Trans. Inst. Indian Geographers
ISSN 0970-9851
Indexed in Scopus

Runoff estimation in the Nambiyar watershed, South India using the soil conservation service curve number method

Libina R. S.*; Jegankumar R.; Saravanan S.; Prakash K.; Dhanabalan S. P. and Arya M. A., Tamil Nadu

Abstract

The study estimates surface runoff in the Nambiyar watershed with the help of the Soil Conservation Service Curve Number (SCS-CN) technique. Land use/land cover, soil texture, antecedent moisture condition, and rainfall data were combined to derive curve numbers for different parts of the watershed and estimate potential runoff. The major finding shows that in the northeast monsoon season, runoff is high in the watershed. The estimation of monthly runoff volume indicates that the runoff volume was low or not significant in January which progressively increased in the following months, reaching its peak during October and November months i.e. northeast monsoon seasons. Among the monsoon seasons, the northeast monsoon has the largest runoff volume, particularly in November, with a runoff volume; of approximately 14 m^3/hr. The north-western part of the watershed mainly the foothill zone is prone to high runoff, especially during monsoon season. Land use patterns and rainfall intensity correlated with runoff potential. Crop diversification and soil quality checks are recommended to ensure suitable crops for different soil types. These measures can reduce flooding risks and optimize water resource utilisation, ultimately contributing to better runoff management in the Nambiyar watershed.

Keywords: *Runoff volume, SCS - Curve Number, GIS.*

Introduction

The present investigation presents possibilities for increasing surface water retention by identifying surface runoff sites and their causes, crucial in preserving a balance between the utilisation of surface as well as groundwater resource in the Nambiyar watershed. This watershed located in the Tirunelveli district of Tamil Nadu forms a part of the Western Ghats extending from the mountainous terrain to the eastern coastal plains adjacent to the Gulf of Mannar, situated in a unique setting with distinctive hydrological characteristics. Over 73 percent of Tamil Nadu state is covered by hard rocks and semi-consolidated and consolidated strata, with the majority occurring in the eastern coastline tract. The state has diverse geological formations, mainly of crystalline rocks from the Archean era which are widely found in the Tirunelveli District. Here, water is primarily found in fractures and connections of these hard crystalline rocks, but over-extraction and low water table make bore wells less reliable (National Institute of

Hydrology, 1999). The watershed's irrigation sources include bore wells, dug wells, tanks, and reservoirs. In the Radhapuram block located near the coast, excessive groundwater pumping and extraction has lowered the groundwater level resulting in saltwater intrusion (Central Ground Water Board, 2022). This creates a huge demand for utilising surface water, especially for irrigation. The uneven and unpredictable distribution of rainfall within the watershed, however, creates a deficiency of surface water. Due to its proximity to the Western Ghats, the western portion of the watershed receives rain during the south-west monsoon even though more rain in the watershed is received from the north-east monsoon season. During the last two decades, major changes have taken place in land use/ cover of the watershed, particularly with the construction of the Kodumudiyar Dam in 2003 and the Nambiyar Dam in 2004. These dams which serve as the primary source of irrigation for over 40 settlements, supported conversion of scrubland to arable land and increased agricultural production in the watershed to a considerable extent (Balachandran, 2009). A few studies have been conducted in the Nambiyar watershed assessing its resource potential and flood susceptibility, but more research is required to identify numerous issues with land and water quality and develop management solutions. Narmada *et al.* (2015) identified five resource potential zones by considering rainfall, slope, land use/ cover, drainage density, and soil depth. The results showed moderate resource potential zones of the watershed are associated with paddy as a major crop and banana plantation. The dominance of a single crop reveals constraints in agricultural operations like more water usage and the presence of scrublands lowers land quality by limiting its infiltration capacity. Multiple cases of flash floods have also been reported in the upper courses of the River Nambiyar, in the foothills of the Western Ghats, impacting the livelihood and infrastructure of the people who live in the nearby villages (Ananth, 2018).

Rainfall-runoff models are categorized into conceptual, physical, and empirical types. Physical mechanistic models are the most complex, whereas empirical models are simple to understand. A complete understanding of the physics behind surface water movement in the hydrological cycle is necessary for both physical and conceptual models. Conceptual models do not consider spatial variability within a catchment. Physical models require a large number of parameters with proper calibration which are considered to be more site-specific. Empirical models, which require less parameter, providing greater accuracy with quicker run time, can be used to tackle these problems (Sitterson *et al.*, 2017). The curve number technique is one of the empirical runoff models mostly employed for ungauged watersheds where runoff is the only needed output. Runoff estimation for an ungauged basin using a curve number is based on its soil texture, land use/cover and antecedent moisture condition (AMC) of the soil prior to a particular storm event (Rao *et al.*, 2020).

In this regard, the present study was conducted with the objective of estimating and mapping the spatial and temporal variation of surface runoff using the Soil Conservation Services Curve Number (SCS–CN) technique which is widely used as it is one of the most accurate and simple methods for runoff modelling (Satheeshkumar et.al, 2017).

