adjustments from the CN values for dry soils (AMC-I) and wet soils (AMC-III) [18].

1The paper outlines a procedure illustrated in Fig. 4 for computing composite CN, involving four sequential steps:

First, NDVI values are gathered and vegetation types are classified, with NDVI values sorted into four categories and each assigned an initial CN value from the TR-55 table. Next, V-I-S fraction images are derived using the LSMA model, extracting fractions for vegetation, impervious surfaces, and soil from satellite imagery. Subsequently, soil is classified based on type, with each soil type assigned an initial CN value from TR-55 according to its properties. Finally, the composite CN is determined as the weighted average of initial CN values for vegetation, impervious surfaces, and soil fractions.

The Composite CNs (Curve Numbers) are predominantly influenced by soil type and antecedent moisture conditions, representing the average moisture levels before a rainfall event. This study assumes a soil condition ranging from dry to wet for CN estimation. Soil types are categorized into four groups (A to D) based on their infiltration characteristics. Class A comprises well-drained sands and gravels with high infiltration rates and minimal runoff potential. Class B includes soils with moderate to coarse textures and moderate infiltration rates under full saturation. Class C encompasses moderately fine to fine textured soils with lower infiltration rates. Class D is characterized by clay soils or soils with clay layers, exhibiting low infiltration rates when saturated. In Guangzhou, four main soil types are identified: paddy soil, deposited soil, red soil and aquic soil, following the Soil Taxonomy of Guangdong Province.

4. RESULTS AND DISCUSSION

Shirahatti et al. [17] conducted a study focusing on surface water resources assessment in the ungauged upper Don River basin in Karnataka, employing Remote Sensing and GIS methodologies. They adopted the SCS-CN along with the Loose Coupling Model for Runoff Computation. Analysis of the annual runoff data revealed that the runoff, expressed as a percentage of annual rainfall, fluctuated between 5.08% and 25.66%, averaging 14.38% (equivalent to 81.6 mm) as shown in Table 3. Furthermore, runoff calculations were conducted across various probability levels for both daily and monthly rainfall events. The average annual runoff yield for each sub-watershed ranged from 121.33 to 927.44 ha-m, with a mean value of 488.88 ha-m. Previous studies by Durbude and Chandramohan [19] as well as Sarkar et al. [20]

employed a similar methodology to produce the curve number map. Fan et al. [18] studied the spatial analysis of large impervious surfaces in the southern region, contrasting with a predominance of vegetation in the northern area and exposed soils in the east. The accuracy assessment, with RSME values of 0.19, 0.21 and 0.35 for impervious surface, vegetation and soil fraction maps respectively (Fig. 8), demonstrates good agreement between estimated and ground reference data. The study further categorizes composite Curve Number (CN) values, identifying higher CN values in the south, correlated with a high percentage of impervious surfaces and low vegetation, emphasizing their significant impact on runoff in the southern part of the study area.

An experiment on modelling surface runoff using the soil conservation service-curve number method [7]. The findings indicated that over half of the rainfall water received in the catchment area was lost through runoff, amounting to 229.8 mm, while the effective rainfall available was lower at 246.9 mm compared to the maize crop's actual water requirement of 330 mm. It was anticipated that farmers could harvest a seasonal surface runoff volume of 3008 m^3 ha^{-1} per season and a total of 1.29 × 106 m3 per season for the entire sub-catchment covering 430 hectares. These results are similar to Xin et al, [21] and Singh et al, [22]. Cyili sub-catchment has a higher potential runoff volume to stabilize the deficit of water demand in the period of short rainy season.

Table 3. Year-wise average annual rainfall and corresponding runoff from the average of the sub-watersheds

Year	Annual rainfall 'P' (mm)	Annual runoff 'Q'(mm)	% of 'P'
1998	777.80	134.56	17.10
1999	539.28	79.48	14.20
2000	566.05	79.22	13.62
2001	525.60	137.03	25.66
2002	297.27	31.12	10.00
2003	177.82	9.84	5.08
2004	516.33	57.95	11.09
2005	389.22	38.42	9.29
2006	662.91	91.70	13.58
2007	649.02	158.26	24.24

