Impact of land use and land cover changes on runoff generation in the Kidangoor watershed, Kerala

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ABSTRACT

In this study, the impact of change in land use and land cover (LULC) on runoff estimation in the Kidangoor watershed was assessed using the SCS-CN technique. Recent flood-like natural disasters in Kerala are thought to be driven by changes in rainfall patterns and LULC. The accurate calculation of runoff from watersheds is urgently needed. In ArcGIS 10.5, the supervised classification approach is used to classify satellite images from 2000, 2011, 2013, and 2017. Similarly, the Inverse Distance Weighted (IDW) technique is used to produce spatial distribution maps of rainfall for each antecedent moisture condition (AMC). The runoff maps were generated by superimposing the distributed rainfall, LULC, and Hydrological Soil Group (HSG) maps. It was observed that the built-up area expanded by 168% between 2000 and 2017, whereas other classes decreased by 10–23%. However, compared to 2000, both with and without a change in LULC, runoff generation increased by just 31%, and 27% in 2017. The SCS-CN technique for runoff estimation indicates that the change in LULC in the Kidangoor watershed is insignificant. Thus, this study will help land use planners and decision-makers in limiting the potential damage from flooding when it comes to flood management techniques.

1 INTRODUCTION

Kerala is one of the states in India that receives heavy rainfall due to the influence of the Indian Summer Monsoon (ISM) (Li et al. 2022). The majority (about 70%) of the annual rainfall falls in this state during the monsoon season (June to September). ISM influences the agricultural activities, economic, and social status of the Kerala (Gadgil and Rupa Kumar 2006; Goswami 2005; Wang and Ho 2002; Webster et al. 1998). It is reported in the literature that the Indian Ocean is getting warmer at a higher rate than the Pacific and Atlantic oceans (Rao et al. 2012; Sun et al. 2019). Hence, the spatial variation of ISM rainfall and the cyclonic vortices over the northern Arabian Sea

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are getting stronger (Roxy et al. 2017). Due to this, the Arabian Sea is warming rapidly than other parts of the Indian Ocean (Li et al. 2022). It enhances the deep convection in the atmosphere in the form of vertical transfer of heat and moisture over the South-East-Arabian Sea in the monsoon season to form clouds and extreme rainfall in Kerala (Varikoden et al. 2018; Mapes and Abhilash 2021). Heavy rain creates severe flooding, destroying buildings and agricultural land in Kerala. Runoff information can be used to understand how watershed hydrological responses evolve. Many factors influence runoff generation in a watershed, including changes in land use and land cover (LULC), spatial patterns of rainfall, and soil type (Mengistu et al. 2022; Rishudh and Barik 2020; Astuti et al. 2019; Fletcher et al. 2013; McGrane 2016). The impact of changes in LULC in runoff generation is significant in watersheds (Ruddiman 2003; Rawat and Kumar 2015). Urbanization is increasing globally to keep pace with the expanding population, but developing nations like India are experiencing it more. Increased urbanization is responsible for changes in LULC in a certain region, which can affect the intensity and volume of surface runoff (Li et al .2021; Shi et al. 2007; Sahour et al. 2014; Sun et al. 2019; Shrestha et al. 2021; Suriya and Mudgal 2012; Oudin et al. 2018). The change in LULC affects the hydrological cycle of a watershed, which results in greater surface runoff and less infiltration (Hu et al. 2020; Shrestha et al. 2021).

Hydrological models have extensively explored the effects of changes in LULC on surface runoff estimation. The performance of a hydrological model depends on the availability of input data, however, many watersheds in India are not gauged. As a result, researchers face challenges while designing and constructing diverse hydrologic structures (Shivashankar et al. 2023; Sarangi et al. 2005a, 2005b).

The runoff from ungagged watersheds can be calculated using a variety of rainfall-runoff models (Chattopadhyay and Choudhury 2009). One of these is the SCS-CN approach, which was developed by the USDA in 1953, and later known as the NRCS-CN method. This technique has become more common among water resources researchers in hydrological studies since it is easy to use and needs less information to predict surface runoff (Mishra et al. 2003; Xiao et al. 2011; Ebrahimian 2012; Sjöman and Gill 2014; Vojtek and Vojteková 2016). According to Pandey and Sahu (2009), the LULC of the watershed is one of the main regulating parameters in runoff calculation using the SCS-CN approach. Many researchers (Rishudh and Barik 2020; Shi et al. 2007; Ghaffari et al. 2010; Wagner et al. 2013; Sahour et al. 2014; Mahmoud and Alazba 2015; Eshtawi et al. 2016; Karamage et al. 2017; Yin et al. 2017) have studied the impact of LULC in runoff estimation using SCS-CN method coupled with Remote Sensing (RS) and Geographic Information Systems (GIS). In the SCS-CN technique, the watershed characteristics and climatic variables are merged into a single entry, the curve number *(CN)*(Shi et al. 2009, Fu 2011). The *CN* is an important factor that is influenced by LULC changes (Chilagane et al. 2021; Melesse and Shih 2002). The SCS-CN approach was applied in the Narmada basin in India by Nayak et al. (2012), and they found a significant increase in runoff because of deforestation.

It is a time-consuming effort in the SCS-CN approach to manage a huge number of different data from a large watershed at a given time, which raises the possibility of errors in the results. Runoff estimation using RS and GIS can overcome this issue (Pandey and Sahu 2009; Zhan and Huang 2004). The incorporation of RS and GIS into the SCS-CN technique can increase the accuracy and reliability of surface runoff estimation in large watersheds (Shadeed and Almasri 2010; Liu and Li 2008). The RS aids in the collection of spatial and temporal data from various satellites and sensors, and it serves as a valuable tool for evaluating surface changes in watersheds and other land regions (Sahour et al. 2014). The impact of LULC change in runoff generation was examined by various researchers using the SCS-CN method in many watersheds all over the world (Thiruchelve et al. 2024; Rishudh and Barik 2020; Kang and Yoo 2020; Karamage et al. 2017; Ghaffari et al. 2010). In these studies, runoff was estimated based on the *CN* value of the average AMC. However, the runoff generation is greatly influenced by the AMC of the watershed (Meißl et al. 2023; Schoener and Stone 2019; de Michele and Salvadori 2002; Wood 1976). Hence, in this study, the runoff estimation was done based on the prevailing AMC of the event day during the study period. The *CN* values were selected from the standard table based on the AMC to estimate the runoff and the impact of LULC change on runoff is evaluated in the Kidangoor watershed.