Study area

The Nambiyar watershed is located in the south of Tirunelveli District, Tamil Nadu stretching from 8º 10'N to 8º 32'N latitudes and 77º 28'E to77º 50'E longitudes (Fig. 1). The basin covers a total area of 665.45 km^2. The River Nambiyar originates from the Kalakkadu reserved forest at an altitude of 1800m in the Western Ghats. The river flows in an eastern direction, enters the plains at Thirukurangudi, and finally drains into the Gulf of Mannar in the Bay of Bengal. The five major tributaries of the river include Kodamadi Ar, Paratai Ar, Tamarai Ar, Valliyuran Kal, and Kallan Odai. The major formation found in this watershed is gneiss with a wide variety of minerals such as Garnet, Sillimanite and Biotite, etc. (Balasubramanian, 2017). Garnet biotite gneiss of the migmatite complex characterised as hard, foliated, and weathered rocks are widely seen in the western and southern portions of the watershed. Garnet-sillimanite gneiss rocks of the Khondalite group cover the northern and eastern parts of the watershed. Composition of silt, clay and sand, clay-sand alluvium and calcareous sandstone are prominent formations along the coast. The 'red garnet sand' also locally known as *teri* sand is widespread in these coastal regions. The western portion of the watershed comprising highly dissected hills and valleys surface exhibits moderate to steep slopes ranging from 7° to 70°. In the south-eastern part where the Nambiyar River debouches into the Gulf of Mannar in the Bay of Bengal, the slope is gentle varying from 0° to 2° (Libina *et al.*, 2023). The watershed falls within three taluks of Tirunelveli district via Nanguneri, and Radhapuram taluks covering about 47 census villages and 7 town panchayats.

Materials and methods

The base map, Survey of India 1:50,000 toposheets (58 H/07, 10, 11, 06, 15, 16) was used in the study to delineate the watershed, sub-watersheds boundary and to extract drainage networks. The land use/cover was generated using the LISS IV image from Resourcesat-2A collected from the National Remote Sensing Agency of India. Soil texture data was gathered from the Tamil Agricultural University's soil map. Further based on these texture classes and infiltration capability, the soils were grouped into hydrological soil groups A, C and D. The annual average rainfall was calculated from the rainfall data of 30 years obtained from the Directorate of Economics and Statistics, Chennai. Land use/cover and soil texture were overlaid and assigned a curve number to each group. Further, depending on the antecedent moisture condition, each unit was assigned a curve number, and the average runoff volume was calculated. The methodology flowchart of all the steps followed in the study is shown in Figure 2.

SCS-CN model

The RCN (Runoff Curve Number) method was originally developed by the Soil Conservation Service in 1954. The curve number (CN) was initially developed as a tool to estimate runoff from rainfall events on agricultural fields. It is an empirical and lumped model used in hydrology for predicting direct runoff or infiltration from rainfall excess. The runoff curve number was developed by the USDA Natural Resources Conservation Service and is based on the area's hydrological soil group, land use and land cover, and antecedent moisture conditions (Chow *et al.* 1988).