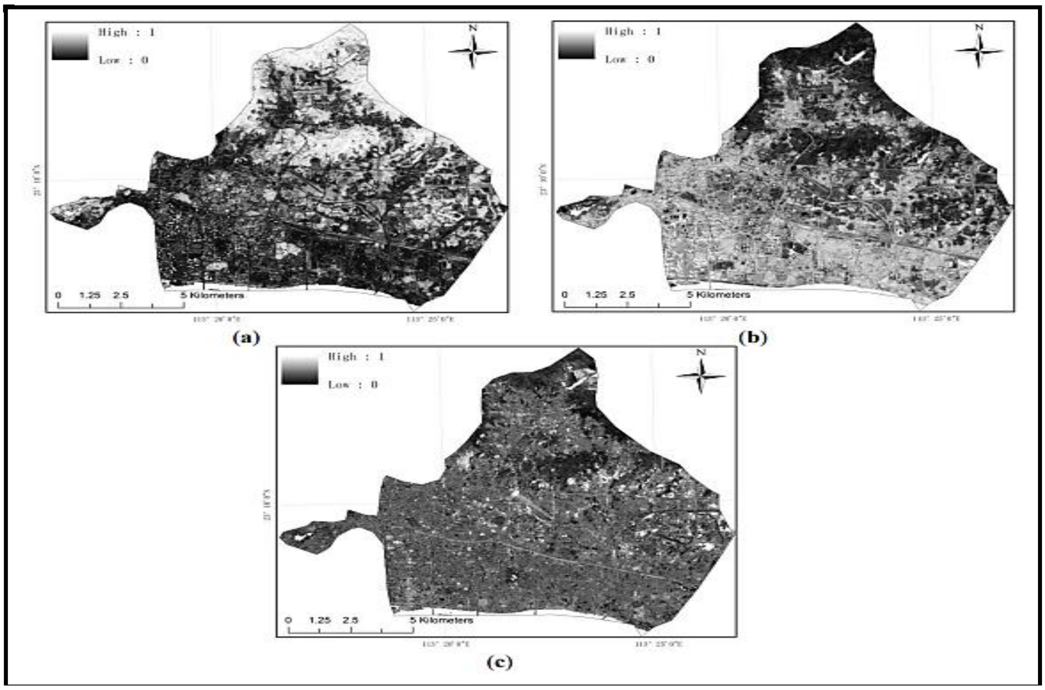

Fig. 8. (a) Vegetation, (b) Impervious surface and (c) Soil fractions

Table 4. Hydrologic soil group classification

Land Group	Information	Infiltration Rate (mm/hr)
A	The smallest running water potential. Including deep sand soil with elements of dust and clay. High infiltration rate.	8-12
B	Water potential. Small runoff, sandy soil shallower than A. fine to medium texture, medium infiltration rate.	4-8
C	Medium runoff water potential. Shallow soil and containing enough clay. Medium to smooth texture. Low infiltration rate	1-4
D	High Runoff Water Potential, mostly clayey, shallow, with an impermeable layer near the soil surface. Very low infiltration	0-1

Table 5. Percentage of land use types in the Benanain watershed

No.	Land Use	Area (Km^2)	Percentage (%)
1	Secondary dryland forest	1,408.20	44.26
2	Shrubs	716.84	22.53
3	Habitation	20.93	0.66
4	Savanna	663.22	20.85
5	Open land	31.72	1.00
6	Primary dryland forest	100.17	3.15
7	Dryland farming mixed with bush	68.26	2.15
8	Body of water	0.25	0.01
9	Dryland farming	171.94	5.40
		3,181.521	100.00

Krisnayanti et al. [4] demonstrated that the land-use analysis of the Benanain watershed yields significant insights, providing valuable information that complements the findings of our study on hydrological dynamics, emphasizing the importance of considering land-use patterns for comprehensive water resource management strategies, The results demonstrated a reduction of 44.26% in secondary dryland forest cover and a 46.502% increase in the hydrological soil group categorized as B, indicating medium to high absorption potential, as detailed in Tables 4 and 5. In the Benanain Watershed, the curve number values varied from 56.54 to 73.90, with a mean CN value of 65.32. The data revealed that surface runoff accounted for only 25.35% of water, marking a 74.65% decrease in rainfall converted to surface runoff across the 29 sub-watersheds in the area. Notably, the pronounced variability in intense rainfall between the rainy and dry seasons exerted a considerable impact on the curve number value, particularly in larger watershed areas [23,24]. Elham Forootan [3] proposed that GIS-based slope-adjusted curve number techniques are effective for estimating runoff in rangelands, a predominant land use type. Removal of vegetation cover significantly increases runoff volume, resulting in the highest slope-adjusted curve numbers for equations a, b, and c (94.99, 95.82, and 95.66) observed in bare land areas, while the lowest slope-adjusted curve numbers (63.11, 66.90, and 74.76) were found in rangelands and agricultural lands, respectively [25,26]. The adjusted slope with 3 parameters gives lower runoff generated, which enables the farmers to adopt suitable conservation measures. Estimated runoff shows good agreement with observed runoff in the study area.