In the Kidangoor watershed, abrupt flooding followed by intense rainfall is a common issue. This will lead to flood-like natural disasters in the Kidangoor watershed which is thought to be driven by changes in rainfall patterns and LULC. The influence of LULC changes on runoff generation in this watershed has never been studied before. The accurate calculation of runoff from watersheds is needed. Hence, in this work, the variation in LULC from 2000 to 2017 is examined, and its effects on producing runoff in the Kidangoor watershed were analyzed using the SCS-CN approach.

2 STUDY AREA AND DATA COLLECTION

The Kidangoor watershed is in the Kottayam district of Kerala state in India between, 76°31'46"E to 76°53'7"E longitude, and 9°32'34"N to 9°50’39"N latitude (Figure1). The total area of the watershed is 615 km^2. The weather is mostly humid throughout the year. The average rainfall varies from 2420 mm to 4686 mm. The maximum and minimum temperatures are 29^oC and 21^oC, respectively. The average wind velocity varies from 6.55 to 10.55 km/hr. The daily rainfall data for the years 2000, 2011, 2013, and 2017 were collected from six rain gauge stations from the India Meteorological Department (IMD) and the Irrigation Design and Research Board (IDRB), Thiruvananthapuram which are situated in and around the study area. The daily observed runoff data for the years 2000, 2011, 2013, and 2017 were collected from CWC, Kochi. The soil information of the study area was obtained from the Department of Soil Survey and Soil Conservation of Kerala. There are three types of soil available in this study area, i.e., sandy gravelly clay, gravelly clay, and clay loam. The satellite images were downloaded from USGS Earth Explorer and used for preparing LULC maps (Table 1).

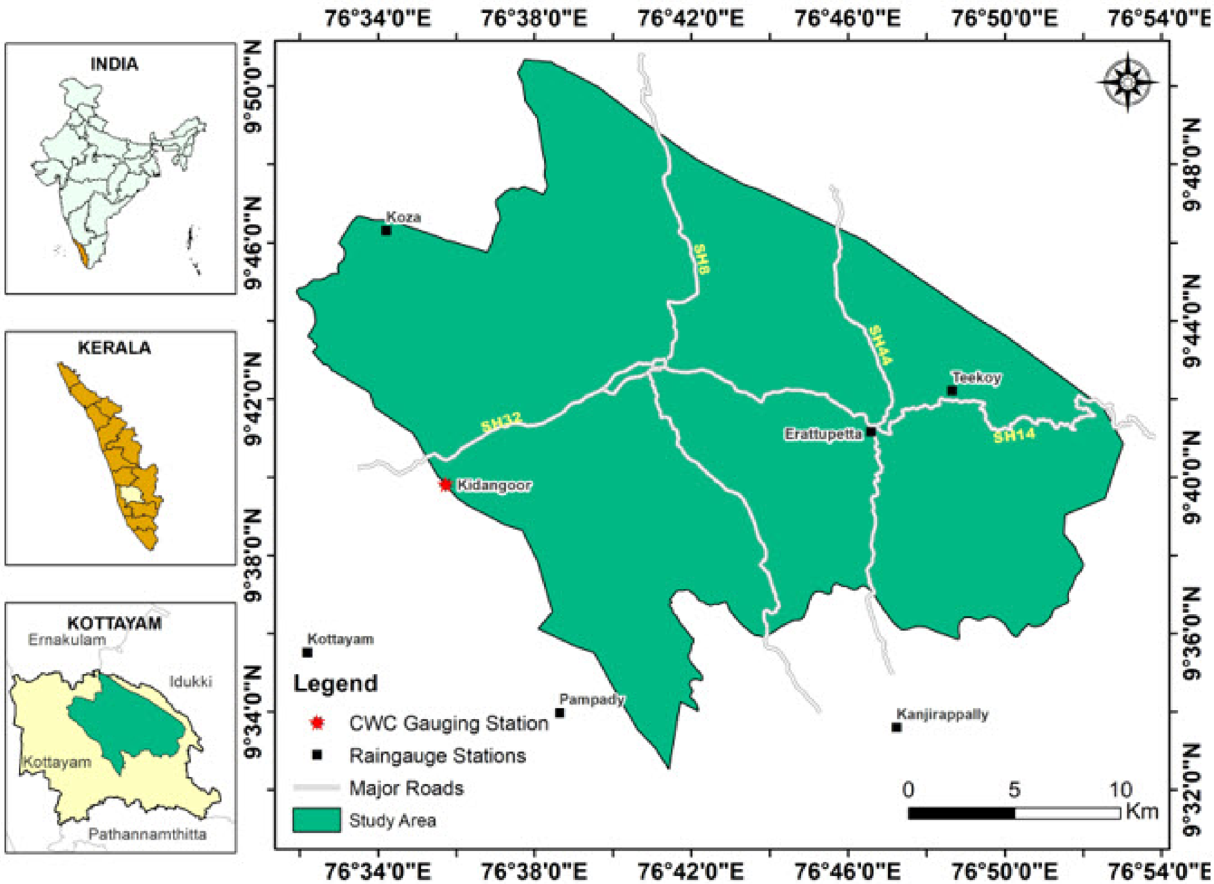


Figure 1 Location of the Kidangoor watershed.

Table 1 Satellite images used LULC classification.

Satellite	Sensor	Band	Path and Row	Date of acquisition
Landsat-7	ETM	NIR, Green, Red	144/53	26 October 2000
IRS	LISS-111	NIR, Green, Red	100/67	9 November 2011
IRS	LISS-111	NIR, Green, Red	100/67	3 March 2013
Landsat-5	TM	NIR, Green, Red	144/53	11 January 2017

3 METHODOLOGY

The Kidangoor watershed was delineated using a digitized toposheet (scale 1: 50,000) in ArcGIS 10.5. The locations of the six rain gauge stations were marked on the delineated watershed (Figure 1) based on GPS information. On the day of the event, the antecedent moisture condition (AMC) of the soil was identified from the previous 5 days' cumulative depth of rainfall for each rain gauge station (Geetha et al. 2007; Tailor and Shrimali 2016). The cumulative depth of rainfall in AMC-I, II, and III for the years 2000, 2011, 2013, and 2017 were estimated for each rain gauge station and used as input in ArcGIS 10.5 to develop the spatial distribution maps (Al-Ghobari et al. 2020; Caloiero et al. 2020; Arianti et al. 2018). Arianti et al. (2018) suggested that the IDW method of interpolation is the best among others. Hence, the average depth of rainfall for each AMC was estimated in the IDW method by considering the minimum and maximum depth of rainfall (Pramono 2008). In the IDW interpolation method, the weight is assigned as the function of the distance between the sample and the interpolation point.