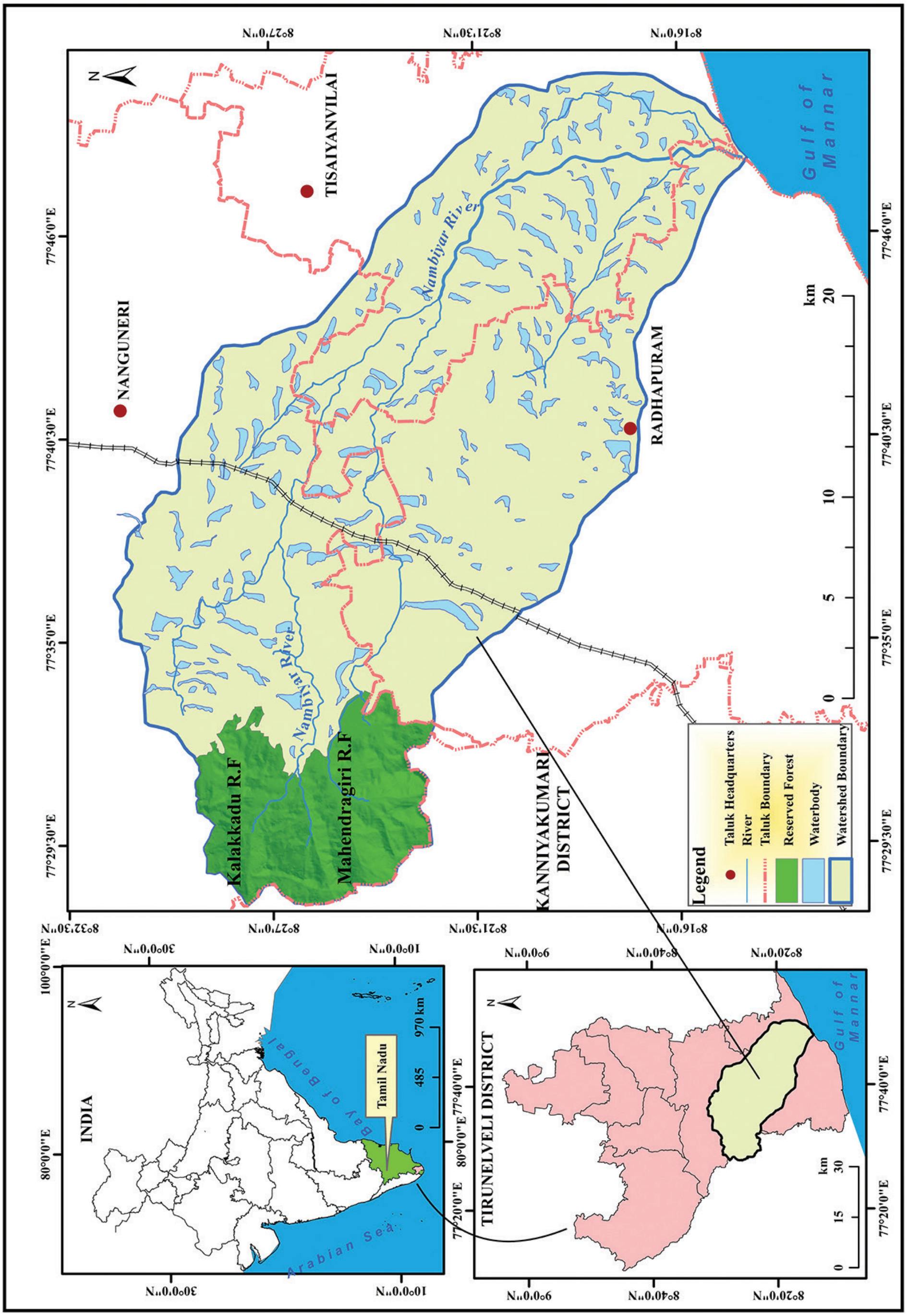

Fig. 1: Location of the Nambiyar watershed

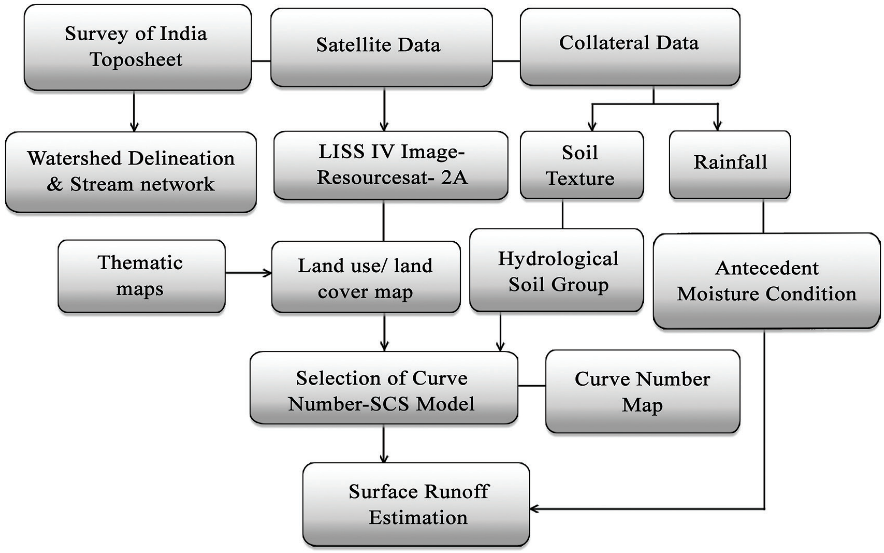

Fig. 2: Methodology flowchart

Table 1: USDA-SCS hydrologic soil group

Group	Texture	Min infiltration rate (in/hr)	Description
A	Deep, Well drained sand and gravel	0.3-0.45High rate	High infiltration rate, deep well-drained sand & gravels
B	Moderately deep well drained	0.15-0.3Moderate	Moderate infiltration
C	Clay loams, shallow sandy loam	0.05-0.15Low	Slow infiltration soil with layers, fine textures
D	Clay soil	0.00-0.05Very low	Very slow infiltration rates, clayey soils, high water table, shallow impervious layer

Source: Part 630 Hydrology, National Engineering Handbook, NRCS, USDA

The SCS-CN runoff equation is the following:

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

$$I_a = 0.2S \qquad (2)$$

Here, Q= actual runoff (in mm),, P = rainfall in mm, S = potential maximum retention in mm $I_a=0.2S$ (The precipitation must exceed prior runoff; which involves the surface depressions, vegetation interception, evaporation and infiltration).

$$P_e = \frac{(P - 0.2S)^2}{P - 0.8S} \qquad (3)$$

Where P_e is the rainfall excess For P > 0.2 valid for all soils under AMC of Type I, II, and III. Values of 'ƛ' varying in the range 0.1≤ 0.4 have been documented in many studies

Table 2: Antecedent moisture classes

AMC Type	Total rain in previous 5 days	
	Dormant Season	Growing Season
I	Less than13 mm	<36mm
II	13 to 28 mm	36 to 53 mm
III	>28mm	>53 mm

Source: Engineering Hydrology, Subramanya (2008)

from different geographical conditions and for Indian conditions $\lambda = 0.1$ and 0.2 are used subjected to constraints of soil type and AMC (Caletka, 2020).

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

Where the (SI Units: 30<CN<100) and finally runoff volume is calculated using the following equation.

$$Q = \frac{\left(P - 0.2 * \left(\frac{25400}{CN} - 254\right)\right)^2}{P + 0.8\left(\frac{25400}{CN} - 254\right)} \qquad (5)$$

Hydrological Soil Group (HSG)

The soil groupings are made based on the climatic conditions where the soil is found, its depth to the water table, the transmission rate of water, texture, structure, and degree of swelling (Table 1).

Antecedent Moisture Condition (AMC)

AMC is the moisture retained earlier in the pervious surface before a storm event which governs abstractions and infiltration rates (Subramanya, 2008). Three categories of AMC conditions have been given by SCS based on their wetness characteristics, which are given below:

AMC I- Soils are dry but not to a wilting point

AMC II- Average conditions

AMC III- Sufficient rainfall has occurred within the immediate past 5 days where saturated soil conditions prevail (Table 2).

When there has been minimal previous rainfall, the AMC is considered low, and when there has been significant rainfall already, it is regarded as high AMC. The following equation is used for the curve numbers I and II in cases of AMC I and II, respectively.

