



Rainfall-surface runoff estimation for the Lower Bhavani basin in south India using SCS-CN model and geospatial techniques

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Abstract

Rainfall and surface runoff are the two most important components, which control the groundwater recharge of the basin. The long-term groundwater recharge of an aquifer gets affected by the population growth, irregular agriculture activities and industrialization. Hence, estimation of rainfall-surface runoff is very much essential for proper groundwater management practices. In the present study, Soil Conservation Service Curve Number (SCS-CN) model was employed in combination with geospatial techniques to estimate rainfall-surface runoff for the Lower Bhavani River basin in South India. To develop the SCS-CN model, rainfall data were obtained for 33 years (1983–2015) from 22 rain gauge stations spread over the basin. IRS LISS-IV satellite data of 5.8 m spatial resolution were used to analyze the land use/land cover (LU/LC) behavior. Based on the soil properties, four Hydrological Soil Groups (HSG) were identified in the basin which is most significant for surface runoff estimation. Curve Number (CN) values were obtained for various Antecedent Moisture Conditions (AMC) such as dry condition (AMC I), average condition (AMC II) and wet condition (AMC III). Spatial distribution of CN values was plotted using Geographical Information System (GIS) for the entire Lower Bhavani Basin to assess the surface runoff potential. The results indicate that the annual rainfall varies from 267 mm (2002) to 1528.6 mm (2005), and the annual surface runoff varies from 102.04 mm (1985) to 463.02 mm (2010). The SCS-CN model outputs predict that the average surface runoff of the basin is 211.99 mm, and the average surface runoff volume is 81,995,380 m³. The study also indicates that nearly 53% of the basin area is dominated by high to very high surface runoff potential. Finally, the output of surface runoff potential was validated with the Average Groundwater Level Fluctuation (AGLF) observed in 57 wells spread over the entire basin. The basin AGLF ranges from 2.32 to 21.72 m. The surface runoff potential categories are satisfactorily matching with the AGLF categories. Moderate surface runoff as well as moderate AGLF zones mostly occupy the central portion of the basin, which possess good groundwater potential. However, the high surface runoff zones in the basin lead more surface water flow into the river channels, which reduce the infiltration rate and decline the water table. This problem can be solved by constructing suitable artificial groundwater recharge structures across the river channels in the high surface runoff potential areas.

Keywords Rainfall-surface runoff · Geospatial techniques · SCS-CN · Runoff potential · Lower Bhavani basin · South India

Introduction

Hydrological modeling is one of the important processes in water resources applications. Especially, rainfall-based surface runoff analysis is the major challenging factor in hydrological modeling, which is essential for the development, planning and management of water resources. The implication of hydrological models to observe the water quantity is a challenging and scientific task in a semi-arid region (Perez-Sanchez et al. 2019; Gajbhiye et al. 2015; Karunanidhi et al. 2020). The stream of water directly runs over the land surface to a channel is overland flow and infiltrate and flow horizontally near the soil surface to a channel is known

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as interflow (Fitts 2002). The groundwater contributes to the stream known as base flow, and the total flow of the stream is known as surface runoff (Fetter 2001). The flow of water is usually considered as surface runoff, which is considered as an instant flow that enters into a stream and combines to form a watershed (Rao et al. 2010). For an effective management, one should have a clear understanding about the hydrological behavior of the watershed characteristics. The surface runoff and sediment transportation are the two significant hydrological processes, which are observed from the rainfall events.

Rainfall is one of the main sources for surface runoff, and these two components are very important in the hydrological cycle (Ashish et al. 2014; Thilagavathi et al. 2014). Rainfall-based surface runoff model is foremost important in water resource development planning (Mishra et al. 2013). Geo-spatial techniques can enhance the conventional methods to significant extent in the rainfall-surface runoff studies. These techniques are effectively used to produce hydrological variables over space and time. The reflected solar energy recorded by the multi-spectral sensors can be used to generate the optical satellite datasets for obtaining the land and water resource information such as land use/land cover (LU/LC), soil, geology, geomorphology, etc., (Mukesh et al. 2014; Thilagavathi et al. 2015a; Subramani et al. 2012). Geographical Information System (GIS) is a tool developed to store, manipulate, retrieve and display the spatial and non-spatial data information (Hema et al. 2010). This tool is useful for assessing the parameters of land use/land cover (LU/LC), soil, topography and hydrological settings (Vaibhav et al. 2013; Thilagavathi et al. 2015b). For rainfall surface-runoff studies, GIS along with remote sensing data is an informal approach to study the watershed in a large scale. The hydrological-based surface runoff models are classified into different types: lumped, distributed and semi-distributed. The lumped models analyze every sub-watershed by a weighted average response of hydrological factors. The distributed model is a grid-based model that permits the watershed to analyze the hydrologic response of a grid cell. The commonly used empirical method is USDA-Soil Conservation Service Curve Number (SCS-CN) in the National Engineering Handbook (NEH-4) (USDA-SCS 1974). It is mostly used to estimate the surface runoff from ungauged watersheds. This model helps to combine the hydrological and climatological factors in a single entity, which is known as 'Curve Number'. Nowadays, numerous models are used for surface runoff predictions. Among them SCS-CN model is very simple, easy to recognize and apply, steady and capable of integrating several runoff generating characteristics such as slope, soil, land use/land cover practices, hydrological and antecedent moisture conditions (AMC). It estimates surface runoff for a small watershed from 5 days' antecedent rainfall. SCS-CN model was initially developed for the small

watersheds having less than 15 km² and later modified for the large watersheds by utilizing the weighting curve method with the spatial inputs of LU/LC and soil characteristics (Ramakrishnan et al. 2009). Major advantage of this method is that GIS techniques can be easily integrated because the parameters needed for the model is in geographical nature.

Many researchers have attempted to estimate the surface runoff using SCS-CN method by combining the remote sensing datasets. The spatial and non-spatial datasets are extracted to evaluate the hydrological characteristics of a watershed with the aid of multi-temporal datasets like monthly rainfall, land use/land cover, soil, slope, etc., (Shi et al. 2009; Tejram et al. 2012; Viji et al. 2015; Ishtiyag et al. 2015; Matej et al. 2016; Shah et al. 2017; Jaimin et al. 2017; Al-Juaidi et al. 2018; Arya et al. 2020a). High-resolution satellite datasets are used to map the impervious surfaces for the execution of SCS-CN model (Mondal et al. 2009; Ansari et al. 2016). The SCS-CN coupled with Universal Soil Loss Equation (USLE) is also used to compute rainstorm-generated sediment yield of a watershed (Mishra et al. 2006). The surface runoff depth can be obtained using SCS-CN method, and average depth can also be calculated for total rainfall (Taher et al. 2015). The direct surface runoff mainly depends upon rainfall, soil type, soil moisture, drainage density, topography, size and shape of a watershed and land use/land cover (Agarwal et al. 2014; Tailor and Shrimali 2016). The seasonal variation of rainfall-surface runoff is generally determined using SCS-CN method for the development of land and water resource management practices such as vegetative and engineering measures (Muthu and Santhi 2015). Anubha et al. (2015) computed the annual surface runoff depth for a watershed using GIS techniques. Joy (2016) applied NRCS-CN method to assess the surface-runoff depth and average runoff. Eight different models were combined with SCS-CN method to assess the accuracy of surface runoff estimation in 15 watersheds by Ajmal et al. (2015). In their study, CN exhibited good results than the fixed value of SCS-CN model. The LU/LC changes also significantly affect the surface runoff and sediment yield (Worku et al. 2017). Saravanan et al. (2015) used geomorphological based linear cascade model (GLCM) combined with SCS-CN rainfall-surface runoff method for flood management during different storm events. Khalid et al. (2015) and Bhura et al. (2015) utilized the SCS model to estimate the surface runoff in an urban area with suitable AMC conditions. The availability of surface runoff for artificial recharge was estimated through SCS-CN method, and it was effectively used to classify the potential areas for water harvesting structures (Anbazhagan et al. 2005; Ajaykumar et al. 2012; Jha et al. 2014; Bhaskar and Suribabu 2014; Dinagara Pandi et al. 2017; Karunani-dhi et al. 2019). Validation and calibration of surface runoff models are very important to reduce uncertainty of the observed modeling inputs (Nastiti et al. 2018).

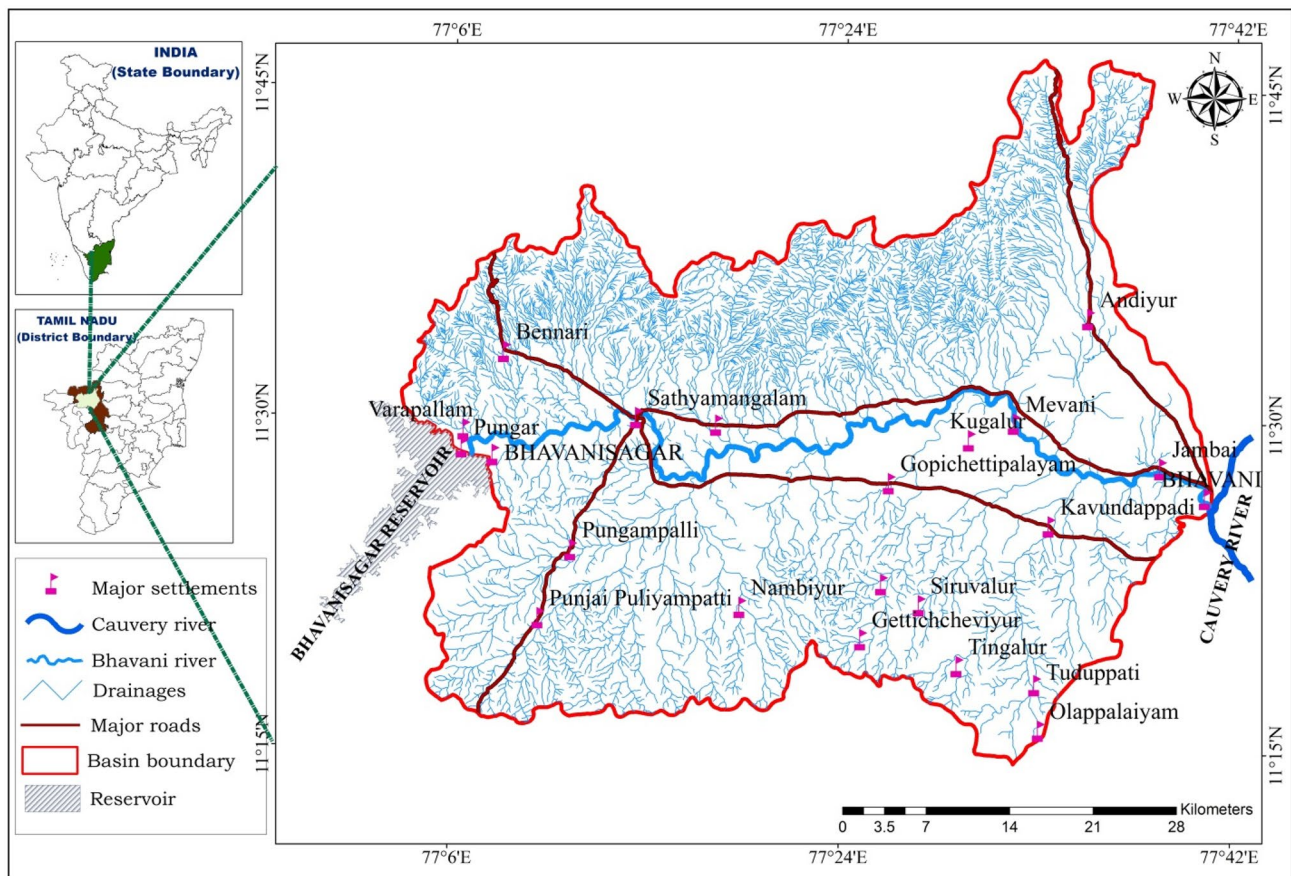


Fig. 1 Location map of the Lower Bhavani River basin

The Lower Bhavani River basin is affected by water scarcity and over exploitation problems, which lead the aquifer into stress. The variation in rainfall intensity and groundwater levels with respect to space, time and depth affected the farmers in this region (Arya and Subramani 2015; Anand et al. 2020). Hence, it is important to improve the groundwater resources through rain water harvesting techniques (Arya et al. 2018). Therefore, it is very much essential to estimate surface runoff of the basin and to apply hydrological based SCS-CN model to identify the surface runoff potential areas in basin with the aid of geospatial techniques.