The hydrological soil group (HSG) map of the Kidangoor watershed was prepared based on the soil map of the Kottayam district. The satellite data for the years 2000, 2011, 2013, and 2017 were used to get the LULC classified maps (Table 1). In this study, the supervised classification method was adopted in ArcGIS 10.5 to classify the LULC. The HSG and LULC maps were overlaid in ArcGIS 10.5 to obtain the spatially distributed map of the *CNs* for the average AMC, i.e., AMC-II. For AMC-I and III, the *CNs* were transformed from AMC-II by using the following equations (Chow et al. 2002).

$$CN_1 = \frac{CN_2}{2.281 - 0.0128CN_2} \tag{1}$$

$$CN_3 = \frac{CN_2}{0.427 + 0.00573CN_2} \tag{2}$$

Where:

CN_1, CN_2, and CN_3 represent the curve numbers for AMC-I, II, and III, respectively.

In this study, the analysis was done on a watershed basis. The whole watershed is considered a hydrological response unit. Hence, the spatial distribution maps of *CNs* and rainfall for each AMC were used to derive the runoff maps for the years 2000, 2011, 2013, and 2017 by using the SCS-CN method. The average of the minimum and the maximum runoff value was considered as runoff for that particular year and compared with the observed runoff to check the performance of the proposed method. The methodology used in this analysis is given in a flowchart in Figure 2.

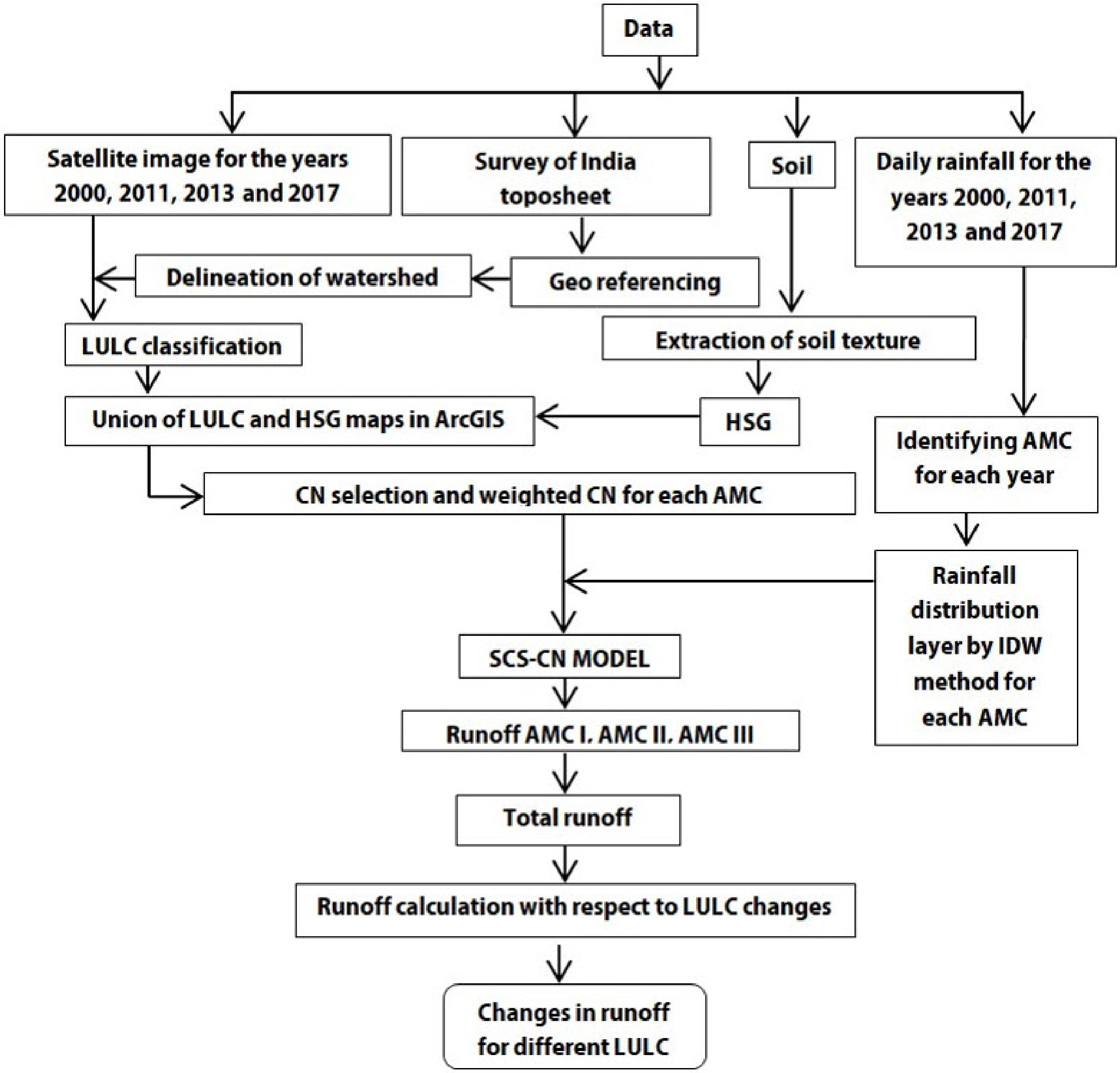


Figure 2 Flow chart of the proposed methodology.

4 RESULTS AND DISCUSSION

The AMC of the soil on the event day was calculated using the daily recorded precipitation during the years 2000, 2011, 2013, and 2017. ArcGIS 10.5 was used to acquire the geographical distribution map of rainfall for all AMCs for the years 2000, 2011, 2013, and 2017. The total depth of rainfall for each AMC was entered for each rain gauge station, and the IDW interpolation technique was used to obtain the runoff. Figures 3(a) to 3(c) depict the spatial distribution maps of rainfall in the Kidangoor watershed for the year 2017 for each AMC. The minimum and maximum rainfall for the year 2017 has been found in AMC-I (932.104 mm and 1031.57 mm), AMC-II (346.6

mm and 650.42 mm), and AMC-III (1185.33 mm and 2040.56 mm) as shown in Figures 3(a) to 3(c). Similar estimates were done for each AMC for the years 2000, 2011, and 2013 and are shown in Table 2.