To obtain AMC-I values, $CNI = \frac{CNII}{2.281 - 0.01281 * CNII}$

For, AMC –III, $CNIII = \frac{CNII}{0.427 + 0.00573 * CNII}$

The land use/land cover and hydrologic soil groups were intersected to obtain the area of each land use and land cover category under a soil group. The curve number of each land use-hydrologic soil group unit has been assigned based on the standard SCS curve number table, which is used for analysis in SCS methodology. The weighted curved number for each sub watershed is computed using a formula.

$$Weighted\ CN = \frac{CN_1 * A_1 + CN_2 * A_2 * \ldots\ldots + CN_n * A_n}{A_1 + A_2 + \ldots\ldots A_n}$$

Where CN_1, CN_2, and CNn are the curve numbers for different land uses and hydrologic soil groups found in each sub-watershed in the watershed. $A_1 + A_2 + A_3$ are the area of each sub-watershed.

Table 3: Mean annual rainfall in each rainfall station

Station	Annual rainfall (mm)	Theissen polygon area (km^2)	Mean annual rainfall
Kalakkadu	654.2	104.79	103.02
Nanguneri	414.2	173.4	108.09
Panagudi	688	112.58	116.39
Radhapuram	485	226.05	164.75
Sathankulam	529.8	13.51	10.76
Balamore	2323.4	3.19	11.14
Keeriparai	1942.6	31.91	93.15
Total		665.43	607.30

Theissen polygon method

The application of rainfall station data as precipitation value carries a lot of uncertainties in runoff calculation. Despite their intrinsic simplicity, nearest neighbour algorithms are regarded as adaptable and powerful algorithms to find a neighbouring point that is nearest and its zone of influence (Satheeshkumar *et al.*, 2017). Hence, the theissen polygon method, a type of nearest neighbour analysis has been used for the computation of rainfall. These polygons are created from a series of sample points in such a way that each polygon establishes an area of influence around its sample point. The individual weights are multiplied by the station observation and the values are summed to obtain the average precipitation. Seven rainfall stations located in and around the watershed have been selected for calculating the area of influence in the watershed.

Results and discussion

Rainfall distribution

The annual rainfall received in the watershed is 607.26 mm. The total rainfall recorded in the seven rainfall stations ranges widely from 414.8mm to 2323.4 mm showing extreme variation. The rainfall shows a decreasing trend from the hilly areas in the western part of the watershed towards the southeast near the coast. The theissen polygons created for the watershed are divided into 7 polygons according to their sphere of influence around each rainfall station. The average rainfall under each station is obtained by dividing the product of theissen polygon area and total rainfall by the total watershed area. The distribution of average annual rainfall generated using theissen polygon is shown in figure 3 and the details are given in table 3.

Hydrological soil group

According to the soil classification system developed by SCS-CN, soil texture was classified into various hydrological groups as shown in Table 1. A, C, and D are the hydrological soil groups found in the watershed, which is shown in Figure 4. HSG 'D' comprising clay, clay loam, and sandy clay dominates the watershed covering 317.62 km^2 (47.72%) i.e. nearly half of the watershed area. This group of soil has a widespread distribution in the watershed from the mountainous terrain in the northwest to the coastal plains in the southeast. Clay soils have a very low infiltration rate ranging from nearly 0 to 0.05 in/hr.