Study area

Climate and rainfall

The Lower Bhavani River basin is situated in Erode district of Tamil Nadu state, India. Bhavani River is the fourth largest tributary of Cauvery River, which confluences near Bhavani town. The total geographical area of the basin is 2424 km², which lies between 11° 15' and 11° 45' North

latitudes and 77° 0' and 77° 40' East longitudes (Fig. 1). The northern part of the study area is covered with hills. The ground elevation varies between 66 and 1473 m with respect to mean sea level (Anand et al. 2017). The regional slope of the basin is towards southeast. The hilly areas are covered with evergreen forest, deciduous forest and plantations, whereas the plain areas comprises crop land, scrub, fallow land and built-up land. The drainage pattern in the basin is mostly dendritic to sub-dendritic. The basin experiences semi-arid climatic condition with the temperature variation between 22 and 40° C. The average annual rainfall of the basin is 739.67 mm, which was calculated from 33-year rainfall data (1983–2015) obtained for 22 rain gauge stations spread over the basin. The basin receives more rainfall during northeast and southwest monsoon seasons. However, the basin also receives considerable rainfall during the transitional period. Rainfall contribution by various monsoon seasons in the study area are as follows: NE monsoon (44%) > SW monsoon (28%) > Pre-monsoon (22%) > Post monsoon (6%) (Anandakumar et al. 2008).

Geology and soil

The Lower Bhavani River basin mainly consists of two major rock types, namely fissile hornblende-biotite gneiss and charnockite. Charnockite is mostly observed in hills, whereas fissile hornblende-biotite gneiss is noticed in the plains (Aravinthasamy et al. 2019a, b). The basin also consists of pyroxene granulite, ferruginous quartzite, garnetiferous-quartzofeldspathic gneiss, quartzite, talc-tremolite schist, amphibolite, gabbro/anorthosite, pink migmatite, dolerite dykes and granite intrusions (Anandakumar and Subramani 2014). The basin area mostly comprises red calcareous and red non-calcareous soils. Brown and black soils are also observed in some places as pockets. Major portion of the study area is dominated by red calcareous soil, which varies from sandy to loamy texture. The coarser soil is noticed in the hilly areas, whereas the finer soil namely clay is deposited in the low-lying areas such as river and water courses. Therefore, the soils of low-lying areas contain higher percentage of clay than the dry land soils (Fao 2014). Alluvium is noticed all along the Bhavani River course, and colluvium is present in the foot hills. The basin comprises different kinds of soil texture such as clay, clay loam, silty clay, loamy sand, sandy clay, loam, sandy clay loam and sandy loam. It is further characterized by hard and compacted nature due to the lime content (CGWB 2008). As agriculture is the backbone of this region, groundwater resources are often overexploited in many places leading the aquifer into stress.

Materials and methods

In the present study, Survey of India (SOI) toposheets of 1:50,000 scale were used to generate base map with details of rivers, tanks, reservoirs, reserve forests, road networks, drainage networks and major settlements. Remote sensing data and secondary datasets pertaining to this study were collected from various government agencies. Indian remote sensing satellite data with the spatial resolution of 5.8 m (LISS-IV) were obtained from the National Remote Sensing Centre (NRSC), Hyderabad, India for February 2015 and December 2015. Soil details were collected from the Tamil Nadu Agricultural University (TNAU), Coimbatore. Rainfall data were obtained from the Tamil Nadu State Ground and Surface Resources Data Centre, Public Works Department (PWD), Chennai for the period of 33 years (1983–2015). Further, CARTOSAT Digital Elevation Model (DEM) with 30 m spatial resolution was acquired from the Bhuvan web-portal belonging to the Indian Space Research Organization (ISRO). All the data products were digitally converted and georeferenced with UTM and WGS-84 projection/coordinate system using ArcGIS software (v.10.2.1). Slope map was derived from the Digital Elevation

Model (DEM) using IMSD (1995) classification system. Satellite imageries were used to prepare land use/land cover (LU/LC) map based on the NRSC classification system. Maximum Likelihood Classifier (MLC) of supervised classification technique was adopted for LU/LC feature extraction from the satellite imageries. The obtained map of LU/LC was spatially intersected to assign the Curve Number (CN) for each respective polygon in GIS environment. Finally, CN values were assigned for all the polygons. The CN value for each polygon was calculated using the ‘area weighted’ method. In this study, rainfall was considered as the key factor to generate surface runoff over the basin using the spatial interpolation technique in GIS. Finally, cross validation was attempted using Average Groundwater Level Fluctuation (AGLF) method (Devi and Katpatal 2016). The detailed methodology adopted to execute this work is shown in the Fig. 2.

SCS-CN model

Soil Conservation Service Curve Number (SCS-CN) method is an empirical method, which is commonly used to quantify the direct surface runoff in a watershed. This method was established by the United States Department of Agriculture—Soil Conservation Service (USDA-SCS) in the year 1954 (Rallison 1980). It basically requires two input parameters, namely rainfall and Curve Number (CN). Further, it also considers two important assumptions. The first assumption suggests that ratio of the quantity of surface runoff ‘*Q*’ to maximum rainfall is equal to the ratio of the volume of infiltration of quantity and amount of potential maximum retention ‘*S*’. The second assumption narrates the initial abstraction ‘*I_a*’ and the potential maximum retention ‘*S*’ (Patil et al. 2008; Satheshkumar et al. 2017). The infiltration losses are combined with external storage by the relationship of

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

The empirical relationship for ‘*I_a*’ is denoted by,

$$I_a = 0.3S \quad (2)$$

Therefore, ‘*Q*’ is the direct surface runoff depth (mm), ‘*P*’ is the rainfall depth (mm) and ‘*I_a*’ is the initial abstraction before surface runoff begins (mm), which includes the surface storage, interception and infiltration with respect to overflow of the watershed. ‘*S*’ is the potential maximum retention after the surface runoff begins (mm).

For Indian condition, ‘*S*’ is the potential maximum retention, which is denoted by

$$S = (25400/CN) - 254 \quad (3)$$

From the above Eq. (3), CN is the curve number which is the dimensionless surface runoff index to determine outcome

Fig. 2 Methodology adopted for computation of rainfall-surface runoff using SCS-CN method

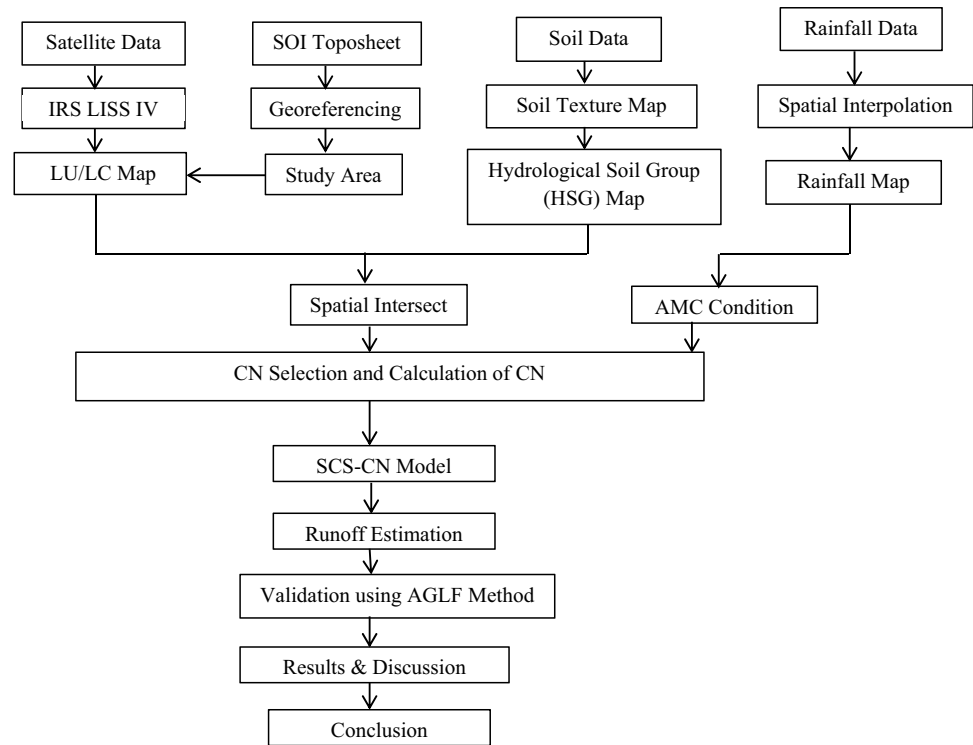


Table 1 Soil conservation service classification scheme (USDA 1974)

S.no	Hydrologic soil group (HSG)	Soil textures	Surface runoff potential	Infiltration rate (mm/h)
1	Group ‘A’	Deep, well drained sands and gravels	Low	< 7.5
2	Group ‘B’	Moderately deep, well drained with moderate fine to coarse structure	Moderate	3.8–7.5
3	Group ‘C’	Clay loams, shallow sandy loam, soils with moderately fine to fine textures	Moderate	1.3–3.8
4	Group ‘D’	Clay soils that swell significantly when wet, very slowly drained	High	< 1.3

of changes in Hydrological Soil Group (HSG) and land use/land cover (LU/LC) pattern on runoff. The value of CN ranges from 1 to 100 (USDA 1972). A higher value indicates high surface runoff, whereas lower value indicates low surface runoff. Now, the Eq. (1) can be modified as

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \tag{4}$$

SCS-curve number runoff equation is furthermost technique to estimate the direct surface runoff of the watershed with simplicity, flexibility and adaptability (Tarun and Jhariya 2016). This method considers the ability of soil to infiltrate water with combination of land use/land cover and Antecedent Moisture Condition (AMC) (Amutha and Porchelvan 2009). From the observation of soil hydrological properties, the SCS-CN soil classification scheme was grouped into four different categories, namely ‘A’, ‘B’, ‘C’

and ‘D’ (Table 1). This classification is useful to increase the probability of surface runoff and absolute infiltration of the watershed.

Antecedent moisture condition (AMC)

Antecedent moisture condition (AMC) states the existing moisture content in the soil on the initial level of rainfall-surface runoff model observation. A well-known factor of initial abstraction and infiltration characteristics are observed by AMC (Mishra et al. 2004). For the execution of SCS-CN model, three levels of AMC are important, which are listed in Table 2. The constraints of AMC classification are totally constructed by the overall rainfall magnitude of previous 5 days, and their limits are considered as two types of seasons: first (growing season) and second (dormant season). AMC II is considered as average moisture condition, which is used in the present study (USDA 1986). Runoff Curve

Table 2 Categories of antecedent moisture condition (AMC)

Amc group	Soil characteristics	Five day antecedent rainfall in mm	
		Dormant season	Growing season
I	Dry condition	< 13	< 36
II	Average condition	13–28	36–53
III	Heavy rainfall/wet condition	> 28	> 53

Numbers (CN) for various LU/LC categories are obtained for average moisture condition (AMC II) and dry condition (AMC I) or wet condition (AMC III). To generate the Curve Number for AMC I and AMC III, the following Eqs. (5) and (6) are used:

$$CN(I) = \frac{CN(II)}{2.281 - 0.0128CN(II)} \quad (5)$$

$$CN(III) = \frac{CN(II)}{0.427 + 0.00573CN(II)} \quad (6)$$

In the above equations, CN (II) is the curve number for the normal condition, CN (I) is for dry condition and CN (III) is for wet condition (Chow et al. 2002).

Area weighted curve number method

The spatial input maps of soil and land use/land cover are used for intersection. Further, the intersection map represents new polygons, which is referred as soil-land map. The curve number value varies with respect to each land use/land cover classes. The obtained results were familiar to compute the total weighted curve number for AMC II condition with respect to each polygon of the land area:

$$CN_w = \sum CN_i \times A_i / A \quad (7)$$

In the above Eq. (7), 'CN_w' represents weighted curve number; 'CN_i' denotes curve number for a particular land area; 'A_i' indicates curve number of 'CN_i' and 'A' represents total area of the basin.

Hydrological soil group (HSG)

The rainfall surface runoff of the basin depends upon the saturation excess of overland flow where the soil texture plays a major role. It is prepared using the soil data. Further, the soil map of the basin was reclassified into various Hydrological Soil Groups (HSG) through observation of infiltration capacity of the soils. HSG is grouped as 'A', 'B', 'C' and 'D'. Group 'A' soil has high infiltration rate and low runoff. Group 'B' soil has moderate runoff potential, and Group 'C' soil observes fairly. Group 'C' has slow infiltration rate and fewer infiltration capacity than 'B' but

downward distance and water table conditions are normally same as group 'B'. Group 'D' has very low infiltration rate and produces high surface runoff potential (Mishra et al. 2008; Tarun and Jhariya 2016). The soil characteristics are influenced by hydrological grouping of soil with the parameters of soil texture, soil depth, average clay content and infiltration capacity of the soil (Arya et al. 2019).