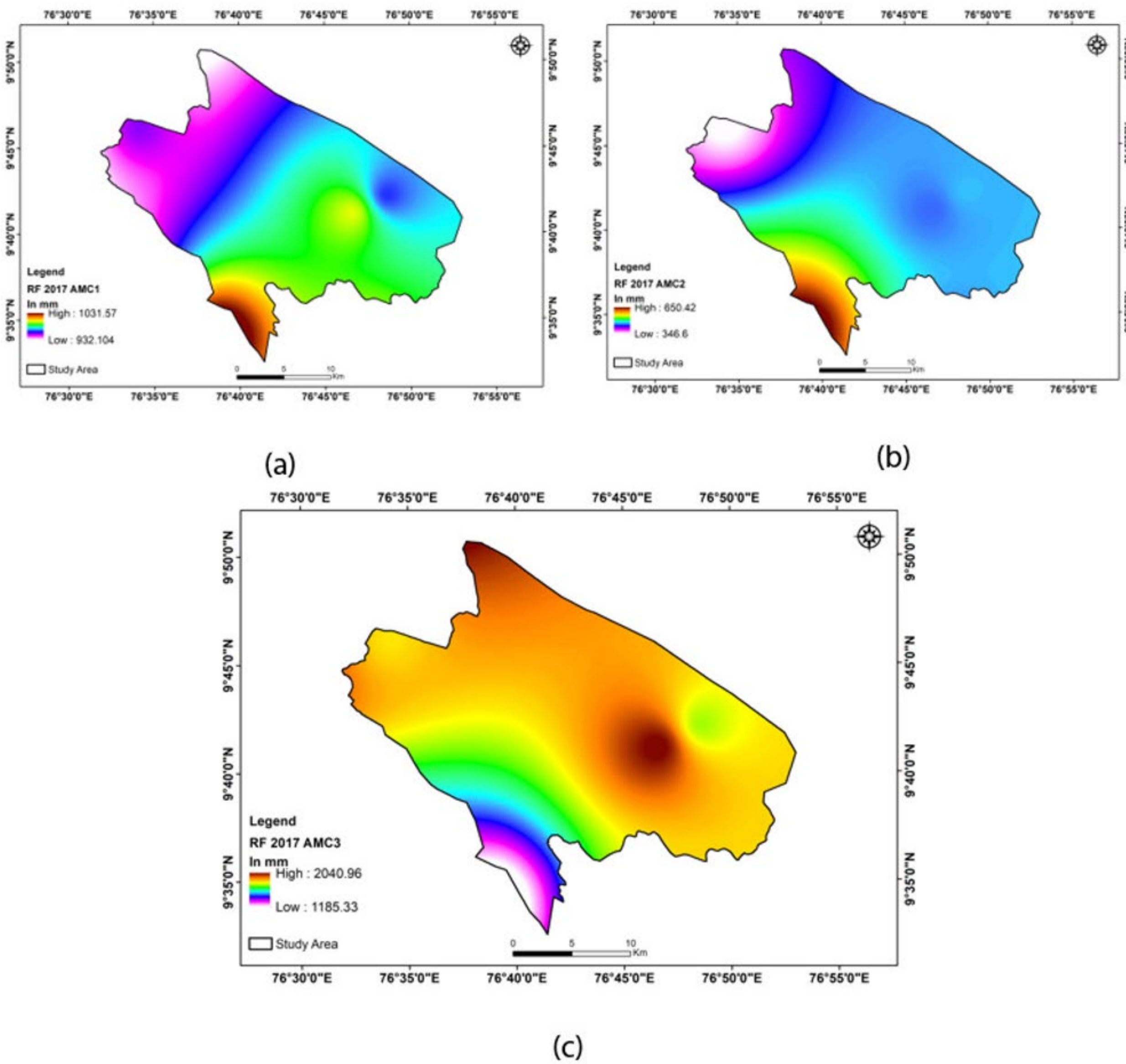


Figure 3 Spatial distribution of rainfall in Kidangoor watershed for (a) AMC-I, (b) AMC-II, and (c) AMC-III in the year 2017.

Table 2 The minimum and maximum rainfall during AMC-I, II, and III for the years 2000, 2011, and 2013.

Year	AMC-I		AMC-II		AMC-III	
	Min. rainfall (mm)	Max. rainfall (mm)	Min. rainfall (mm)	Max. rainfall (mm)	Min. rainfall (mm)	Max. rainfall (mm)
2000	613.61	728.92	215.12	456.71	1218.52	1680.30
2011	720.83	947.00	274.00	547.70	1597.38	3275.00
2013	635.35	886.80	212.00	417.60	2656.03	3260.90

The soil of the research area contains sandy gravelly clay (4.9%), gravelly clay (35.5%), and clay loam (59.6%). Each of the above soils has a different rate of infiltration. As a result, the soil in the Kidangoor watershed was divided into the three HSG types (A, B, and C) based on their infiltration rates, as shown in Figure 4.