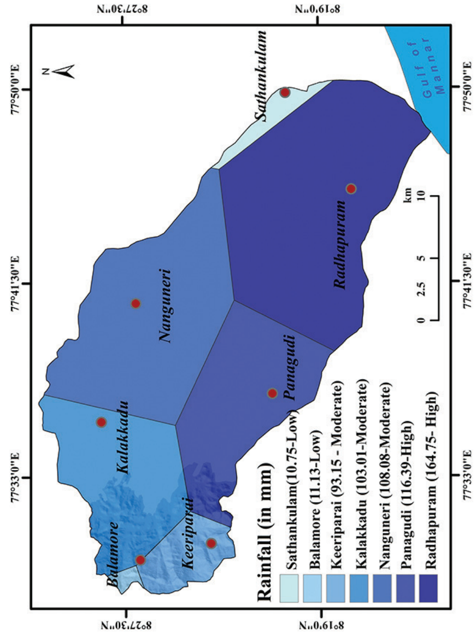

Fig. 3: Average annual rainfall distribution in the Nambiyar watershed

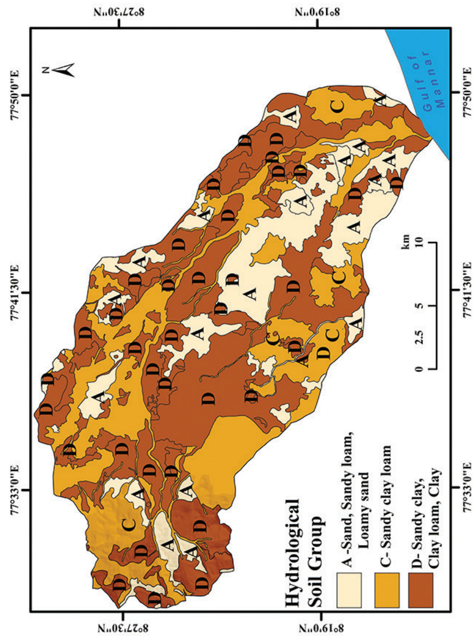

Fig. 4: Hydrological soil group in the Nambiyar watershed

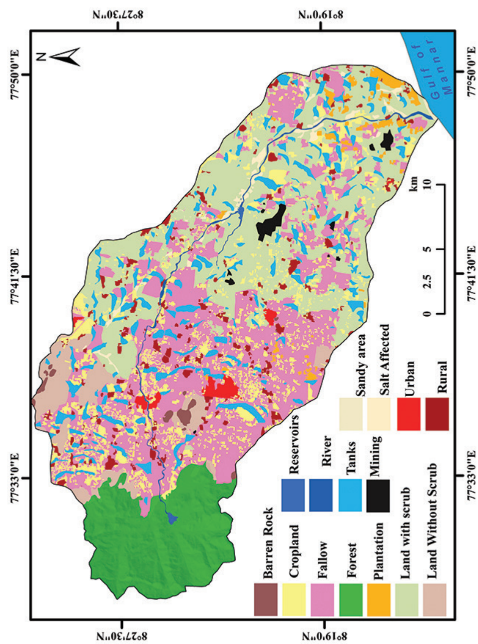

Fig. 5: Land use/ land cover category in the Nambiyar watershed

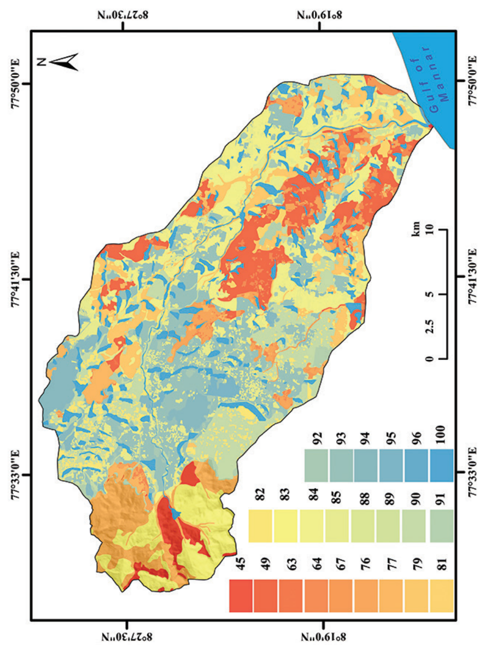

Fig. 6: Curve number distribution in the Nambiyar watershed

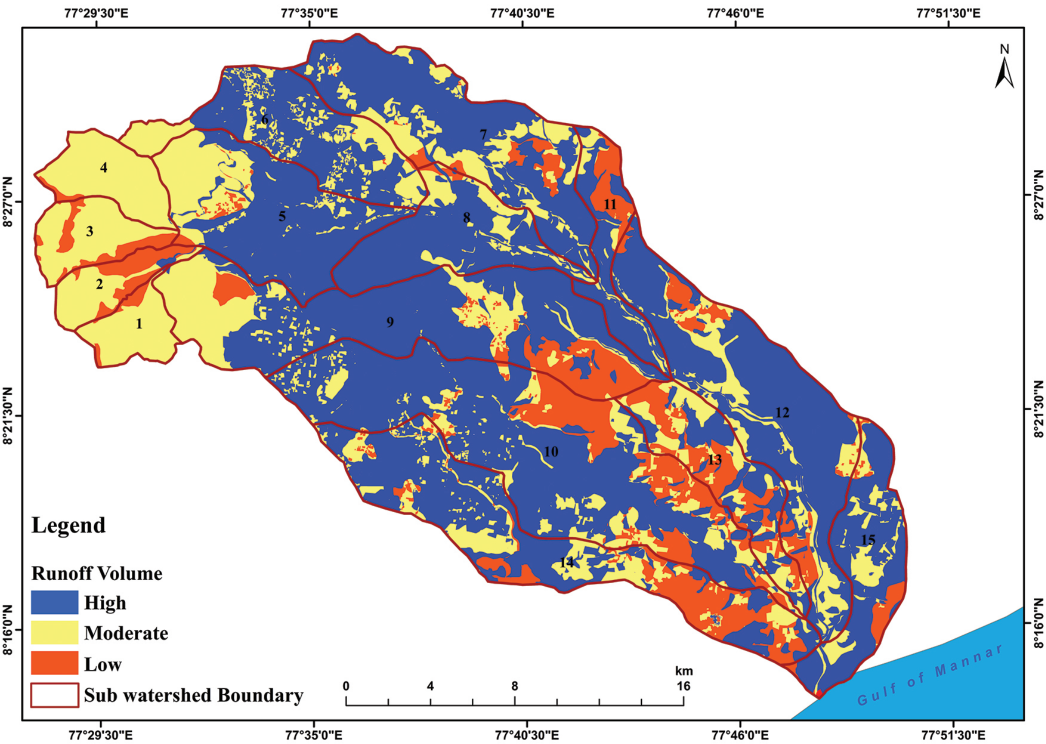

Fig. 7: Nambiyar watershed: Surface runoff

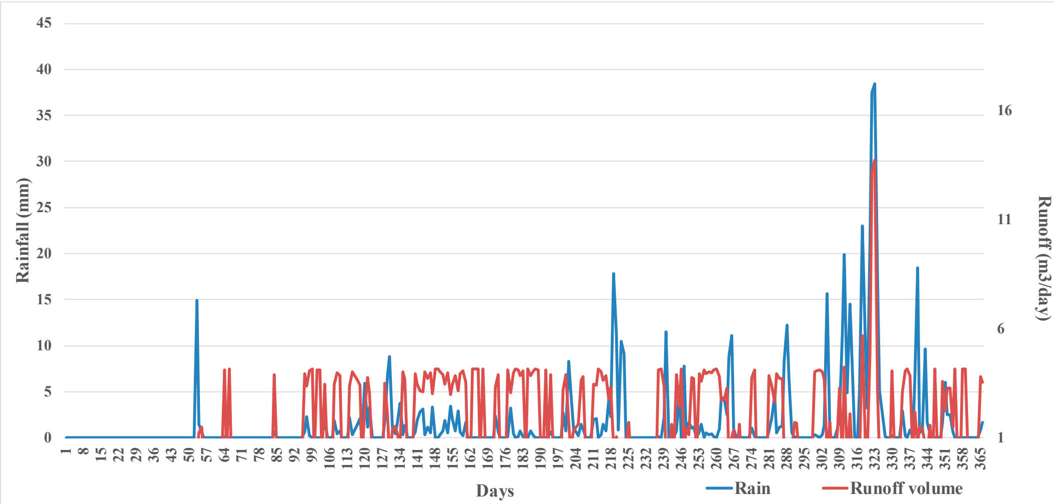

Fig. 8: Daily runoff volume of the Nambiyar watershed, 2020

Table 4: Land use/land cover categories and CN for each HSG

Classes	HSG	Area	CN	Area (%)	CN*Area (%)	Weighted CN
Builtup(Urban)	A	0.09	89	0.01	1.20	AMC-I=67 AMC-II=83 AMC-III=92
	C	1.38	94	0.21	19.50	
	D	4.58	95	0.69	65.40	
Builtup(Rural)	A	4.06	77	0.61	46.99	
	C	5.32	90	0.80	71.97	
	D	12.21	92	1.84	168.85	
Cropland	A	11.43	64	1.72	109.96	
	C	24.47	82	3.68	301.60	
	D	39	85	5.86	498.28	
Fallow	A	24.04	76	3.61	274.62	
	C	63.99	90	9.62	865.65	
	D	96.62	93	14.52	1350.64	
Plantation	A	3.62	67	0.54	36.46	
	C	2.2	85	0.33	28.11	
	D	4.36	89	0.66	58.33	
Forest	A	12.88	45	1.94	87.12	
	C	35.13	77	5.28	406.59	
	D	37.84	83	5.69	472.08	
Land with scrub	A	55.92	49	8.41	411.86	
	C	47.36	79	7.12	562.38	
	D	76.16	84	11.45	961.60	
Land without scrub	A	7.78	77	1.17	90.04	
	C	5.61	91	0.84	76.73	
	D	17.1	94	2.57	241.61	
Barren rock	A	0.03	77	0.00	0.35	
	C	0.26	91	0.04	3.56	
	D	3.01	94	0.45	42.53	
Salt affected	A	0.15	63	0.02	1.42	
	C	4.91	85	0.74	62.73	
	D	2.34	88	0.35	30.95	
Sandy area	A	0		0.00	0.00	
	C	0.09	96	0.01	1.30	
	D	0.37	96	0.06	5.34	
Mining	A	2.78	81	0.42	33.85	
	C	1.59	91	0.24	21.75	
	D	0.27	93	0.04	3.77	
Tanks	A	11.59	100	1.74	174.21	
	C	16.45	100	2.47	247.26	
	D	23.06	100	3.47	346.62	
Reservoirs	A	0.16	100	0.02	2.40	
	C	0.49	100	0.07	7.37	
	D	0.12	100	0.02	1.80	
River	A	0.07	100	0.01	1.05	
	C	3.9	100	0.59	58.62	
	D	0.5	100	0.08	7.52	
Total		665.3				

The next prominent soil group is 'C' which includes sandy clay loam covering about 213 km^2 (32.04%) of the watershed. The soil group 'C' is found in all parts of the watershed. This group has a low infiltration rate of around 0.05 to 0.15in/hr due to its fine and layered textures.

HSG 'A' comprises loamy sand, sand and sandy loam which spans over 134.64 km^2 of total watershed area. These soil textures are found in the north-western part mainly in the valley fills of the Western Ghats. Also, this soil group is found in the central and southeast portions of the watershed. The infiltration rate of this soil group is high ranging from 0.3 to 0.45 in/hr mainly composed of deep, well-drained sand and gravels which allows water to penetrate fast and deep.