Rainfall-surface runoff estimation

Daily rainfall data of the Lower Bhavani River basin were analyzed for the period from 1983 to 2015 (33 years). The spatial and temporal variations of rainfall-runoff were evaluated using the geospatial inputs in the GIS environment (Subramani et al. 2015). The calculated average annual rainfall was used to evaluate the surface runoff depth and volume of runoff for the period of 33 years. Interpolation is the process of estimating the value of properties of unsampled locations within the area through existing observation of data (Burrough 1986). Several traditional and geostatistical interpolation methods like inverse distance weighting (IDW), Thiessen polygon, linear regression, ordinary kriging, and simple kriging with varying local means are used to estimate rainfall. Among these methods ordinary kriging is generally recommended for the mountainous regions (Mair and Fares 2011). Binh and Thuy (2008) recommended spline method for mountainous areas, ordinary kriging method for small area containing flat terrain and hills, and IDW method for the large areas containing flat terrain and hills. The distance-based weighting method has been adopted to interpolate the climatic variable of rainfall by Legates et al. (1990), Stallings et al. (1992) and Goovaerts (2000) in different parts of the world. Subramani et al. (2012) have applied IDW method to compute surface runoff and groundwater resources from the monsoon rainfall for the Chithar River basin, south India. They have used 70 years' (1933–2002) rainfall data of eight rain gauge stations situated at different elevations (plain and mountain regions) in that basin.

Spatial interpolation technique of inverse distance weighted (IDW) method was used because it is a global technique used to fit a model through the prediction variable over all points in the study region. The interpolation method is a deterministic approach used to estimate values at unsampled points and determined by a grouping of values at known sampled points (Hartkamp et al. 1999). The values of

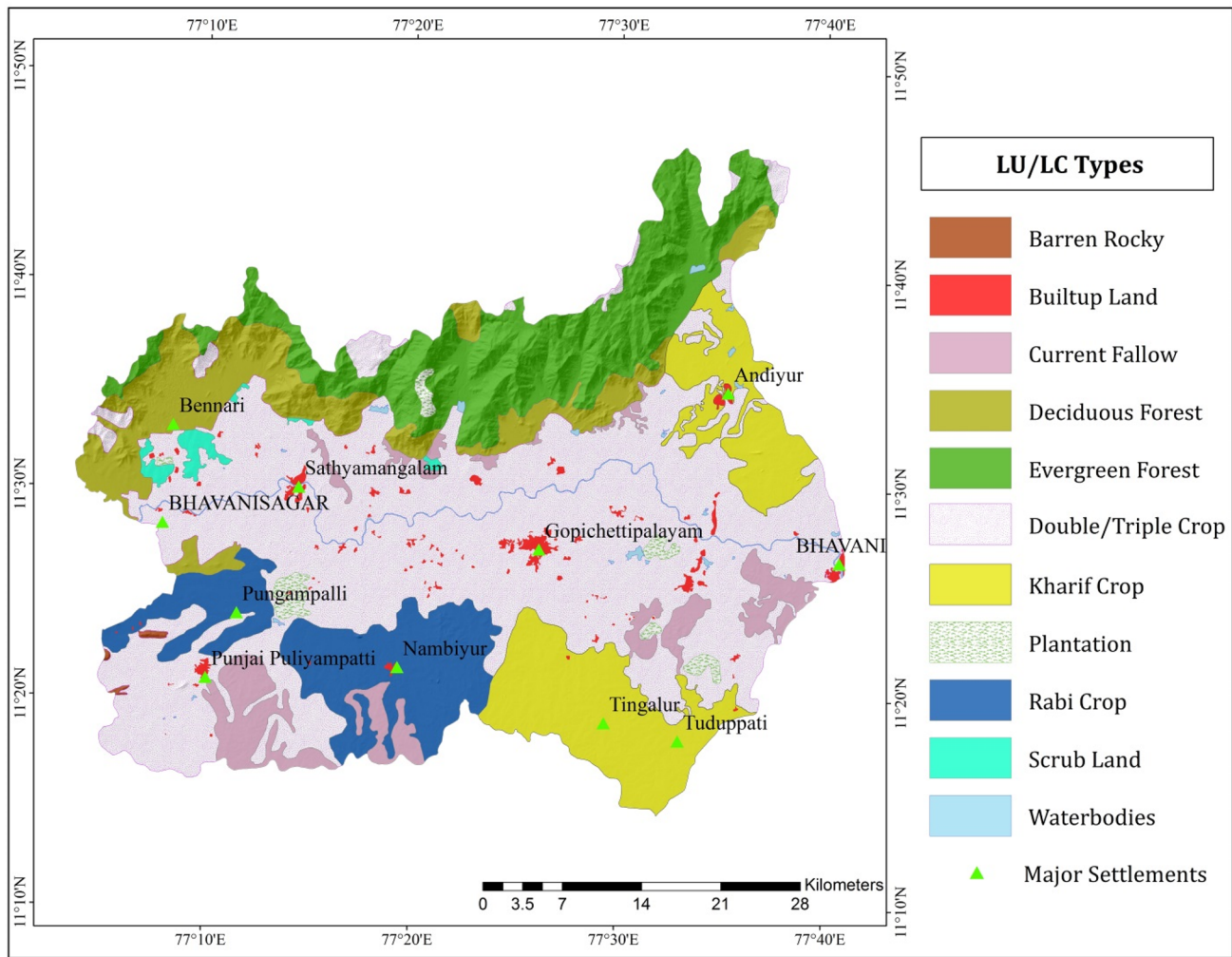


Fig. 3 Land use/land cover map of the Lower Bhavani River basin

surrounding locations are weighted by the distance from the spatial location point of rain gauge station. This approach governs the cell values using a linear weighted combination of trial points and allows user to control the important familiar points upon the interpolated values. Further, the distance of known points is perceived from the obtained values (Naoum et al. 2004). As one-fourth of the Lower Bhavani River basin (612 km² out of 2424 km²) falls under hilly terrain, and only 2 rain gauge stations out of 22 are situated in the hill ranges, the IDW method has been used in the present study. However, accuracy of the output has to be ascertained by comparing with the other methods since this method has some limitations in the mountainous areas (Schut 1976; Mair and Fares 2011). Finally, the spatial inputs (soil, land use/land cover, curve number, HSG) were modeled using the SCS-CN method and cross validation was made with the help of 57 existing wells in the basin.

Results and discussion

Land use/land cover

Land use/land cover (Lu/LC) is commonly used for sustainable management of the environment. The Lu/LC map was prepared from the satellite data using GIS (Thilagavathi et al. 2015b; Arya et al. 2020a). The Lower Bhavani River basin comprises of various Lu/Lc features such as evergreen forest, deciduous forest, Rabi crop, Kharif crop, double/tripls crop, plantation, current fallow, scrub land, barren rocky and built-up land (Fig. 3). The forest cover (evergreen and deciduous forest) mainly occupies the northern hilly terrain. It covers an area of 577.05 km². The agricultural land spreads in the flat terrain, which includes Kharif crop (291.74 km²), Rabi crop (225.62 km²), double/triple crop (1109.1 km²) and current fallow land (136.82 km²). The scrub land occupies 17.56 km², and plantation covers an

Table 3 Areal representation of various land use/land cover categories

Land use/land cover categories	Area (km ²)	Area (%)
Barren rocky	3.3	0.14
Deciduous forest	231.09	9.53
Evergreen forest	345.96	14.27
Double/triple crop	1109.1	45.75
Kharif crop	291.74	12.03
Rabi crop	225.62	9.3
Current fallow	136.82	5.65
Scrub land	17.56	0.72
Plantation	25.12	1.04
Water bodies	10.46	0.43
Built-up land	27.43	1.14

area of 25.12 km². The built-up land occupies 27.43 km², which is mainly surrounded by the agricultural land. The barren rocky area is exposed over 3.3 km², which is mostly in the western part of the basin. Water bodies (10.46 km²) are seen all over the basin. The areas occupied by each Lu/LC categories are presented in Table 3.

Soil texture

Soil type is a major factor to determine erosion, surface runoff, infiltration and sediment control of a particular basin, and soil texture refers to the combination of sizes of the soil particles. It is a unique property of a soil because it provides the possibility of rainwater to infiltrate and accumulate in the soil strata and then causes extension of runoff start time (Xu et al. 2015; Subramani et al. 2013). Soil that has high clay content represents low infiltration and low hydraulic conductivity but the slope factor (steepness) is also directly related to the runoff accumulation in down fall area (Subramani et al. 2012; Magesh et al. 2016). The study indicates clay loam (917.7 km²) is primarily distributed in the northern and eastern parts where its surface colour varies from grey to dark grey and represents red and black soils (Fig. 4). It mostly occupies the flat terrain and is subject to erosional activities of the area. Sandy loam (536.2 km²) occurs in the central and eastern parts of the basin, which is mainly in the terrain. It represents the alluvial deposits noticed in the Bhavani River course. This type of soil has moderate to high water content, and it is most suitable for cultivation of crops like paddy, sugarcane and groundnut. The loamy sand (415.8 km²) occurs over moderate to gentle slope in the northern part, which is supposed to have dark reddish to red lateritic gravel derived from gneissic rocks in the upstream side of the basin. This kind of soil is probably suitable for cultivation of pulses, grain crops and oilseeds. Sandy clay (243.78 km²) deposits are found over the gentle to moderate slope

areas in the foothills. This soil colour varies from reddish-brown to brown. The water availability in this soil is quite low, and hence it is suitable for the cultivation of fodder, black gram, grass and trees. The loam (152.92 km²) occupies the hilly region in the northern part of the study area where the slope is very steep. It is mostly unconsolidated in nature. This soil colour varies from brown to reddish brown. Sandy clay loam (118.4 km²) is mostly darker in tone and denser in nature. This soil is noticed in the flat to gentle sloping area, and its surface colour varies from reddish brown to dark brown. Generally, sandy clay loam lies in between sandy loam and clay loam, which is prone to sheet erosional activities. Silty clay (31.36 km²) occurs the nearly leveled ground, which is composed of very dark grey clayey calcareous material seen in the central part of the basin. The clay dominant calcareous content is derived from the calcium carbonate rich rocks, which leads to poor permeability of water (Kaliraj et al. 2015). This soil has lower buried pediments, which tends typically lighter and loose materials due to erosional effect. Clay (8.41 km²) occurs in small portion mainly in the bajada region. Loam and sandy clay loam categories are found to be adequate towards high permeability of surface water. The areal coverage and percentage of various soil texture categories are shown in Table 4.

Hydrological soil group (HSG)

Hydrological soil group (HSG) is one of the main components used to calculate the curve number (CN). Hydrological soil groups were identified for the Lower Bhavani River basin based on the USDA-Soil Conservation Service (SCS) guidelines to determine the rainfall-surface runoff of the basin (Table 4) (Fig. 5). The HSG classification of soil mainly depends on the infiltration rate of each soil texture category. Group 'D' (926.07 km²) soil has very low infiltration capacity and mostly impervious in nature. It represents mostly fine-grained soil. It mainly occurs in the southern and western boundaries of the basin. The second dominant HSG group of soil is 'B', which spreads over an area of 777.95 km². This soil has medium to coarse texture, which possesses moderate to good infiltration rate. This type of soil group contains loamy sand to sandy soil observed mainly in northern hilly areas. Group 'A' soil category represents coarser texture, which spreads over an area of 689.13 km² in the central part of the basin where the main stream of Bhavani River flows. It mainly includes gravel and alluvial soil where the infiltration rate is very high and surface runoff is very poor. Group 'C' soil occupies only 31.35 km² area, which occurs as linear patch in the central part of the basin. This soil has moderate to high surface runoff potential including sandy clay loam or clay loam (Table 5).