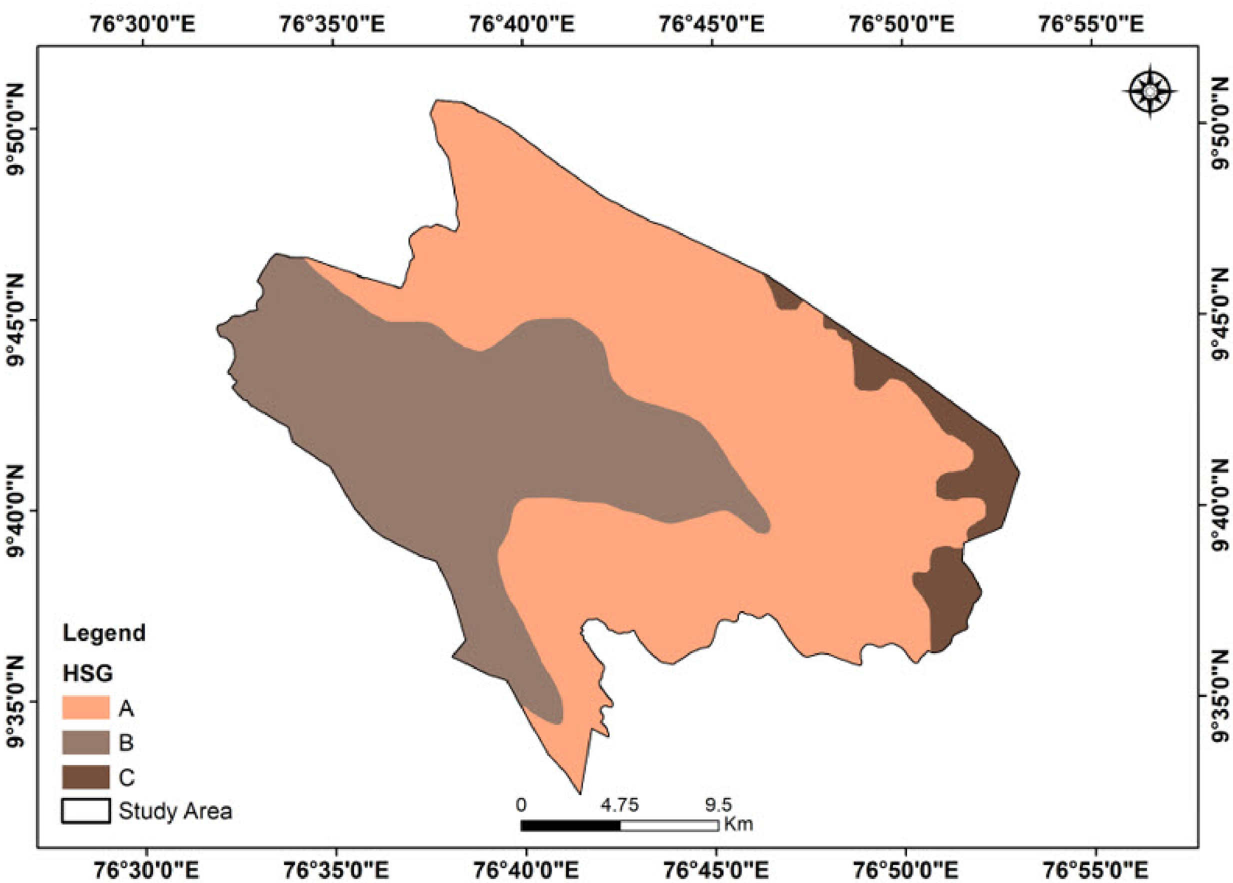


Figure 4 Hydrological soil groups in the Kidangoor watershed.

Using satellite images from the years 2000, 2011, 2013, and 2017, the temporal changes of LULC in the Kidangoor watershed were analyzed in ArcGIS 10.5. To obtain the LULC maps of the study area, the supervised classification was carried out.

The study region was classified into six categories: (i) barren land, (ii) built-up area, (iii) mixed crop, (iv) rubber plantations, (v) teak wood, and (vi) water body. The maps for the LULC classification for the years 2000, 2011, 2013, and 2017 are shown in Figures 5(a) to 5(d). During the years 2000 and 2017, a change in LULC was seen across all classes. Table 3 displays the percentages of area change over time for each class.

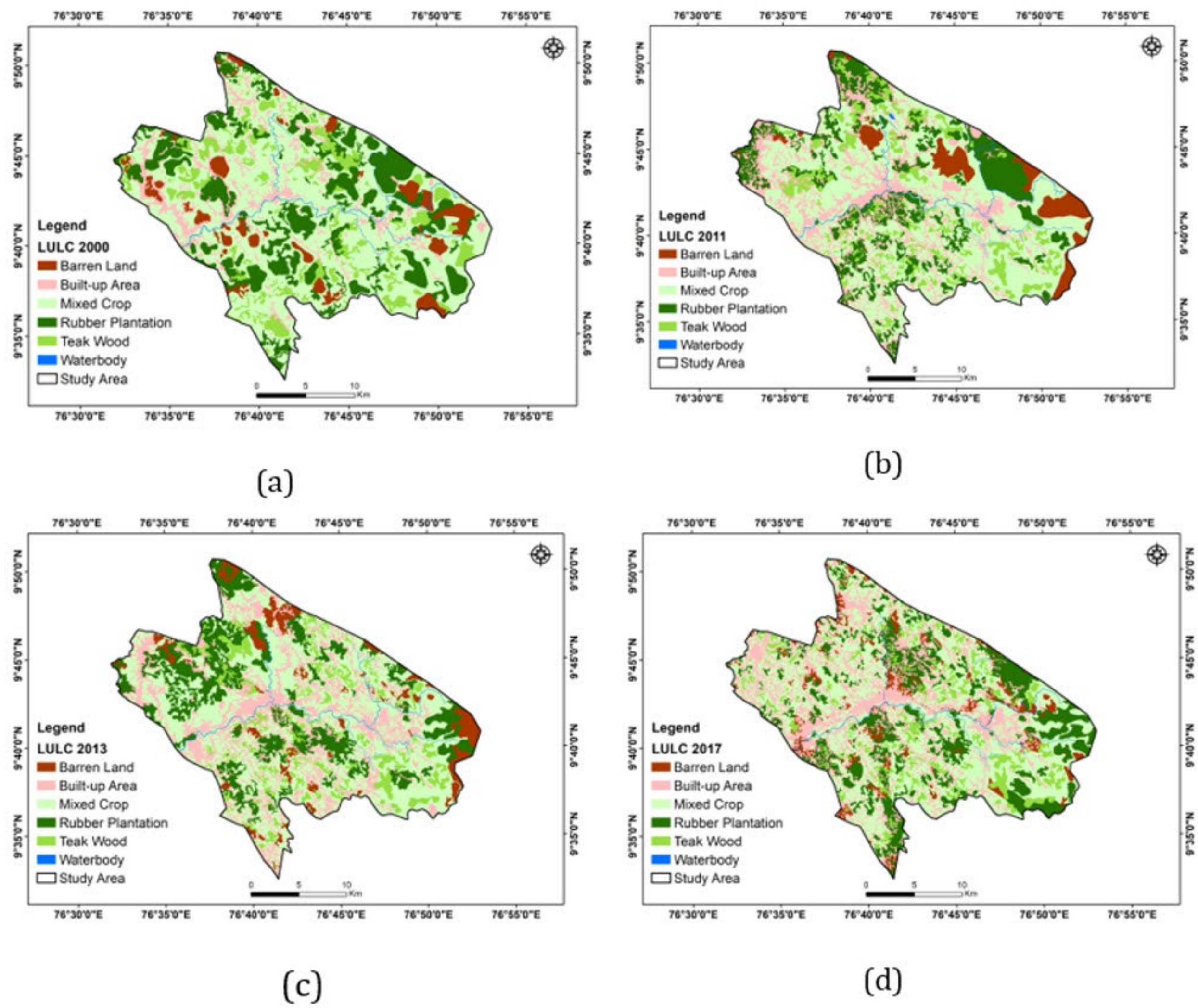


Figure 5 The LULC classification maps for the years 2000 (a), 2011 (b), 2013 (c), and 2017 (d).

Table 3 The change in LULC for the years 2000, 2011, 2013, and 2017 for different classes in the Kidangoor watershed.