The comprehensive analysis highlights the significance of annual runoff percentages, spanning from 5.08% to 25.66%, with an average of 14.38%. Sub-watershed average annual runoff volumes ranged widely from 121.33 to 927.44 ha-m, with a mean of 488.88 ha-m. These findings hold paramount importance for water balance assessments and are instrumental in designing effective water harvesting and drainage systems within the study region. By combining hydrological analysis with GIS and remote sensing, the study becomes more relevant for implementing efficient and affordable water management strategies. Specifically, the Cyili sub-catchment exhibits a significant potential for runoff volume, which can help mitigate water deficits during periods of limited rainfall. The fact that more than half of the rainwater is lost as runoff underscores the need for integrated watershed management practices and rainwater harvesting initiatives, particularly in drought-prone agro-ecological zones, to enhance water availability and boost crop productivity. The higher elevation and slope of the Cyili sub-catchment have been affecting the hydrology process. Enhancing the SCS-CN method through the integration of remote sensing variables has proven to be a practical and efficient approach for runoff estimation. The CN map, particularly the surface runoff map derived from this method, serves as a valuable tool for effectively managing stormwater. The hydrologic soil group was determined according to soil texture, resulting in four distinct classes, with the dominant class (B) accounting for 68.95% of the watershed. Analysis comparing mean observed and estimated runoff using four performance indicators revealed that the highest agreement between observed and predicted runoff was achieved using equation (a). Leveraging GIS-based methodologies aids water resource decision-makers in accurately identifying critical areas responsible for runoff generation. The Benanain watershed exhibits a curve number range of 56.55 to 73.90, with the W-310 sub-basin recording the highest value due to its predominant scaly clay composition interspersed with boulders and other rock formations. The calculation of CN values within such a vast watershed, coupled with the notable variability in rainfall intensity, markedly influences the overall CN values observed. Accurate calibration of curve numbers necessitates extensive rainfall data over time and precise runoff depth observations, providing crucial calibration data for effective curve number utilization.

5. CONCLUSION

The fusion of the Soil Conservation Service Curve Number (SCS-CN) method with Geographic Information System (GIS) techniques in surface runoff analysis significantly improves the accuracy of runoff potential estimations. By incorporating variables such as land use patterns and soil characteristics, this integrated approach provides a holistic view of watershed behaviors. The synergy between the SCS-CN method and GIS enables precise modeling and enables swift decision-making in areas like water resource management, land use planning, and conservation strategies. This collaborative methodology emerges as an invaluable resource for tackling the intricacies of surface runoff across various geographical contexts.

This research endeavours could focus on enhancing the precision of surface runoff estimations by incorporating more advanced remote sensing techniques and high-resolution spatial data. Additionally, exploring the integration of climate change projections into the hydrological modeling framework would provide valuable insights into potential shifts in runoff patterns. Further studies could also investigate the effectiveness of different water management strategies, such as the implementation of sustainable land use practices and the construction of water harvesting structures, in mitigating water deficits. Long-term monitoring and data collection efforts, especially in drought-prone areas, would contribute to a more comprehensive understanding of hydrological processes and improve the accuracy of predictive models. Lastly, collaborative efforts between researchers, policymakers and local communities are essential for the successful implementation of integrated watershed management practices to ensure sustainable water resource utilization in the face of changing environmental conditions.

DATA AVAILABILITY STATEMENT

- The datasets generated and analyzed during the study are not publicly available due to privacy or ethical restrictions. However, anonymized data may be available from the corresponding author upon reasonable request and with permission from the relevant authorities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Anonymous. Water conservation measures in the arid and semi-arid area of hard rock region. Technical bulletin No. CS/AR - 32/99-2000. National Institute of Hydrology, Roorkee. 2000;39.
2. Srivastava HS, Patel P, Manchanda ML, Adiga S. Use of multi-incidence angle Radarsat-1 SAR data to incorporate the effect of surface roughness in soil moisture estimation. IEEE Transaction on Geoscience and Remote Sensing. 2003; 41:1638–1640.
3. Elham Forootan. GIS-based slope-adjusted curve number methods for runoff estimation. Environmental Monitoring and Assessment. 2023;195: 489.
4. Krisnayanti DS, Bunganaen W, Frans JH, Seran YA, Legono D. Curve number estimation for ungauged watershed in