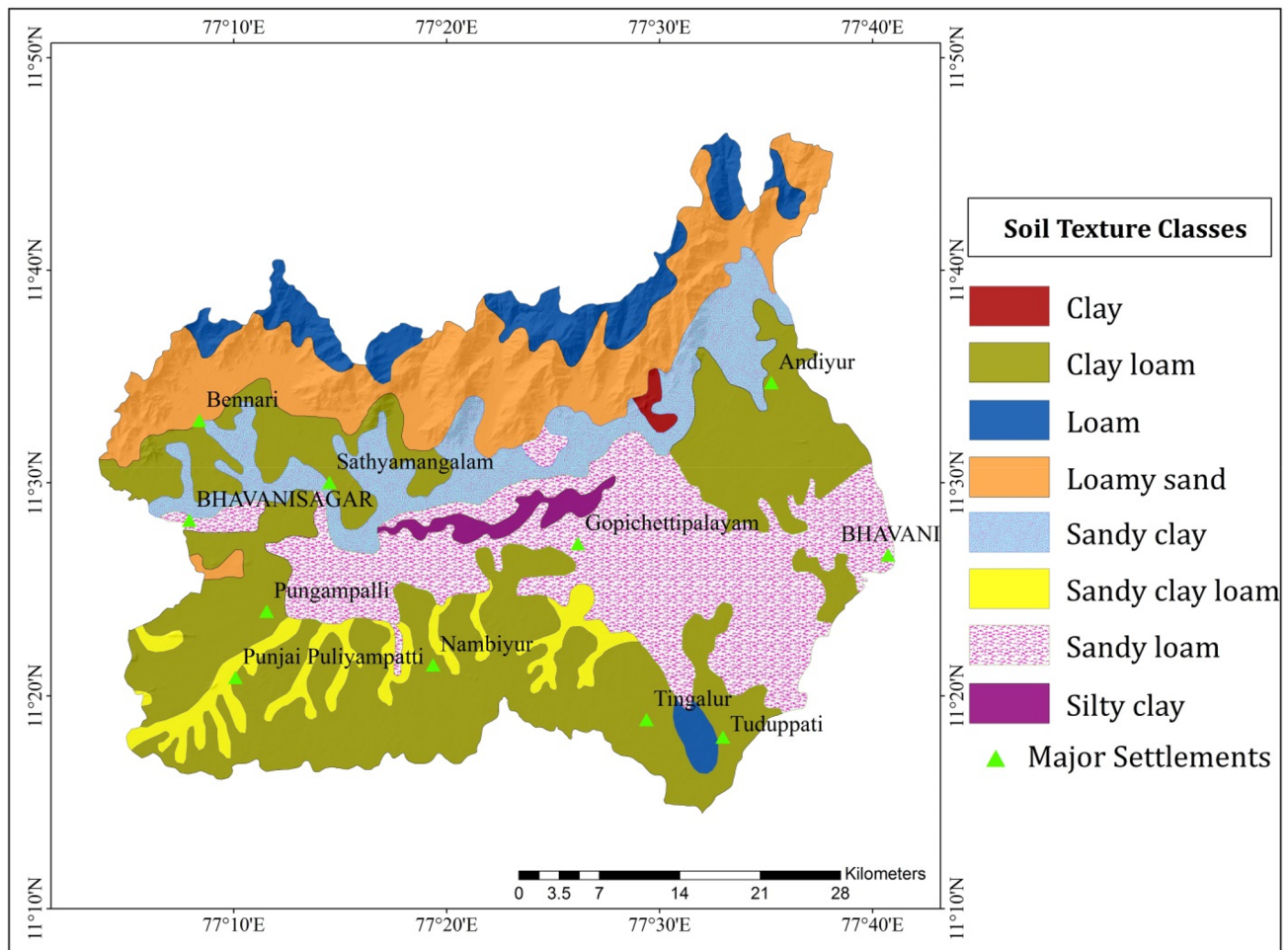


Fig. 4 Map showing various soil texture classes in the Lower Bhavani River basin

Table 4 Soil texture classes and their aerial coverage

Soil texture classes	Area (km ²)	Area (%)
Clay	8.41	0.34
Clay loam	917.7	37.86
Silty clay	31.36	1.3
Loamy sand	415.8	17.15
Loam	152.92	6.3
Sandy clay	243.78	10.05
Sandy clay loam	118.4	4.89
Sandy loam	536.2	22.11

Slope

Slope is an important factor for groundwater recharge computation and rainfall-runoff estimation (Arya et al. 2020b). The slope map of Lower Bhavani Basin is shown in the Fig. 6. The variation of slope (steep to gentle) greatly influences the infiltration rate of groundwater. Slope map of the

study area was prepared based on the integrated mission suitable development (IMSD) classification system, which comprises of seven slope categories (nearly level, very gentle level, gentle, moderate, strong, moderately steep and very steep). Various slope categories and their surface runoff behavior are shown in Table 6. The study area comprises of both hilly and plain regions. The nearly level slope category covers most of the basin area (1852.64 km² i.e., 76.4%), which is favourable for groundwater recharge because of slow rate of surface runoff.

Curve number (CN)

The curve number method (USDA 1972) is also recognized as the hydrologic soil cover complex method, which is mostly used for the surface runoff estimation. It requires the combination of rainfall data and CN value. This method estimates the surface runoff capability of the basin, which expresses through statistical values, varies between 0 and 100 (Ketul et al. 2017). The CN values are employed to

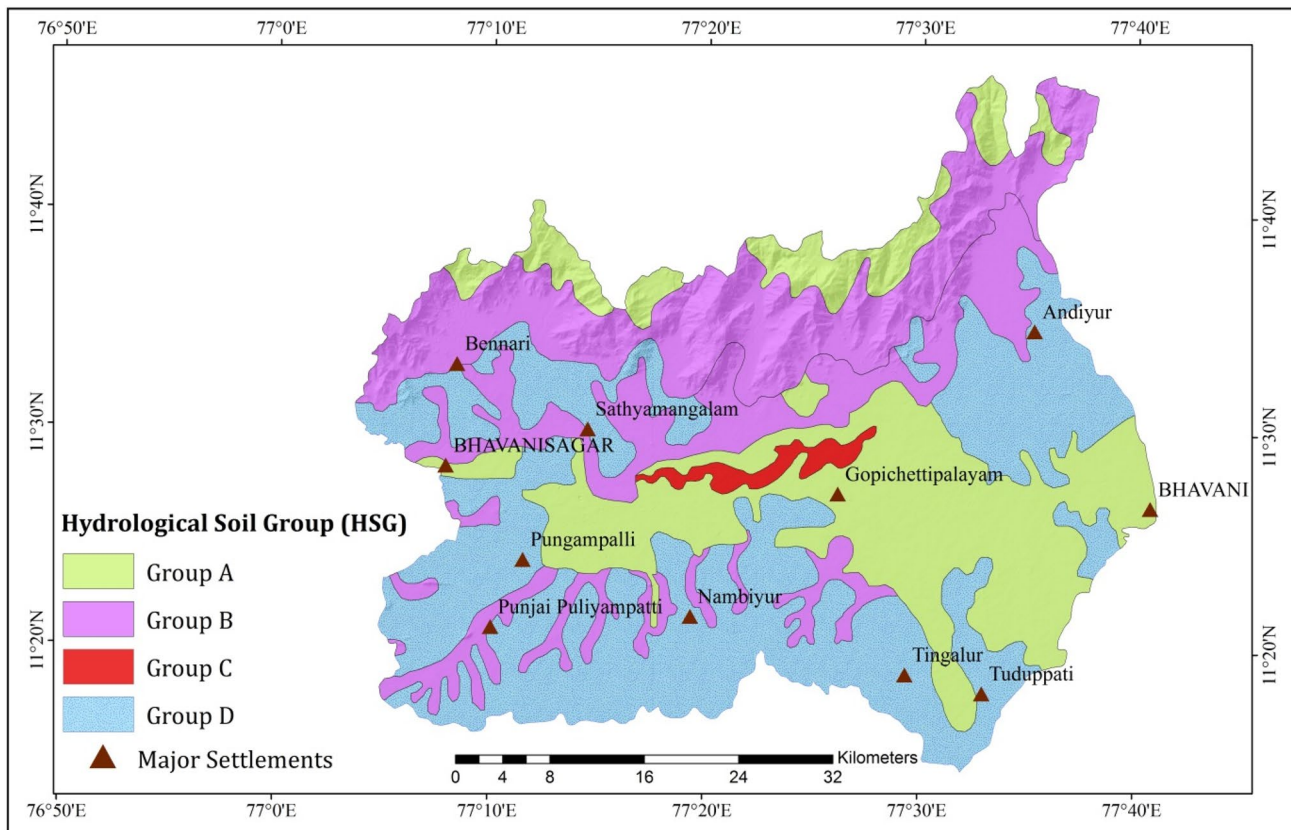


Fig. 5 Map showing the spatial distribution of hydrological soil groups (HSG) in the Lower Bhavani River basin

Table 5 Hydrological Soil Groups (HSG) in the Lower Bhavani River basin and their aerial coverage

Hydrological soil groups (HSG)	Area (km ²)	Area (%)
Group A	689.13	28.42
Group B	777.95	32.08
Group C	31.35	1.3
Group D	926.07	38.2

convert the rainfall distribution into runoff distribution. The Lu/Lc and soil maps were intersected by using spatial intersection tool in GIS software. Further, CN value was assigned for each spatial polygon of soil and LU/LC classes. The double/triple crop (47.03%) category of LU/LC class is dominated in the study area, which includes all the four HSG groups (A, B, C and D). The other Lu/LC categories in the basin are evergreen forest (13.91%), Kharif crop (11.73%), deciduous forest (9.28%), Rabi crop (9.06%), current fallow (5.49%), scrub land (1.12%), built-up land (1.08%), plantation (0.99%), water body (0.43%) and barren rocky (0.13%). Runoff Curve Number (CN) values were computed for various Antecedent Moisture Condition categories such

as average condition (AMC II), dry condition (AMC I) and wet condition (AMC III). The weighted CN values obtained for AMC I, AMC II and AMC III are 49.24, 68.9 and 83.84, respectively (Table 7). The Curve Numbers (CN) obtained for various Hydrological Soil Groups and LU/LC categories for the average Antecedent Moisture Condition (AMC II) are given in Table 8. The spatial distribution of CN values plotted using GIS for the entire Lower Bhavani basin (Fig. 7) indicates that lower CN values are observed over 37.44% of the basin area, whereas the higher CN values are noticed over 62.56% of the basin area. The higher CN value generates more surface runoff, and the lower CN value generates less surface runoff from the rainfall data.

Rainfall-runoff estimation

Using the SCS-CN model, the initial abstraction ($I_a = 0.3S$) was determined where 'S' is the potential maximum retention, which is calculated for the AMC II condition. Further, spatial variation of rainfall intensity map was generated using IDW spatial interpolation method (Vennila et al. 2007; Karunanidhi et al. 2013) (Fig. 8). All these input parameters were employed to estimate the surface runoff of the basin. The average surface runoff is calculated as 211.99 mm,