Land use/Land cover

The land use/cover categories found in the watershed are built-up, cropland, plantations, fallow, forest, land with scrub, land without scrub, sandy areas, salt-affected land, barren rock, mining, reservoirs, tanks, ponds, and rivers as shown in figure 5. Fallow and scrub land dominate the land use/cover 184.62 km^2 and 179.57 km^2 of area respectively. Cropland with 75.05 km^2 of area in the watershed accounts for only 11 percent of the total area. Cropland mainly comprises paddy, banana and coconut plantations. The reserved forest classified in the western part of the watershed form part of Western Ghats namely Kalakkadu and Mahendragiri reserved forest. Scrublands in the watershed are classified into land with and without scrubs. Land without scrub is 31 km^2. Tanks and reservoirs are the major surface water sources of irrigation in the watershed, covering around 51.90 km^2. A significant proportion of the watershed is salt-affected found mainly in the agricultural land due largely to the over usage of chemical fertilisers leading to excess sodium, calcium and magnesium ions in the topsoil that limits soil permeability.

The water bodies in the watershed are divided into three categories: rivers, tanks and ponds, and reservoirs, which were given higher ranks since they are considered excellent recharge zones. The area of each land use/cover its area and respective hydrological soil group are given in Table 4.

Curve number

Soil texture and land use/cover affect the runoff rate and pattern of a region. Hence, according to the SCS method, curve number (CN) was assigned to each land use and soil texture class that is used in runoff calculation. The weighted curve number of the watershed is 83 for average AMC, indicating high runoff potential, while for dry and wet conditions, it is 67 and 92, respectively. In general, vegetation cover helps to reduce the runoff rate significantly. The curve number of the watershed ranges from 45 to 100 (Fig. 6). Low CN values indicate areas with high infiltration capacity, covered by thick vegetation leading to low runoff, whereas high CN values indicate impervious surfaces with low cover, such as concrete surfaces, scrublands, open spaces, etc.

The hydrological soil group, land use/cover and rainfall are used as input data to obtain the runoff depth of the watershed. The curve number and weighted curve number are assigned to each HSG, land use/cover type according to its antecedent moisture condition (Table 3).