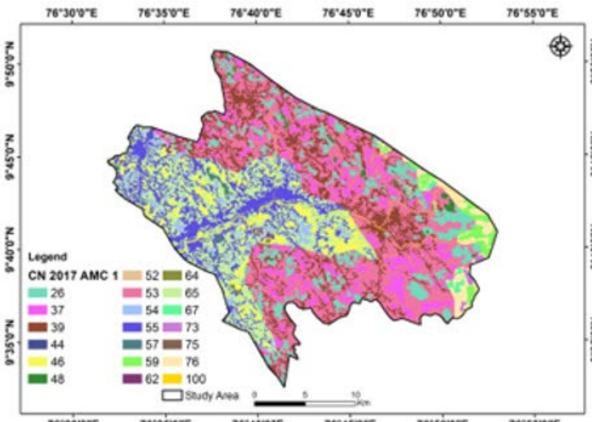
LULC type	Year							
	2000		2011		2013		2017	
	Area		Area		Area		Area	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Barren land	41.72	6.80	39.78	6.50	38.95	6.30	35.28	5.70
Built-up area	54.88	8.90	118.13	19.2	132.29	21.5	147.16	23.9
Mixed crop	304.32	49.4	268.73	43.7	263.54	42.9	250.76	40.8
Rubber plantation	141.42	23.0	121.03	19.7	121.64	19.8	125.69	20.4
Teak wood	68.51	11.10	62.77	10.2	54.61	8.9	52.52	8.50
Waterbody	4.75	0.80	5.24	0.90	4.65	0.80	4.27	0.70

In the Kidangoor watershed, mixed crops make up the majority of LULCs, ranging from 40 to 50% (Table 3) which can produce good runoff. From 2000 to 2017, the built-up class experienced an ongoing increase (8.9% to 23.9%). These statistics demonstrated that throughout the study times, some portions of rubber plantations, mixed crops, and bare land were turned into built-up regions. As opposed to this, the mixed crop class has dropped from 49.4% to 40.8%. Other classes have decreased as well but not so significantly. Table 4 shows the change in LULC over time for each type of soil. These details have been useful in obtaining *CNs* for various LULCs in the Kidangoor watershed.

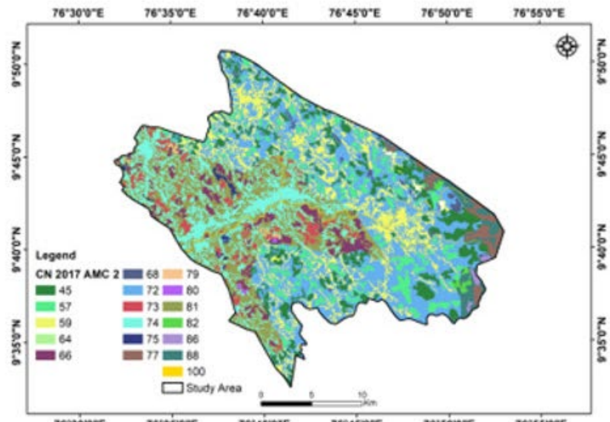
Table 4 The change in LULC classes in different types of soil.

Soil Type	LULC Classes	Year			
		2000	2011	2013	2017
		Area (%)	Area (%)	Area (%)	Area (%)
Clay loam	Barren Land	0.5	2.2	1.9	0.4
	Built-up Area	0.2	0.1	0	0
	Mixed Crop	2.9	1.8	1.8	2.1
	Rubber Plantation	1.0	0.5	0.9	2.1
	Teak Wood	0.4	0.3	0.4	0.4
	Water body	0.0	0.1	0.0	0.0
Gravelly clay	Barren Land	2.3	0.2	0.9	1.8
	Built-up Area	4.9	10.4	9.5	11.7
	Mixed Crop	18.4	15.3	14.2	14.3
	Rubber Plantation	6.8	6.5	8.9	5.5
	Teak Wood	2.8	2.8	1.7	2.0
	Water body	0.3	0.3	0.3	0.3
Gravelly sandy clay	Barren Land	4.0	4.1	3.6	3.5
	Built-up Area	3.9	8.8	12.0	12.2
	Mixed Crop	28.2	26.5	26.9	24.5
	Rubber Plantation	15.1	12.7	10	12.9
	Teak Wood	8.0	7.2	6.8	6.2
	Water body	0.4	0.5	0.4	0.4

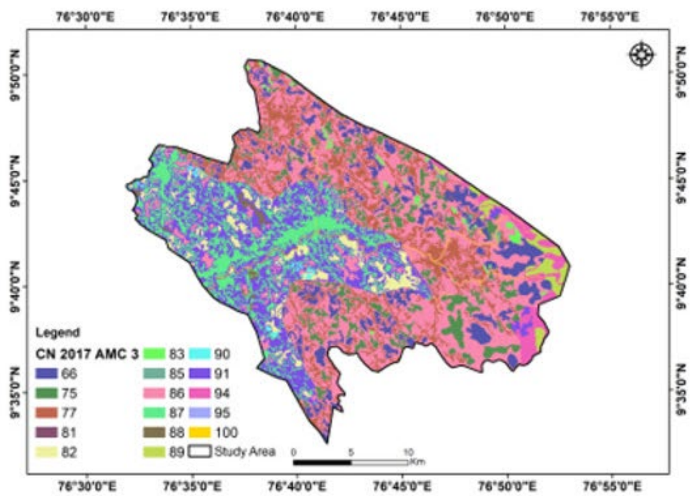
After overlaying the distributed maps of HSG and LULC in ArcGIS 10.5, the spatial distribution maps CNs for AMC-I, II, and III for the years 2000, 2011, 2013, and 2017 were obtained. Figures 6(a) to 6(c) show the spatial distribution of CNs for AMC-I, II, and III in 2017. From Figures 6(a) to 6(c), the CNs range from 26 to 100, 45 to 100, and 66 to 100 in AMC-I, II, and III, respectively. Similar maps were obtained for the years 2011, 2013, and 2017. The geographically distributed maps of *CN* for AMC-I, AMC-II, and AMC-III were used to calculate the weighted *CN* for each AMC in ArcGIS 10.5, and given in Table 5.



(a)



(b)



(c)

Figure 6 The spatial distribution maps of *CN* for AMC-I (a), AMC-II (b), and AMC-III (c) in the year 2017 in Kidangoor watershed.

Table 5 The weighted *CNs* for AMC-I, II, and III in the Kidangoor watershed for the years 2000, 2011, 2013, and 2017.

Year	Weighted *CN*		
	AMC I	AMC II	AMC III
2000	51.8	69.7	83.7
2011	53.2	71.4	84.8
2013	51.3	69.3	83.5
2017	52.8	70.7	84.4

The runoff distribution maps for the years 2000, 2011, 2013, and 2017 were generated by considering the maps of rainfall, and *CNs* for each AMC. Figures 7(a) to 7(c) show the runoff maps for each AMC, for the year 2017. The minimum and maximum runoffs were estimated to be (683.9 mm and 779.5 mm for AMC-I), (236.14 mm and 528.9 mm for AMC-II), and (1126.15 mm and 1981.04 mm for AMC-III).