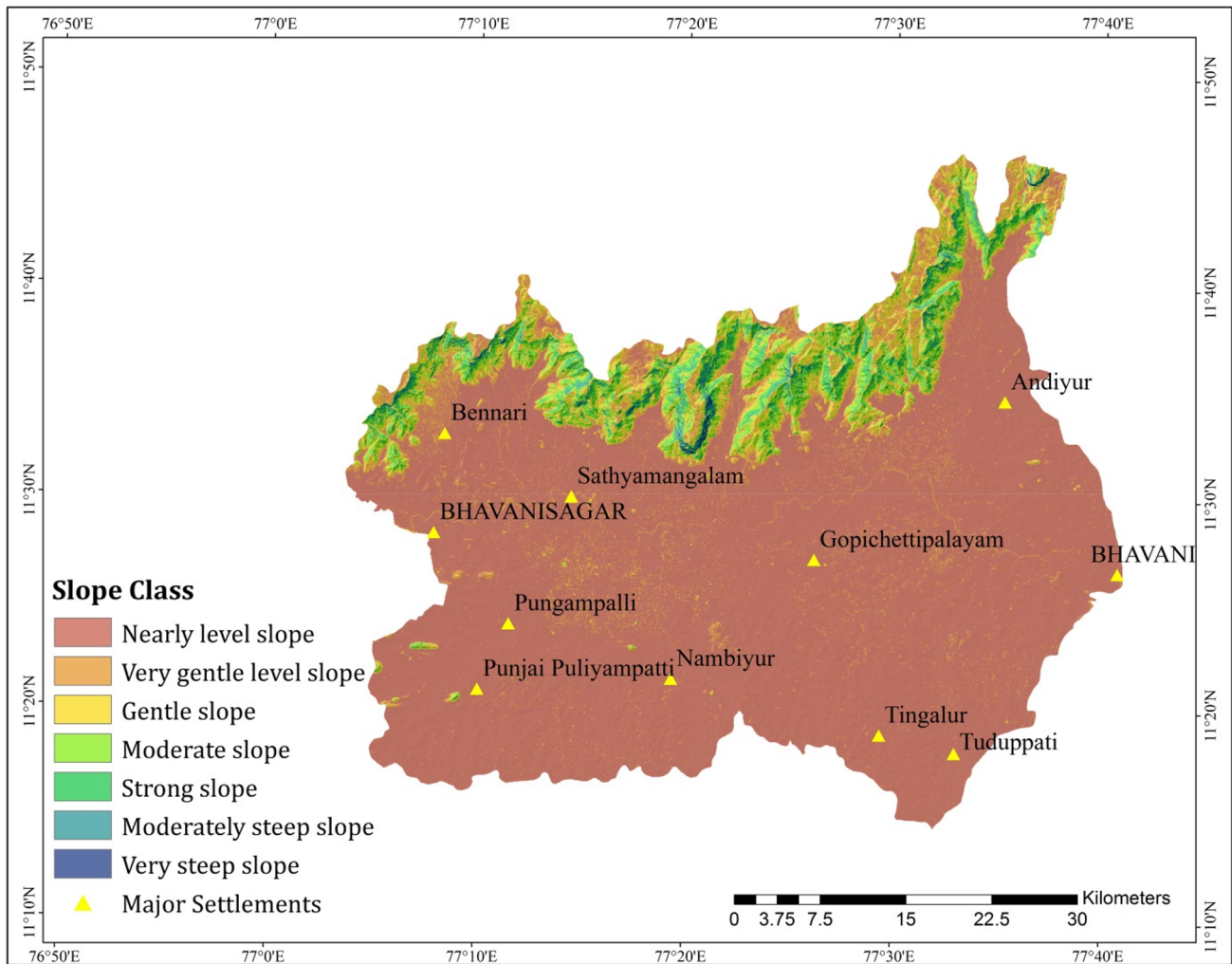


Fig. 6 Slope map of the Lower Bhavani River basin

Table 6 Slope categories and their surface runoff behavior

Slope categories (%)	Area (km ²)	Area (%)	Significance of runoff
Nearly level	1852.64	76.4	Low surface runoff
Very gentle level	207.42	8.56	Low surface runoff
Gentle	134	5.53	Low surface runoff
Moderate	129.62	5.35	Moderate surface runoff
Strong	77.48	3.2	Moderate surface runoff
Moderately steep	20.58	0.85	High surface runoff
Very steep	2.85	0.11	High surface runoff

and the average volume of surface runoff is calculated as 81,995,380 m³. The estimated annual rainfall, surface runoff and runoff volume are shown in Table 9. The annual surface runoff was estimated from the monthly rainfall data available

Table 7 Weighted CN values obtained for various antecedent moisture conditions (AMC)

AMC	Weighted CN value	Potential maximum retention (s)	P > 0.3S
I	49.24	261.84	78.55
II	68.9	114.65	34.39
III	83.84	48.95	14.68

at 22 stations using SCS-CN method. In order to find out the surface runoff volume, each year’s runoff value was multiplied with the basin area ($A = 2,424,000,000 \text{ m}^2$) (Satheshkumar et al. 2017). The data analysis indicates that rainfall intensity varies from 267 mm (2002) to 1528.6 mm (2005), and the surface runoff varies from 102.04 mm (1985) to 463.02 mm (2010) in the Lower Bhavani River basin. The annual rainfall of the basin gradually increases from 1983

Table 8 Curve Numbers obtained for various HSG and LU/LC categories based on AMC II condition

LU/LC classes	Hydrological soil groups (HSG)	Curve number (CN)	Area (km ²)	Area (%)	Area (%) * CN
Barren rocky	B	66	1.52	0.06	3.96
	D	83	1.75	0.07	5.81
Built-up land	A	57	14.58	0.58	33.06
	B	72	5.954	0.23	16.56
	C	81	0.27	0.01	0.81
	D	86	6.53	0.26	22.36
Current fallow	A	77	26.37	1.06	81.62
	B	86	21.22	0.85	73.1
	D	94	89.15	3.58	336.52
Deciduous forest	A	28	24.76	0.99	27.72
	B	44	158.91	6.39	281.16
	D	64	47.33	1.9	121.6
Evergreen forest	A	26	100.63	4.05	105.3
	B	40	245.06	9.86	394.4
	D	61	0.191	0.007	0.427
Double/triple crop	A	62	489.54	19.7	1221.4
	B	71	257.75	10.37	736.27
	C	88	31	1.24	109.12
	D	91	390.59	15.72	1430.52
Kharif crop	A	72	31.81	1.28	92.16
	B	81	47.11	1.89	153.09
	D	91	212.78	8.56	778.96
Plantation	A	45	18.36	0.73	32.85
	B	53	4.93	0.19	10.07
	D	72	1.8	0.07	5.04
Rabi crop	A	61	11.35	0.45	27.45
	B	70	38.09	1.53	107.1
	D	80	176.1	7.08	566.4
Scrub land	B	60	10.33	0.83	49.8
	D	79	7.22	0.29	22.91
Water bodies	-	100	10.98	0.43	43

to 2000 and suddenly decreases from 2000 to 2003. Further, there has been a tremendous rise in rainfall between 2004 and 2011. The surface runoff curve shows gentle ups and downs, which mostly resembles the rainfall intensity (Fig. 9). However, there are some mismatches noticed between the rainfall curve and runoff curve. The event-based runoff coefficient is one of the important parameters to infer the multi-time series information on rainfall-runoff response datasets. The employed linear statistical model was ***assisted in identification of runoff coefficients, through the runoff process. Two variables were considered for the evaluation such as independent variable (rainfall) and dependent variable (runoff). A scatter plot was prepared to understand the linear relationship between annual rainfall intensity and surface runoff. Their relationship is moderately significant ($R^2 = +0.42$) (Fig. 10), indicating that for a given rainfall event, the predicted surface runoff has been

lesser for all annual years. Hence, identified response proved that rainfall alone is not influencing the runoff of the basin. Along with other environmental factors such as monsoonal effect, soil and its antecedent moisture condition, interception, land use/land cover, agricultural activities, geology and slope characteristics play major roles in the basin. Especially, clay and loamy soils observed in steep slope regions contribute to surface runoff due to interaction of base flow during non-monsoonal period.

Eventually, the surface runoff potential areas were obtained through the spatial inputs of LU/LC, soil types and texture, slope, HSG and annual average rainfall of the study area. The integrated surface runoff potential map is presented in Fig. 11. The rainfall-surface runoff potential was grouped into five classes such as 'very high', 'high', 'moderate', 'low' and 'very low'. The northern portion of the study area falls under the categories of very low to low

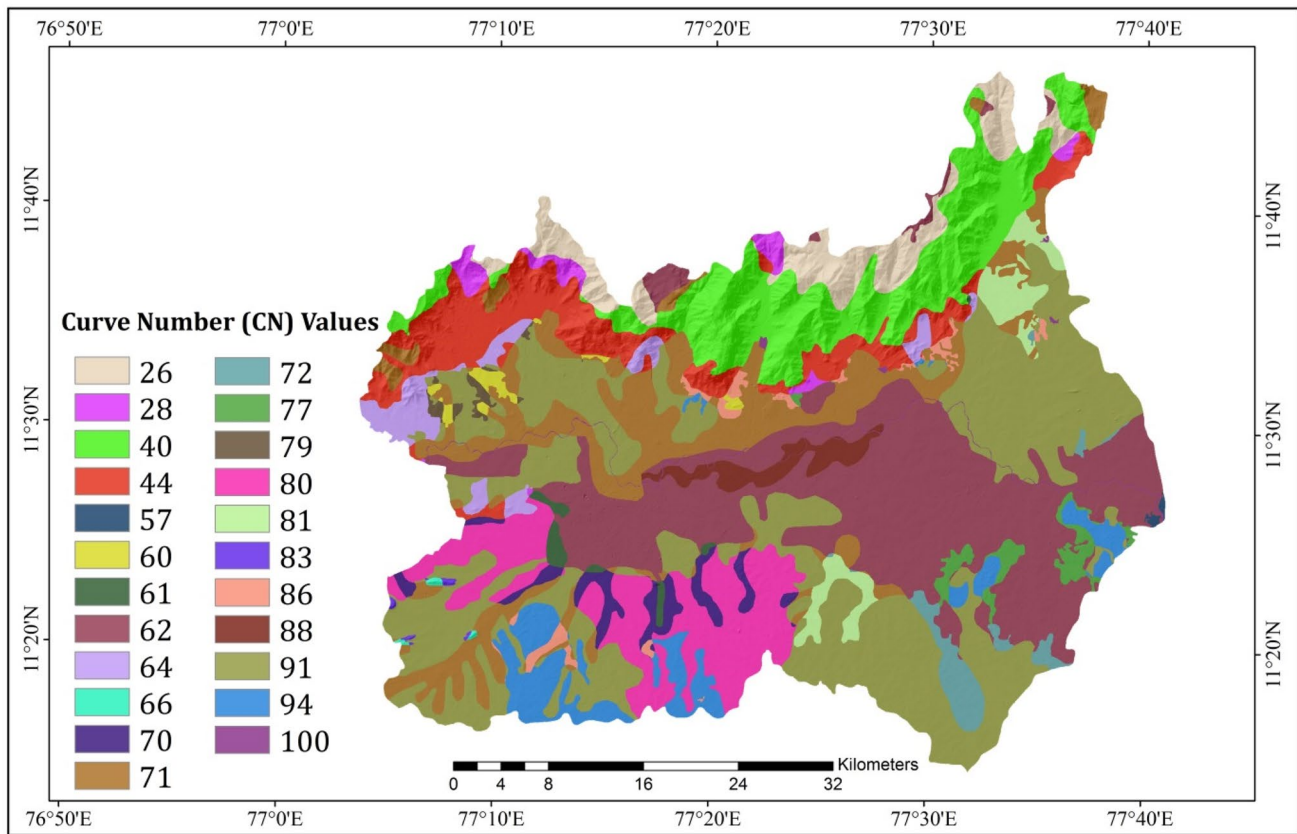


Fig. 7 Spatial representation of curve numbers (CN) generated for the Lower Bhavani River basin

surface runoff potential, which covers an area of 125.1 km² (5.16%) and 408.35 km² (16.84%), respectively. The moderate surface runoff potential zones mainly occupy the central and western parts of the basin with the areal extent of 614.28 km² (25.34%). High surface runoff potential zone is generally noticed along the foothill regions in the northern part of the basin. It is also noticed in the southern part along the tributaries. Its areal extent is 551.72 km² (22.76%). Very high surface runoff potential areas are observed in the northeast, southeast and southwest portions of the basin, which covers an area of 724.89 km² (29.9%). The present study indicates that nearly 53% of the basin area is dominated by ‘high to very high’ surface runoff potential. The high surface runoff potential zones in the study area will affect the groundwater recharge.

Validation of model output

The estimated surface runoff of the basin was validated with the average groundwater level fluctuation (AGLF) observed at 57 wells spread over the study area. The basin AGLF ranges from 2.32 to 21.72 m (Fig. 12). The AGLF range between 8 and 12 m indicates moderate water table decline, and the range between 12 and 21 m indicates deep water

table decline. From the comparison of runoff and AGLF, nearly 62% of the basin area (1495.73 km²) falls in the categories of moderate to high declining water level. High groundwater level fluctuation is observed in the northeast and southeast parts of the basin, which perfectly matches with the very high surface runoff potential category. Moderate runoff potential also matches with the moderate AGLF exists in the central part of the basin. Therefore, this comparison clearly indicates that most of the basin area lies between moderate to high surface runoff as well as AGLF categories. In the high surface runoff potential areas, the surface runoff leads more flow along the river channels, which reduces the infiltration rate and declines the water table (Lannerstad and Molden 2009). This problem can be solved by adopting the efficient water management practices including construction of suitable artificial recharge structures across the river channels in the high runoff potential areas.