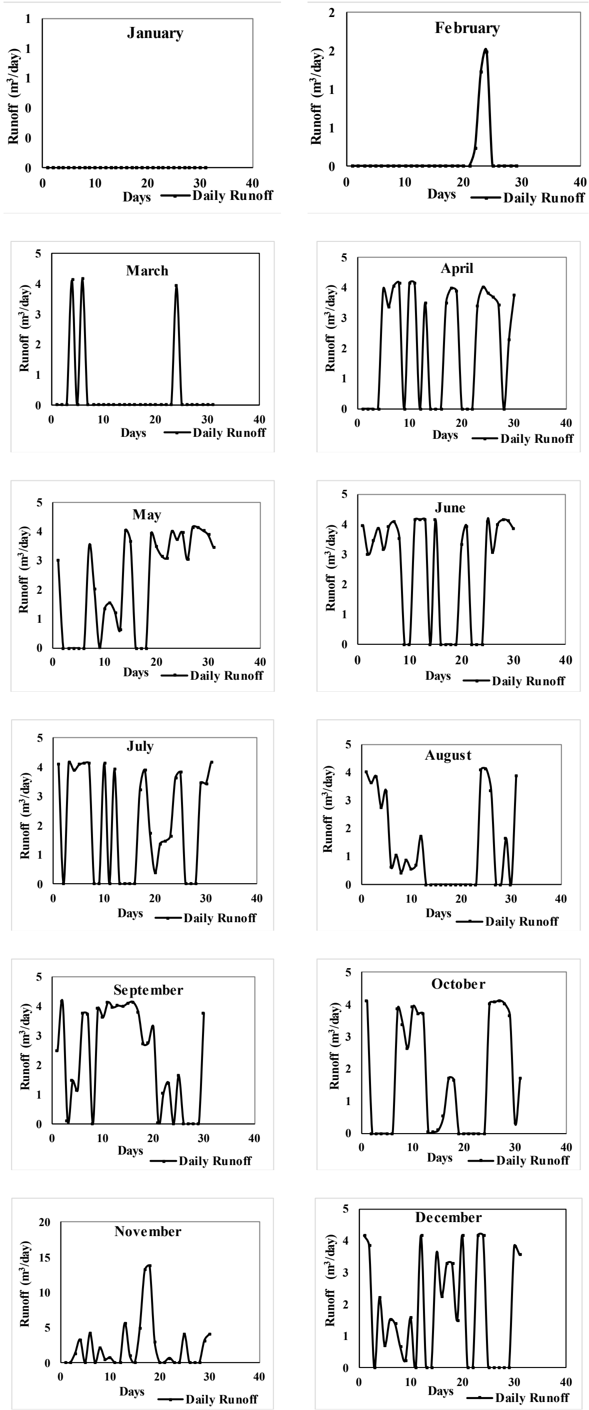

Fig. 9: Monthly runoff volume of the Nambiyar watershed

Fig. 10: a) Nambiyar River in its upper reaches, b) Nambiyar dam at Kottaikarungulam, Tirunelveli district, c) Scrublands in the watershed d) Barren rocky surface in the watershed

Surface runoff volume

Rainfall, HSG, land use/cover and curve number are used as input for estimation of spatial variation in surface runoff volume. The spatial variation of runoff volume in the watershed is shown in Figure 7. The area with maximum runoff potential indicates a high rate of soil erosion and a low infiltration rate and vice versa. Surface runoff volume is high in sub-watersheds 5,6,7,8,9,10,12,14 and 15 characterised by built-up area, land with and without scrub, and water bodies which are found to have high runoff volume. It is obvious that HSG in the high runoff volume zone is 'C' and 'D' making low to very low infiltration rate which induces more surface runoff.

Spatially, runoff volume is moderate in the western part of the watershed dominated by reserved forest, croplands and HSG 'A' indicating moderate susceptibility to runoff.

The runoff volume is very low in the south-eastern part of the watershed especially, in the right bank of the lower reaches of the River Nambiyar and also in some areas in the western part of the watershed with land use under forest, cropland and land with scrub where there is occurrence of HSG 'A' with very high infiltration rate.

Figure 8 represents the daily runoff volume generated for the year 2020 in the watershed. It is obvious that during the northeast monsoon, the runoff is higher in the watershed. Monthly runoff data helps to assess intra-year variability in the runoff volume. It is clear from Figure 9 that runoff volume was not significant in the month of January and subsequently increased in succeeding months, reaching its peak in the southwest and northeast monsoon seasons. High runoff volume is observed during the northeast monsoon, especially during the month of November, where runoff is around 14 m^3/hr. Surface runoff volume was very low in the winter season.

Spatial variation in runoff volume brings out the fact that the land without scrub, fallow land and built-up areas are characterised by higher runoff potential in the watershed. Moreover, the sandy clay loam and clay soil categorised under HSG 'C' and 'D' in the watershed contributes to increased runoff volume. This indicates a strong relationship between surface runoff and land use and land cover categories and soil texture.

Rainfall analysis made in the study projects the temporal variation in the runoff volume which is observed to be higher in the northeast monsoon season, the season which receives a higher amount of rainfall compared to other seasons.

Figure 10a is the River Nambiyar at its upper reaches where broken embankments are visible which causes erosion of river banks. Figure 10b is the Nambiyar dam constructed across the River Nambiyar in its down reaches with huge storage, supporting irrigation in nearby villages. Figure 10c is the scrubland and figure 10.d shows barren rocks associated with scrublands widely found in the watershed that are prone to more surface runoff which can be converted to arable lands for increasing the infiltration.