semi-arid region. Civil Engineering Journal. 2021;7(6):2676-6957.
5. Ramesh H, Pradeep MP, Putti MRY. Evaluating and mapping of SCS-curve number for Lokapavani catchment using remote sensing and GIS. In: 3 International Ground Water Conference, Coimbatore. 2007;1-15,1-8.
6. Rao BK, Singh DK, Bhattacharya AK. Applicability of curve number method for runoff estimation from extended duration of rainfall. Journal of Soil and Water Conservation. 2002;1(2&3):163-170.
7. Uwizeyimana D, Mureithi SM, Mvuyekure SM, Karuku G, Kironchi G. Modelling surface runoff using the soil conservation service-curve number method in a drought prone agro-ecological zone in Rwanda. International Soil and Water Conservation Research. 2018;7:9-17.
8. Jahan K, Pradhanang SM, Bhuiyan MAE. Surface runoff responses to suburban growth: an integration of remote sensing, GIS, and curve number. Land. 2021; 10(5):452.
9. Verma RK, Verma S, Mishra SK, Pandey Ashish. SCS-CN-based improved models for direct surface runoff estimation from large rainfall events. Water Resour. Manag. 2021;35(7):2149–2175.
10. Gajbhiye S. Estimation of surface runoff using remote sensing and geographical information system. International Journal of u-and e-Service, Science and Technology. 2015;8(4):113-122.
11. Verma S, Singh A, Mishra SK, Singh PK, Verma RK. Efficacy of slope-adjustedcurve number models with varying initial abstraction coefficient for runoff estimation. Int. J. Hydrol. Sci. Technol. 2018;8(4):317–338.
Available:https://doi.org/10.1504/IJHST.2018..
12. Shi W, Wang N. An improved SCS-CN method incorporating slope, soil moisture, and storm duration factors for runoff prediction. Water. 2020;12(5):1335.
Available:https://doi.org/10.3390/w12051335.
13. Kumar T, Jhariya DC. Identification of rainwater harvesting sites using SCS-CN methodology, remote sensing and geographical information system techniques. Geocarto Int. 2017;32(12): 1367–1388.
14. Verma S, Mishra SK, Verma RK.. Improved runoff curve numbers for a large number of watersheds of the USA. Hydrol. Sci. J. 2020a;65(16):2658–2668.
15. Verma S, Singh PK, Mishra SK, Singh VP, Singh V, Singh A. Activation soil moisture accounting (ASMA) for runoff estimation using soil conservation service curve number (SCS-CN) method. J. Hydrol; 2020b.
Available:https://doi.org/10.1016/j.jhydrol.2020. 125114.
16. United states of department of agriculture (USDA). National engineering handbook of hydrology handbook Section-4, Chapter-21; 1972.
17. Shirahatti MS, Ranghswami MV, Manjunath MV, Sivasamy R, Bosu SS. Surface water resources assessment in ungauged upper Don river basin of Karnataka by using Remote Sensing and GIS techniques. Indian Journal of Soil Conservation. 2017;45(2):148-156.
18. Fan F, Deng Y, Hu X, Weng Q. Estimating composite curve number using an improved SCS-CN method with remotely sensed variables in Guangzhou, China. Remote Sensing. 2013;5:1425-1438.
19. Durbude DG, Chandramohanb T. Application of remote sensing technique for estimation of surface runoff from an unguaged watershed using SCS curve number method, Journal of Applied Hydrology. 2000;XIII(1&2):1-9.
20. Sarkar MK, Behera S, Panda RK, Chowdary UM. Evaluation of suitability of composite and distributed curve number techniques using remote sensing and GIS. In: Proc. International Conference on Emerging Technologies in Agricultural and Food Engineering, IIT, Kargpur. 2004;73-77.
21. Xin J, Tian G, Liu W, Chen L. Combining vegetation index and remotely sensed temperature for estimation of soil moisture in China. International Journal of Remote Sensing. 2006;27:2071–2075.
22. Singh RP, Oza SR, Chaudhary KN, Dadhwal VK. Spatial and temporal patterns of surface soil moisture over India estimated using surface wetness index from SSM/I microwave radiometer. International Journal of Remote Sensing. 2005;26:1269–1276.
23. Tailor D, Shrimali NJ. Surface runoff estimation by SCS curve number method using GIS for Rupen-Khan watershed, Mehsana district, Gujarat. J. Indian Water Resour. Soc. 2016; 36(4):1-5.

24. Dappa D, Ndukwu BC, Obafemi AA. Spatial assessment of land use/land cover dynamics from 1988 to 2018 in Bonny LGA, Rivers State, Nigeria. J. Geo. Env. Earth Sci. Int. [Internet]. 2019 Nov. 1 [cited 2024 May 17];23(4):1-12. Available:https://journaljgeesi.com/index.php/JGEESI/article/view/443
25. Djagre L, Gnammytchet Koffi B, Ouattara G. Structural Analysis of the Bagoué Furrow (South Boundiali) in the Northwest of Ivory Coast: Fracturing, Kinematics and Chronology. Asian J. Geol. Res. [Internet]. 2022 Dec. 31 [cited 2024 May 17];5(3):215-26. Available:https://journalajoger.com/index.php/AJOGER/article/view/125
26. Noor NM, Rosni NA. Determination of spatial factors in measuring urban sprawl in Kuantan using remote sensing and GIS. Procedia-Social and Behavioral Sciences. 2013 Sep 20;85:502-12.

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