Conclusions

In the present study, SCS-CN model combined with geospatial techniques was used to delineate the surface runoff potential zones. Rainfall intensity, soil types, soil texture,

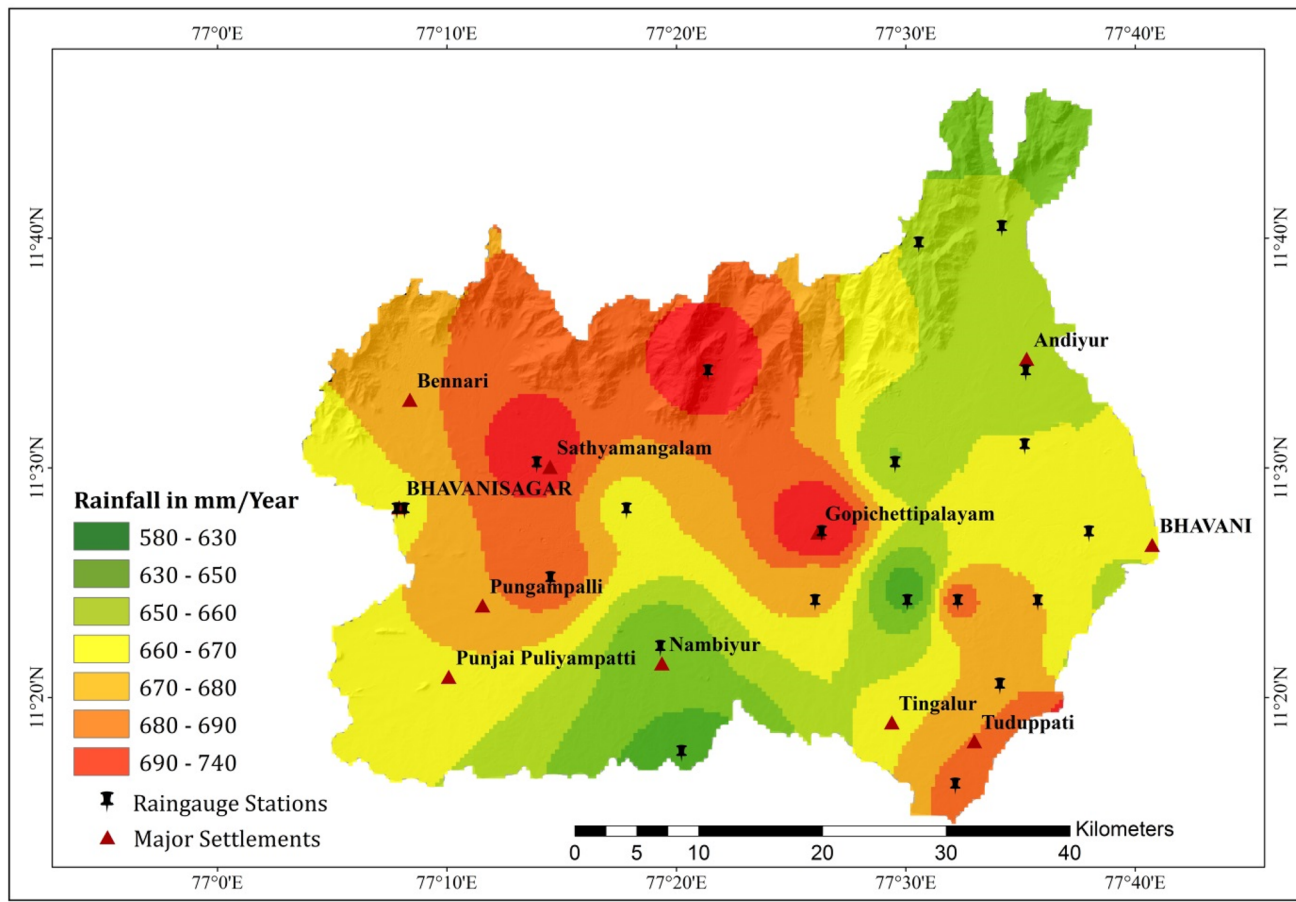


Fig. 8 Spatial variation of average annual rainfall intensity in the Lower Bhavani River basin

slope and land use/land cover were considered as important input parameters for the SCS-CN model. GIS was mainly used to prepare and integrate maps pertaining to this study and also to plot the spatial distribution of various outputs. Based on the infiltration capacity of soils in the study area, Hydrological Soil Groups (HSG) were identified for computation of CN values. Group 'D' soil is dominated in the study area (926.07 km²), which has very low infiltration capacity and high surface runoff. Group 'A' soil represents coarser texture, which spreads over an area of 689.13 km² in the central part of the basin. This soil mainly consists of river alluvium where the infiltration rate is very high, and runoff is poor. This soil group possesses good groundwater potential in this basin.

The Antecedent Moisture Condition (AMC) of a soil also plays an important role because CN value changes according to the soil texture. Based on the field observations, AMC II condition (average soil moisture) was adopted for the surface runoff estimation. The CN values were employed to convert the rainfall distribution into surface runoff distribution. The spatial distribution map of CN indicates that lower CN values were observed over 37% of the basin area, whereas

the higher CN values were noticed over 63% of the basin area. The higher CN values indicate more surface runoff potential in the basin. The study indicates that the annual rainfall intensity varied from 267 mm (2002) to 1529 mm (2005), and the surface runoff varies from 102 mm (1985) to 463 mm (2010) over the period of 33 years (1983–2015). For the Lower Bhavani River basin the average rainfall-surface runoff was estimated as 211.99 mm, and the average surface runoff volume was estimated as 81,995,380 m³. The study highlights that nearly 53% of the basin area is dominated by 'high to very high' surface runoff potential. The moderate surface runoff potential zones fell in the central and western parts of the basin with the areal extent of 614.28 km² (25.34%).

For the accuracy assessment of the SCS-CN model output, the surface runoff potential zones of the basin were cross validated with the Average Groundwater Level Fluctuation (AGLF) observed in 57 wells spread over the study area. It signifies that high surface runoff potential zones matches with high groundwater level fluctuation zones. Similarly, moderate to low surface runoff potential zones facilitate good recharge resulting low groundwater level fluctuation.

Table 9 Estimation of annual rainfall, surface runoff depth and runoff volume for the period of 33 years

Year	Rainfall (mm)	Runoff (mm)	Runoff volume (m ³)
1983	660.3	146.00	35,390,783
1984	679.9	116.07	28,135,106
1985	566.5	102.04	24,733,719
1986	550.6	155.64	37,726,247
1987	736.9	230.76	55,936,314
1988	659.1	118.16	28,642,411
1989	707	132.19	32,042,471
1990	635.6	143.96	34,895,962
1991	785	219.21	53,137,430
1992	770.2	186.28	45,155,045
1993	859.2	233.80	56,672,755
1994	804	317.06	76,856,527
1995	556	148.58	36,015,947
1996	835.1	159.62	38,692,889
1997	802.4	249.15	60,394,600
1998	616.6	194.58	47,167,399
1999	761	244.04	59,155,835
2000	552	317.52	76,967,134
2001	496	158.66	38,460,012
2002	267	161.09	39,048,851
2003	294.6	179.65	43,547,876
2004	968.2	273.20	66,223,767
2005	1528.6	380.41	92,211,820
2006	1057	242.69	58,828,439
2007	777.2	200.79	48,672,121
2008	865.4	233.18	56,523,094
2009	686	189.98	46,051,111
2010	1095.8	463.02	1,122,365,78
2011	944	247.81	60,069,765
2012	562.8	147.16	35,672,467
2013	751.4	145.44	35,254,062
2014	798.6	261.06	63,282,136
2015	779.4	296.69	71,917,668
Average	739.67	211.99	81,995,380

This is clearly noticed in the central part of the basin where the groundwater potential is high. The study also concludes that the high surface runoff potential zones in the basin promote more surface water flow into the river channels, which affects the infiltration rate, and thus declines the groundwater table. This leads the aquifer into stress particularly during summer season. To overcome this situation, rainwater augmentation practices will be helpful to restrict the surface runoff and to store the water in the aquifer medium. Hence, artificial recharge of groundwater is recommended to store the surplus runoff of the basin. In practical, it can be attempted through artificial recharge structures like check dam, percolation pond, recharge shaft and farm ponds etc.

Recommendations

- Check dams can be promoted as a small-scale structure both in steep and moderate slope areas in the basin, where the pattern of stream flow is straight and narrow.
- Percolation ponds can be constructed in the low-lying areas where the slope is gentle to flat. It will increase the groundwater level in shallow aquifers. This method is an added advantage for the agricultural practices of the basin to sustain the availability of water throughout the year.
- Farm ponds can be created adjacent to the agricultural fields for the augmentation of surface runoff. Farm ponds will be useful in collecting the excess surface runoff during the monsoonal seasons and also conserves the soil moisture. Hence, these ponds are considered as the supplementary sources to irrigational crops for prolonged periods.
- Recharge shafts are recommended for the poor permeable medium of aquifer. However, separate study has to be carried out to identify the suitable sites for the construction of suitable artificial recharge structures in the basin. Overall, this study provides detail information to the government agencies, policy makers and farmers for framing sustainable development goals (SDGs).

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Agarwal SP, Praveen KT, Bhaskar RN, Vaibhav G (2014) Integrated approach for snowmelt run-off estimation using temperature index model, remote sensing and GIS. *Curr Sci* 106(3):397–407
- Ajaykumar KK, Sanjay SK (2012) Identifying potential rainwater harvesting sites of a semi-arid, Basaltic Region of Western India using SCS-CN method. *J Water Res Manag* 26(9):2537–2554
- Ajmal M, Kim TW (2015) Quantifying excess stormwater using SCS-CN based rainfall runoff models and different curve number determination. *J Irrig Drain Eng* 141(3):1–12
- Al-Juaidi AEM (2018) A simplified GIS-based SCS-CN method for the assessment of land-use change on runoff. *Arab J Geosci* 11:269
- Amutha R, Porchelvan P (2009) Estimation of surface runoff in malattar sub-watershed using SCS-CN method. *J Indian Soc Remote Sens* 37:291–304
- Anand B, Karunanidhi D, Subramani T, Srinivasamoorthy K, Raneesh KY (2017) Prioritization of subwatersheds based on quantitative

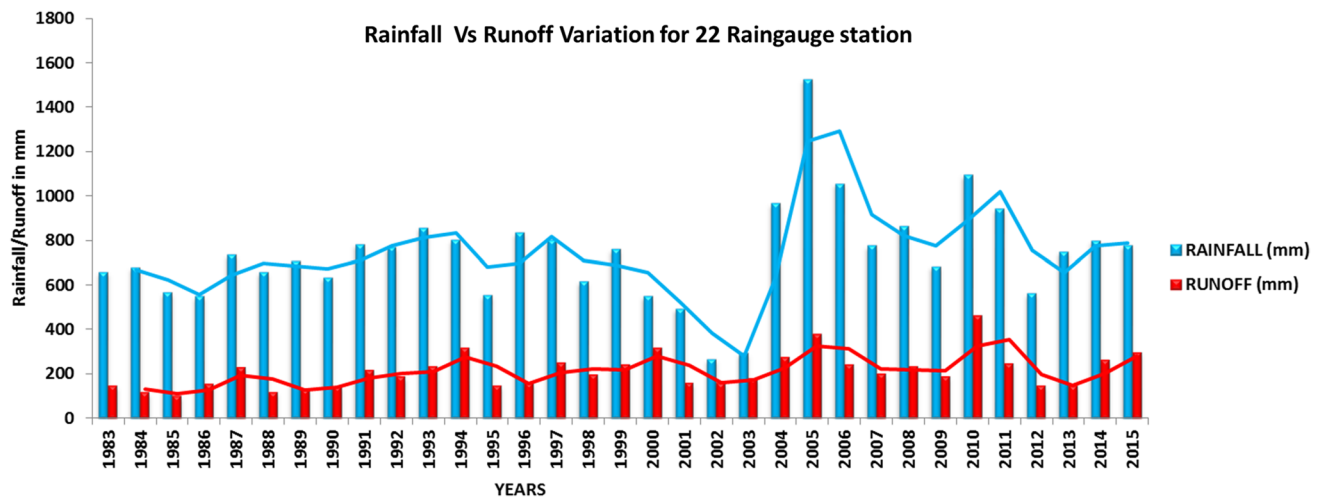
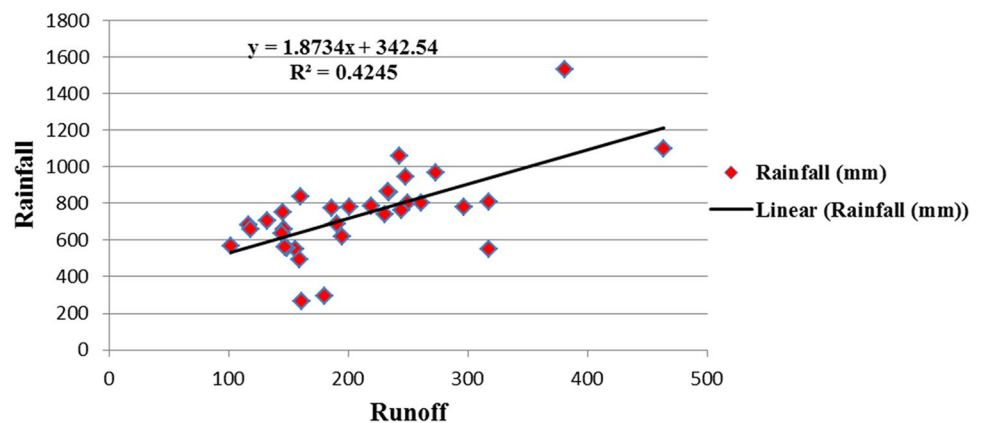