Conclusions

In order to optimise the use of water resources in arid and semi-arid regions, surface runoff estimation is inevitable. The study identified potential sites for surface runoff and its spatial and temporal disparities in the Nambiyar watershed combining the SCS-CN and geospatial techniques.

In the watershed, the north-western part adjacent to the foothills of the Western Ghats has high runoff volume, especially in the sub-watersheds 5, 6, 7, 8, and 9. Among the monsoon seasons, runoff volume is high during the northeast monsoon season, particularly in November. The Nambiyar watershed's runoff potential is significantly linked to land use/ cover patterns and rainfall intensity.

Special Area Development Programme and the National Watershed Development Project for Rainfed Areas (NWDPRA) are schemes implemented under the Tamil Nadu Watershed Development Agency (TAWDEVA) in order to restore and conserve water resources in Tamil Nadu. Although such schemes are running successfully, constant monitoring and area-specific solutions are needed to conserve and utilize water resources effectively.

Based on the findings and analysis, the study suggests controlling the watershed's land use/cover pattern and transforming open spaces into arable land for improved soil infiltration and runoff reduction. Conducting quality checks on soil types and combining dryland and rainfed farming can improve soil quality and cropping patterns. Also to improve the water retention capacity, the study recommends installing check dams and rainwater harvesting systems in flood-prone areas. These measures can be adopted to regulate and manage water resource utilisation patterns in the watershed.

Competing interest

The corresponding author declares that they have no conflict of interest.

References

Ananth, M. K. (2018, June 9). Tamil Nadu: Flooded Nambiyar river leaves devotees stranded at Thirukkurngudi. *The Times of India*. https://timesofindia.indiatimes.com/city/madurai/tamil-nadu-flooded-nambiyar-river-leaves-devotees-stranded-at-thirukkurungudi/articleshow/64522731.cms.

Balachandran, A. (2009). *District Groundwater Brochure, Tirunelveli District: Technical Report series*. Central Ground Water Board, South Eastern Coastal Region. https://cgwb.gov.in/sites/default/files/2022-10/tirunelveli.pdf.

Balasubramanian, A. (2017). *Geological Formations of India* (Technical Report:2). University of Mysore. https://doi.org/10.13140/RG.2.2.35307.75042.

Caletka, M., Michalkova, M. S., Karasek, P., & Fucík, P. (2020). Improvement of SCS-CN initial abstraction coefficient in the Czech Republic: A study of five catchments. *Water, 12*(7),3-6. https://doi.org/10.3390/w12071964.

Central Ground Water Board (2022). *National Compilation on Dynamic Ground Water Resources of India, 2022*. In. Ministry of Jal Shakti. https://static.pib.gov.in/WriteReadData/userfiles/file/GWRA2022(1)HIDO.pdf.

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology* (International Edition 1988). McGraw-Hill Book Co.

Libina, R. S., Prakash, K., Jegankumar, R., Dhanabalan, S. P., & Arya, M. A.(2023). Assessment of groundwater level and fluctuations using geospatial techniques in Nambiyar Watershed, South India. In

P.K.Rai (Ed) *Advances in geographical and environmental sciences* (pp. 203–220). Springer Nature. https://doi.org/10.1007/978-981-99-3660-1_12.

Narmada, K., Gobinath, K., & Bhaskaran, G. (2015). An Assessment of Resource Potentials for Sustainable development of micro-watershed in Tirunelveli District using geoinformatics– A case of Nambiyar Micro-watershed in Tirunelveli District, Tamil Nadu, India. *Aquatic Procedia, 4*, pp. 1299–1306. https://doi.org/10.1016/j.aqpro.2015.02.169

National Institute of Hydrology (1999). *Hydrological Problems of Hard Rock Region:* A State-of-Art Report (SR-5/98-99). https://nihroorkee.gov.in/sites/default/files/Hydrological_Problems_of_Hard_Rock_Region.pdf

Rao, K. N. (2020). Analysis of surface runoff potential in ungauged basin using basin parameters and SCS-CN method. *Applied Water Science*, 10(1), 1 – 5. https://doi.org/10.1007/s13201-019-1129-.

Satheeshkumar, S., Venkateswaran, S., & Kannan, R. (2017). Rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India. *Modeling Earth Systems and Environment, 3*(1),5-8. https://doi.org/10.1007/s40808-017-0301-4.

Sitterson, J., Parmar, R., Wolfe, K., Muche, M., & Avant, B. (2017). *An overview of Rainfall-Runoff model types.* In www.epa.gov/research (EPA/600/R-14/152).United States Environmental Protection Agency.pp.11-15. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=339328&Lab=NERL.

Subramanya, K. (2008), *Engineering Hydrology* (3rd ed.), Tata Mc Graw – Hill Publishers.

Libina R. S.*
Research Fellow (UGC-SRF),
Department of Geography,
Bharathidasan University, Tiruchirappalli,
Tamil Nadu

Jegankumar R.
Professor and Head,
Department of Geography,
Bharathidasan University, Tiruchirappalli,
Tamil Nadu

Saravanan S.
Associate Professor,
Department of Civil Engineering,
National Institute of Technology,
Tiruchirappalli, Tamil Nadu

Prakash K.
ICSSR Doctoral Research Fellow,
Department of Geography,
Bharathidasan University, Tiruchirappalli,
Tamil Nadu

Dhanabalan S. P.
ICSSR Doctoral Research Fellow,
Department of Geography,
Bharathidasan University, Tiruchirappalli,
Tamil Nadu

Arya M. A.
Research Fellow,
Department of Geography,
Bharathidasan University, Tiruchirappalli,
Tamil Nadu

* Author for Correspondence
E-mail: libinageog@bdu.ac.in