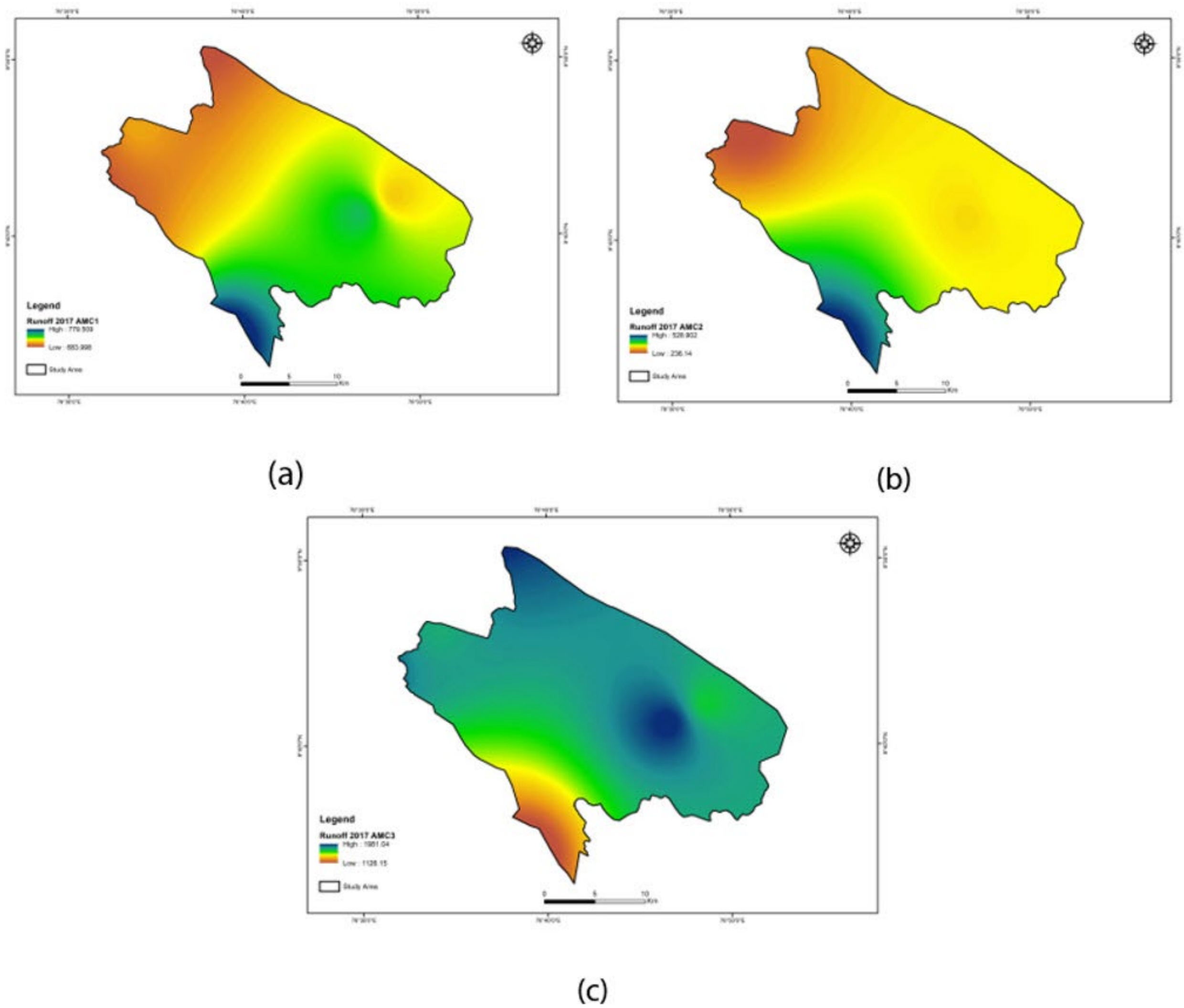


Figure 7 The spatial distribution maps of runoff for AMC-I (a), AMC-II (b), and AMC-III (c) in the Kidangoor watershed in 2017.

Similar runoff distribution maps were derived for 2011, 2013, and 2017, and the average runoffs were estimated for each AMC for the respective years as shown in Table 6.

Table 6 The runoff for AMC-I, II, and III in the Kidangoor watershed.

Year	Runoff (mm)		
	AMC I	AMC II	AMC III
2000	511.8	265.9	1279.4
2011	594.4	301.8	2378.0
2013	511.0	203.1	2894.0
2017	731.7	382.5	1553.6

The summation of the runoff of each AMC was used to generate the runoff distribution maps for the respective years in ArcGIS 10.5 (Figures 8(a) to 8(d)). The annual minimum and maximum ruoff are estimated as (1845.99 mm and 2279.39 mm), (2357.04 mm and 4089.68 mm), (3236.98 mm and 3899.87 mm), and (2434.54 mm and 3059.63 mm) in 2000, 2011, 2013, and 2017 (Figures 8(a) to 8(d)). The mean of these minimum and maximum runoff values were used to estimate the yearly runoff for the Kidangoor watershed, and it was compared with the observed runoff.