Fig. 9 Graph illustrating annual rainfall Vs. surface runoff variations computed for the period of 33 years (1983–2015) at 22 rain gauge stations in the Lower Bhavani River basin

Fig. 10 Scatter plot illustrating the relationship between rainfall and surface runoff



morphometric analysis in lower Bhavani basin, Tamil Nadu, India using DEM and GIS techniques. *Arab J Geosci* 24(10):1–18. <https://doi.org/10.1007/s12517-017-3312-6>

Anand B, Karunanidhi D, Subramani T, Srinivasamoorthy K, Suresh M (2020) Long-term trend detection and spatiotemporal analysis of groundwater levels using GIS techniques in Lower Bhavani River basin, Tamil Nadu, India. *Environ Dev Sustain*. <https://doi.org/10.1007/s10668-019-00318-3>

Anandakumar S, Subramani T (2014) Regional groundwater flow modeling in Lower Bhavani River basin, Tamil Nadu, India. *Disaster Adv* 7(12):41–52

Anandakumar S, Subramani T, Elango L (2008) Spatial variation and seasonal behaviour of rainfall pattern in Lower Bhavani River basin, Tamil Nadu, India. *Ecoscan* 2(1):17–24

Anbazhagan S, Ramasamy SM, Das S (2005) Remote sensing and GIS for artificial recharge study, runoff estimation and planning in Ayyar basin, Tamil Nadu, India. *Environ Geol* 48:158–170

Ansari TM, Katpatal YB, Vasudeo AD (2016) Spatial evaluation of impacts of increase in impervious surface area on SCS-CN and runoff in Nagpur urban watersheds, India. *Arab J Geosci* 9:702

Anubha T, Singh AK, Vaishya RC (2015) SCS CN runoff estimation for Vindhyachal region using remote sensing and GIS. *Int J Adv Remote Sens GIS* 4(1):1214–1223

Aravinthasamy P, Karunanidhi D, Subramani T, Srinivasamoorthy K, Anand B (2019a) Geochemical evaluation of fluoride contamination in groundwater from Shanmuganadhi River basin, South India: implication on human health. *Environ Geochem Health*. <https://doi.org/10.1007/s10653-019-00452-x>

Aravinthasamy P, Karunanidhi D, Subramani T, Anand B, Roy PD, Srinivasamoorthy K (2019b) Fluoride contamination in groundwater of the Shanmuganadhi River Basin (south India) and its association with other chemical constituents using geographical information system and multivariate statistics. *Geochemistry*. <https://doi.org/10.1016/j.chemer.2019.125555>

Arya S, Subramani T (2015) Groundwater flow and fluctuation using GIS in a hard rock region, South India. *Indian J Geo Mar Sci* 44(9):1422–1427

Arya S, Vennila G, Subramani T (2018) Spatial and seasonal variation of groundwater levels in Vattamalaikarai River Basin, Tamil Nadu, India—study using GIS and GPS. *Indian Geo Mar Sci* 47(9):1749–1753

Arya S, Subramani T, Vennila G, Karunanidhi D (2019) Health risks associated with fluoride intake from rural drinking water supply and inverse mass balance modeling to decipher hydrogeochemical processes in Vattamalaikarai River basin, South India. *Environ Geochem Health*. <https://doi.org/10.1007/s10653-019-00489-y>

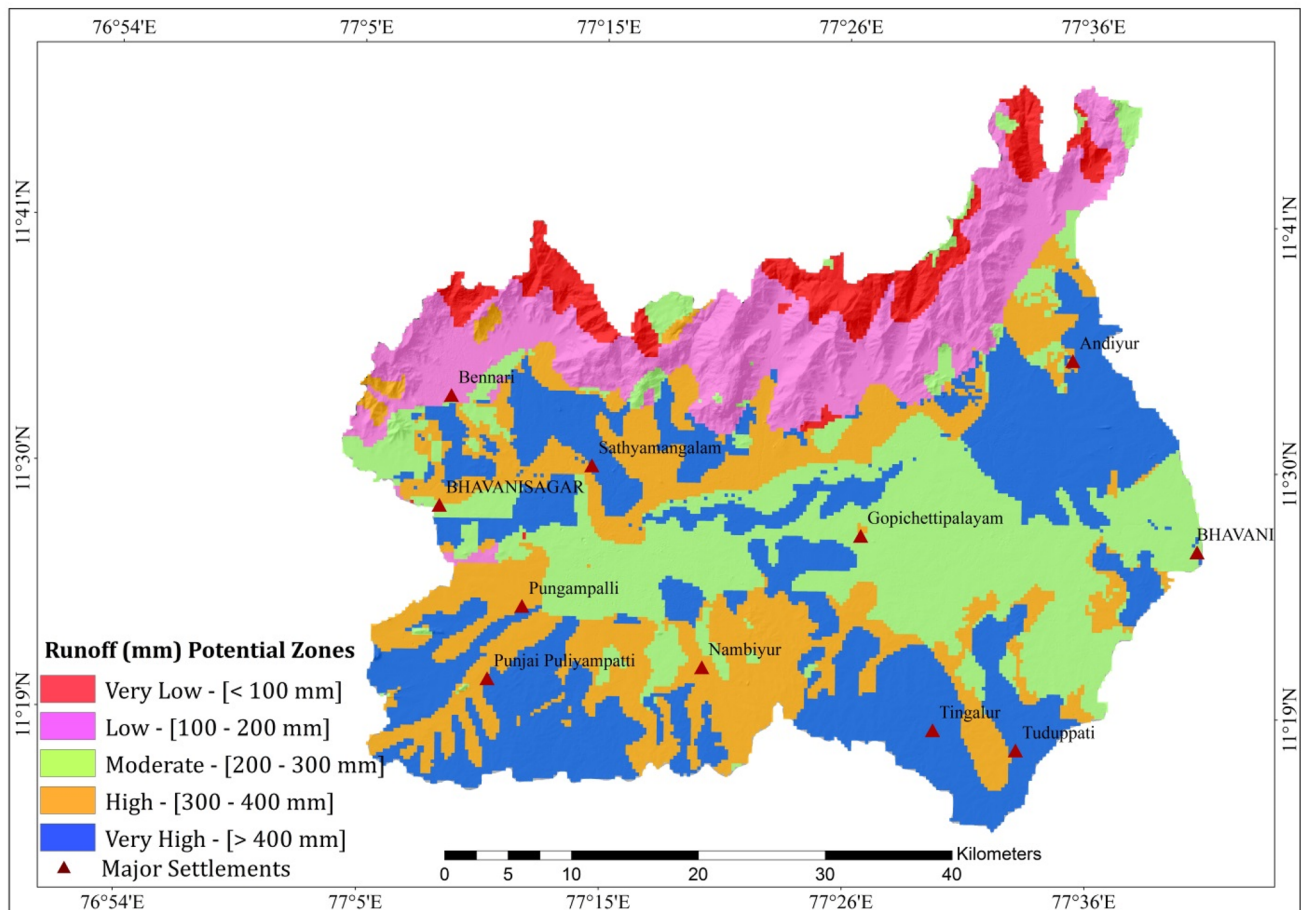


Fig. 11 Map illustrating surface runoff potential zones in the Lower Bhavani River basin

- Arya S, Subramani T, Karunanidhi D (2020a) Delineation of groundwater potential zones and recommendation of artificial recharge structures for augmentation of groundwater resources in Vattamalaikarai Basin, South India. *Environ Earth Sci* 79:102. <https://doi.org/10.1007/s12665-020-8832-9>
- Arya S, Subramani T, Vennila G, Roy PD (2020b) Groundwater vulnerability to pollution in the semi-arid Vattamalaikarai River Basin of south India through DRASTIC index evaluation. *Geochemistry*. <https://doi.org/10.1016/j.chemer.2020.125635>
- Ashish B, Patil KA (2014) Estimation of runoff by using SCS curve number method and arc GIS. *Int J Sci Engg Res* 5(7):1283–1287
- Bhaskar J, Suribabu CR (2014) Estimation of surface runoff for urban area using integrated remote sensing and GIS. *Jordan J Civil Eng* 8(1):70–80
- Bhura CS, Singh NP, Mori PR, Prakash I (2015) Estimation of surface runoff for Ahmedabad urban area using SCS-CN method and GIS. *Int J Sci Tech Eng* 1(11):411–416
- Binh TQ, Thuy NT (2008) Assessment of the influence of interpolation techniques on the accuracy of digital elevation model. *VNU J Sci Earth Sci* 24:176–183
- Burrough PA (1986) *Principles of geographical information systems for land resources assessment*. Oxford University Press, Oxford
- Central Ground Water Board (CGWB) (2008) *District groundwater brochure*. CGWB, Erode
- Chow VT, Maidment DK, Mays LW (2002) *Applied hydrology*. McGraw-Hill Book Company, Newyork
- Devi TT, Katpatal YB (2016) Surface Runoff depth by SCS curve number method integrated with satellite image and GIS techniques. *Urban Hydrol Watershed Manag Soc Econ Aspects* 71:51–68
- Dinagara Pandi P, Saravanan K, Mohan K (2017) Identifying runoff harvesting sites over the Pennar Basin, Andhrapradesh using SCS-CN method. *Int J Civil Eng Technol* 8(8):65–73
- FAO (2014) *World reference base for soil resources 2014, International soil classification system for naming soils and creating legends for soil maps*. FAO, Washington
- Fetter CW (2001) *Applied hdrogeology*. Prentice Hall, Upper Saddle River
- Fitts CR (2002) *Groundwater science*. Academic press, New York
- Gajbhiye S, Sharma SK, Tignath S (2015) Application of remote sensing and geographical information system for generation of runoff curve number. *J Appl Water Sci* 7(4):1773–1779
- Goovaerts P (2000) Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. *J Hydrol* 228(1–2):113–129
- Hartkamp AD, De Beurs K, Stein A, White JW (1999) *Interpolation techniques for climate variables, NRG-GIS Series 99–01*. CIMMYT, Mexico
- Hema S, Subramani T, Elango L (2010) GIS study on vulnerability assessment of water quality in a part of Cauvery River. *Int J Environ Sci* 1(1):1–17

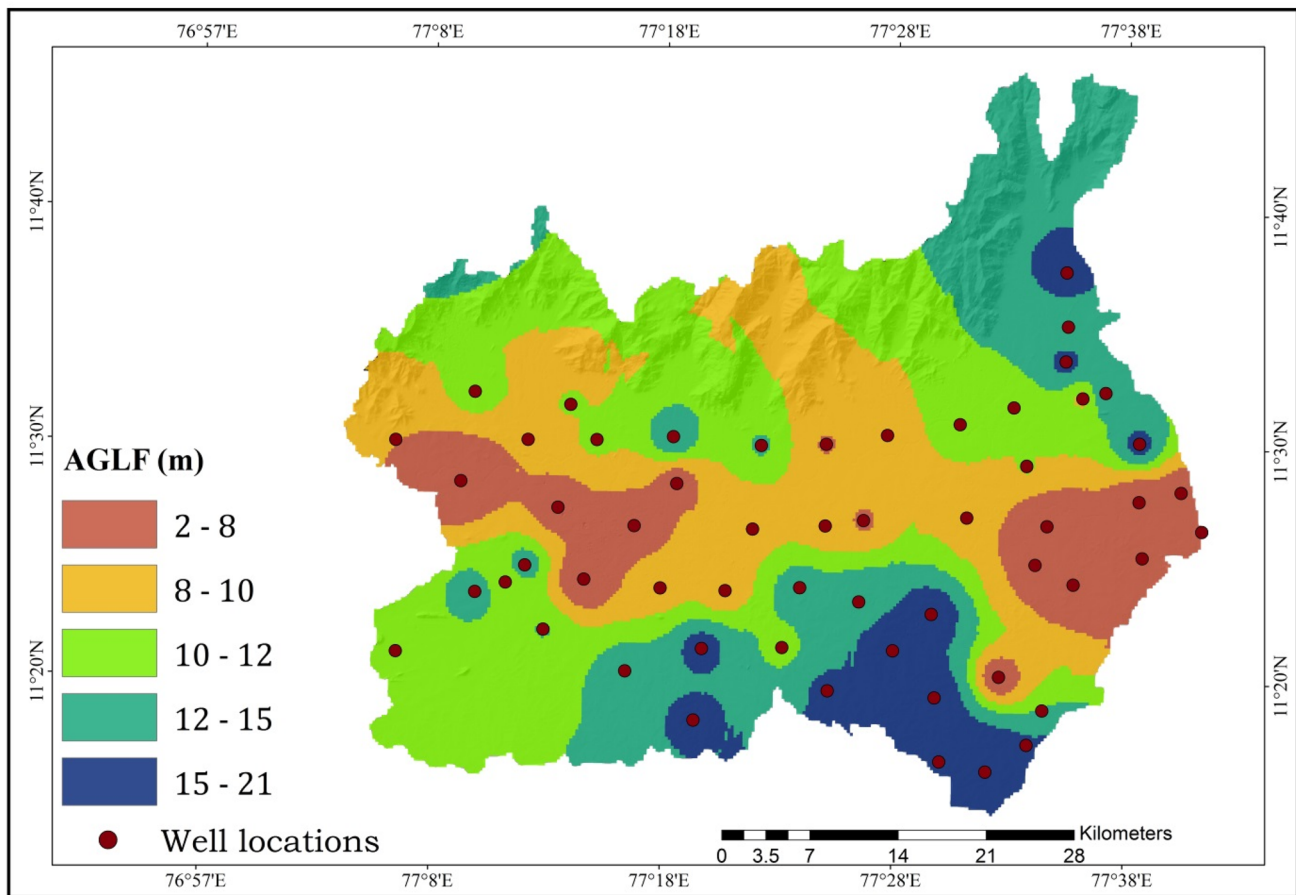


Fig. 12 Map showing average groundwater level fluctuation (AGLF) in the Lower Bhavani River basin

- IMSD (1995) Technical guidelines, integrated mission for sustainable development. National Remote Sensing Centre (NRSC), New York
- Ishtiyak A, Vivek V, Mukesh Kumar V (2015) Application of curve number method for estimation of runoff potential in GIS environment. *Int Conf Geol Civil Eng* 80(4):16–20
- Jaimin P, Singh NP, Prakash I, Khaldi M (2017) Surface runoff estimation using SCS-CN method—a case study on Bhadar Watershed, Gujarat. *India Imper J Interdiscip Res* 3(5):1213–1218
- Jha MK, Chowdary VM, Kulkarni Y, Mal BC (2014) Rainwater harvesting planning using geospatial techniques and multicriteria decision analysis. *Resour Conserv Recycl* 83:96–111
- Joy R (2016) Estimation of runoff depth and volume using NRCS-CN method in Konar Catchment (Jharkhand, India). *J Civil Environ* 6(7):1–6
- Kaliraj S, Chandrasekar N, Magesh NS (2015) Evaluation of multiple environmental factors for site-specific groundwater recharge structures in the Vaigai River upper basin, Tamil Nadu, India using GIS-based weighted overlay analysis. *Environ Earth Sci* 74(5):4355–4380
- Karunanidhi D, Vennila G, Suresh M, Karthikeyan P (2013) Geoelectrical Schlumberger investigation for characterizing the hydrogeological conditions using GIS in Omalur Taluk, Salem District, Tamil Nadu, India. *Arab J Geosci* 7(5):1791–1798
- Karunanidhi D, Aravinthasamy P, Subramani T, Roy PD, Srinivasamoorthy K (2019) Risk of fluoride-rich groundwater on human health: remediation through managed aquifer recharge in a hard rock terrain, South India. *Nat Resour Res*. <https://doi.org/10.1007/s11053-019-09592-4>
- Karunanidhi D, Aravinthasamy P, Roy PD, Praveenkumar RM, Prasant K, Selvapraveen S, Thowbeekrahman A, Subramani T, Srinivasamoorthy K (2020) Evaluation of non-carcinogenic risks due to fluoride and nitrate contaminations in a groundwater of an urban part (Coimbatore region) of south India. *Environ Monit Assess* 192:102
- Ketul S, Motiani AT, Prakash I, Khalid M (2017) Application of SCS-CN method for estimation of runoff using GIS. *Int J Adv Eng Res Dev* 4(4):558–567
- Khalid K, Ali MF, Rahman, NFA (2015) The development and application of Malaysian soil taxonomy in SWAT watershed model. In: *Proceedings of international symposium on flood research and management*. ISFRAM 2014:79–88.
- Lalitha Muthu AC, Helen Santhi M (2015) Estimation of surface runoff potential using SCS-CN method integrated with GIS. *Indian J Sci Technol* 8(28):1–5
- Lannerstad M, Molden D (2009) Adaptive water resource management in the South Indian Lower Bhavani Project Command Area. Colombo, International Wate Management Institute, (IWMI Research Report 129) 22.
- Legates DR, Willmott CJ (1990) Mean seasonal and spatial variability in global surface air temperature. *Theor Appl Climatol* 41:11–21
- Magesh NS, Chandrasekar N (2016) Assessment of soil erosion and sediment yield in the Tamiraparani sub-basin, South India, using an automated RUSLE-SY model. *Environ Earth Sci* 75:1208

- Mair A, Fares A (2011) Comparison of rainfall interpolation methods in a mountainous region of a tropical island. *J Hydrol Eng* 16:371–383
- Matej V, Jana V (2016) GIS-based approach to estimate surface runoff in small catchments: a case study. *Quaestiones Geographicae* 35(3):97–116
- Mishra SK, Jain MK, Sing VP (2004) Evaluation of the SCS-CN based model incorporating antecedent moisture. *J Water Res Manag* 18:567–589
- Mishra SK, Tyagi JV, Singh VP, Singh R (2006) SCS-CN based modeling of sediment yield. *J Hydrol* 324(4):301–322
- Mishra SK, Pandey RP, Jain MK, Singh VP (2008) A rain duration and modified AMC-dependent SCS-CN procedure for long duration rainfall-runoff events. *J Water Resour Manag* 22(7):861–876
- Mishra SK, Gajbhiye S, Pandey A (2013) Estimation of design runoff curve numbers for Narmada watersheds (India). *J Appl Water Eng Res (Taylor and Francis)* 1(1):69–79
- Mondal MS, Pandey AC, Garg RD (2009) Groundwater prospects evaluation based on hydrogeomorphological mapping using high resolution satellite images: a case study in Uttarakhand. *J Indian Soc Remote Sens* 36:69–76
- Mukesh KT, Gaur ML, Pappu Ram S, Ankushh K (2014) Impact assessment of land use change on runoff generation using remote sensing and geographical information system. In: *ESRI India User Conference*, pp 1–12.
- Naoum S, Tsanis IK (2004) Ranking spatial interpolation techniques using a GIS based GSS. *Global Nest Int J* 6(1):1–20
- Nastiti KD, An H, Kim Y, Jung K (2018) Large-scale rainfall-runoff-inundation modeling for upper Citarum River watershed. *Indones Environ Earth Sci* 74:640
- Patil JP, Sarangi A, Singh AK (2008) Evaluation of modified CN methods for watershed runoff estimation using a GIS-based interface. *J Biosys Eng* 100(1):137–146
- Perez-Sanchez J, Senent-Aparicio J, Segura-Mendez F, Pulido-Velazquez D, Srinivasan R (2019) Evaluating hydrological models for deriving water resources in peninsular Spain. *Sustainability* 11(2872):1–32
- Rallison RE (1980) Origin and evolution of the SCS runoff equation. In: *Proceedings of ASCE irrigation and drainage division symposium on watershed mgment*. ASCE, New Delhi 2, pp 912–924
- Ramakrishnan D, Bandyopadhyay A, Kusuma KN (2009) SCS-CN and GIS based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India. *J Earth Syst Sci* 114(4):355–368
- Rao KN, Narendra K, Latha PS (2010) An Integrated study of geospatial information technologies for surface runoff estimation in an Agricultural watershed, India. *J Indian Soc Remote Sens* 38:255–267
- Saravanan S, Manjula R (2015) Geomorphology based semi-distributed approach for modeling rainfall-runoff modeling using GIS. *Aquat Proc* 4:908–916
- 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. *Model Earth Syst Environ* 3(12):1–8
- Schut GH (1976) Review of interpolation methods for digital terrain modeling. *Can Suveyor* 30(5):389–412
- Shah M, Fazil SM, Ali SR, Pandey Y, Faisal S, Mehraj I (2017) Modeling of runoff using curve expert for Dachigam-Telbal catchment of Kashmir Valley. *India Int J Curr Microbiol Appl Sci* 6(11):3822–3826
- Shi ZH, Chen LD, Fang NF, Qin DF, Cai CF (2009) Research on the SCS-CN initial abstraction ratio using rainfall-runoff event analysis in the Three Gorge area. *China Catena* 77(1):1–7
- Stallings C, Huffman RL, Khorram S, Guo Z (1992) Linking gleams and GIS, ASAE Paper, St. Joseph, Michigan: American Society of Agricultural Engineers, pp 92–3613
- Subramani T, Savithri B, Elango L (2012) Computation of groundwater resources and recharge in Chithar River basin, South India. *Environ Monit Assess* 185:183–194. <https://doi.org/10.1007/s10661-012-2608-y>
- Subramani T, Anandakumar S, Kannan R, Elango L (2013) Identification of major hydrogeochemical processes in a hard rock terrain by NETPATH modeling. A book on Earth resources and environment, chap. 29. Research Publishing, Singapore, pp 365–370
- Subramani T, Prabakaran S, Karunanidhi D (2015) Groundwater prospecting in a part of Thamirabarani River basin, South India using remote sensing and GIS. *Indian J Geo Mar Sci* 44(9):1401–1408
- Taher TM (2015) Integration of GIS database and SCS-CN method to estimate runoff volume of Wadis of intermittent flow. *Arab J Sci Eng* 40(3):685–692
- Taylor D, Shrimali NJ (2016) Surface runoff estimation by SCS curve number method using GIS for RUPEN-KHAN Watershed, Mehsana District, Gujarat. *J Indian Water Resour Soc* 36(4):1–5
- Tarun K, Jhariya DC (2016) Identification of rainwater harvesting sites using SCS-CN methodology, remote sensing and geographical information system techniques. *J Geocarto Int* 32(12):1367–1388
- Tejram N, Verma MK, Hema Bindu S (2012) SCS curve number method in Narmada basin. *Int J Geomat Geosci* 3(1):219–228
- Thilagavathi N, Subramani T, Suresh M, Ganapathy C (2014) Rainfall variation and groundwater fluctuation in Salem Chalk Hills area, Tamil Nadu, India. *Int J Appl Innov Eng Manag* 3(1):148–161
- Thilagavathi N, Subramani T, Suresh M (2015a) Land use/land cover change detection analysis in Salem Chalk hills, South India using remote sensing and GIS. *Disaster Adv* 8:44–52
- Thilagavathi N, Subramani T, Suresh M, Karunanidhi D (2015b) Mapping of groundwater potential zones in Salem Chalk Hills, Tamil Nadu, India, using remote sensing and GIS techniques. *Environ Monit Assess* 187:164
- USDA (1972) Soil conservation service, national engineering handbook, hydrology section 4, chapters 4–10. USDA, Washington
- USDA (1986) Urban hydrology for small watersheds, TR-55, 2nd edn. United States Department of Agriculture, Washington
- USDA-SCS (1974) Soil survey of Travis County, Texas. USDA, Washington
- Vaibhav G, Bhaskar RN, Praveen KT, Agarwal SP (2013) Assessment of the effect of slope on runoff potential of a watershed using NRCS-CN method. *Int J Hydrol Sci Technol* 3(2):141–159
- Vennila G, Subramani T, Elango L (2007) Rainfall variation analysis of Vattamalaikarai sub-basin, Tamil Nadu. *India Appl Hydrol* 20(3):50–59
- Viji R, Rajesh Prasanna R, Ilangovan R (2015) GIS based SCS—CN for estimating runoff in Kundahpalam watershed, Nilgries District, Tamil Nadu. *J Earth Sci Res* 19(1):59–64
- Worku T, Khare D, Tripathi SK (2017) Modeling runoff-sediment response to land use/land cover changes using integrated GIS and SWAT model in the Beressa watershed. *Environ Earth Sci* 76:550
- Xu G, Tang S, Lu K et al (2015) Runoff and sediment yield under simulated rainfall on sand covered slopes in a region subject to wind-water erosion. *Environ Earth Sci* 74:2523