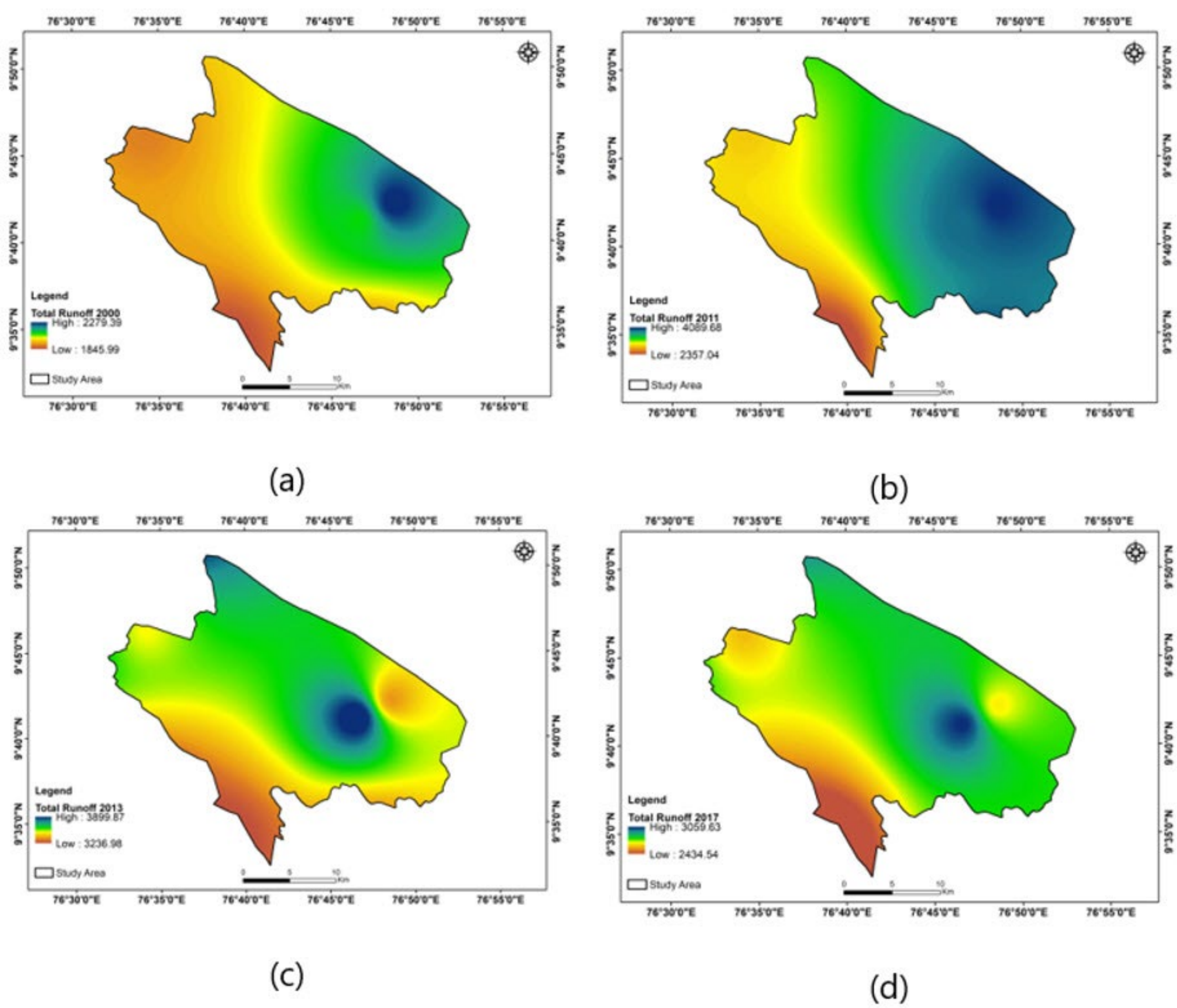


Figure 8 The spatial distribution maps of runoff for 2000 (a), 2011 (b), 2013 (c), and 2017 (d) in the Kidangoor watershed.

The change in LULC and runoff were detected during the study period (Figures 5 and 8). The depth of runoff from the watershed is controlled by the HSG, LULC, AMC, and rainfall. In most of the studies the role of AMC in runoff estimation is not considered rather, the average AMC has been used in the SCS-CN method to estimate runoff (Basha et al. 2024; Thiruchelve et al. 2024; Umukiza et al. 2024; Riche et al. 2023; AnhTu et al. 2023; Mfwango et al. 2022). In this study, the effect of each AMC was considered to select the appropriate *CN* values from the standard table in runoff estimation. Similarly, the IDW method has been used to obtain spatial distribution rainfall maps for each AMC. The results obtained in this approach were compared with the observed runoff data and it matched well with minimum errors (Table 7). It is observed that different runoff is generated with different AMCs. Hence, in the SCS-CN method, AMC should be considered to get better results, if proper observed data are available.

Table 7 Comparison of the runoff estimation in SCS-CN method by using IDW interpolation technique and the observed runoff, with and without change in LULC.

Year	Rainfall (mm)	Runoff with LULC change (mm)	Runoff without LULC change (mm)	Observed runoff (mm)	% Error with LULC change	% Error without LULC change
2011	3664.47	3208.0	3231.5	2985.8	6.9	8.2
2013	4002.85	3548.0	3580.3	3677.8	3.5	2.6
2017	3092.75	2737.0	2649.2	2701.5	2.3	1.9

In this study, the built-up area has increased substantially (about 168%), and other classes have decreased between 10% and 23% during the years 2000 to 2017. The increase in the built-up area reduces the time of concentration and increases surface runoff (Ghadirian et al. 2023). It can be observed from Table 6 that runoff has increased to 31% from 2000 to 2017 based on rainfall, actual LULC, and HSG. The same analysis has been done by keeping LULC constant, and the runoff has increased to 27% from the year 2000 to 2017, with the same rainfall and HSG. In both cases, the increment in runoff is not substantial as compared to the change in the built-up area. This may be due to the % of the share of the built-up area in the Kidangoor watershed being very low, i.e., 8.9%, as compared to the other LULCs, like mixed crop and rubber plantation (Table 3). In addition, the dominant soil type in this study area is gravelly sandy clay which has low runoff potential. Further, it is found that the area where runoff potential is low has been covered by a higher density of built-up areas than the area that has high runoff potential. Hence, the weighted *CNs* have not varied significantly in the years 2000, 2011, 2013, and 2017 in all the AMCs.

The performance of the SCS-CN method was analysed by comparing the results with the observed runoff in both cases. The errors in calculating surface runoff for the years 2000, 2011, 2013, and 2017 were found to be less than 10% in both cases, which is within the acceptable range (Table 7). Though fluctuation in the depth of runoff was observed throughout the study period, there is not any trend. Because the input parameters rainfall and LULC are changing with respect to time, the soil will not vary much within a short period. Consequently, this research demonstrated that, while considering changes in the LULC of the Kidangoor watershed during the analysis period, there were no significant changes in runoff estimation using the SCS-CN method. Hence, rainfall may be the major influencing factor in generating runoff from the Kidangoor watershed, as opposed to LULC changes in the case of extreme rainfall events.

5 CONCLUSIONS

In this investigation, it is observed that the Kidangoor watershed contains three different types of HSG, and six LULC classes. The built-up area is expanding as the mixed crop and rubber plantation classes are gradually declining over time. As compared to the whole watershed, the % share of mixed crop and rubber plantation is significantly higher than the built-up area. Reduced mixed crops means reduced runoff, while increased built-up area means increased runoff. However, during the analysis period, runoff increased by 31% from the year 2000 to 2017, with observed rainfall and LULC in the SCS-CN method. In the case of constant LULC with the same rainfall and HSG, runoff increased by 27%in the year 2017, as compared to 2000. In terms of runoff generation, these two classes of LULC changes are counteracting one another. Hence, it can be concluded that the change in LULC had less impact on runoff generation in the Kidangoor watershed during the study period. Rainfall can play a significant role in runoff production. This suggested approach of estimating runoff may be a helpful tool in managing flood situations during extreme rainfall, which frequently occurs in Kerala because of climate change. Although the SCS-CN approach can produce satisfactory results with annual time steps, this can be explored for shorter time steps as well.

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