

Assessment of Surface Runoff from Sub Basin of Kodayar using NRCS CN model with GIS

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Abstract

Objectives: To estimate the runoff from the sub basin of Kodayar, Tamilnadu using Natural Resources Conservation Service Curve Number (NRCS-CN) method with GIS and Remote sensing techniques. **Methods:** The GIS and remote sensing techniques facilitate accurate estimation of surface runoff from watershed. Thematic maps such as soil map, land use and hydrologic soil group (HSG) maps have been generated with GIS environment. Weighted CN value for the basin was obtained and the runoff for the selected rainfall event was estimated. **Findings:** In the HSG map, the region predominantly comprises of group B (56%) followed by group C (27.4%), group D (12.4%) and A (3.9%) respectively. In order to calculate the CN value of the basin, it is divided into 12 sub basins of which each sub basin has area less than 150km² which gives more accurate result than considering the whole basin. The CN values for these 12 sub basins are ranging from 69 to 80. Composite curve number value for each sub-basin was calculated by multiplying weights according to the area occupied by each land use class and the corresponding curve number. Weighted CN value and the storage retention (S) for the entire basin are estimated as 75 and 85 respectively. Runoff values are estimated on four different rainfall events selected during the study period in this basin. **Conclusion:** The study ultimately leads to the development of the rainfall runoff model based on NRCS-CN-GIS technique. The runoff for any rainfall event occurred can be estimated by feeding the inputs into this corresponding model which would in turn be helpful on significant conservation of water in the study area.

Keywords: Curve Number, GIS, Kodayar Basin, NRCS Model, Runoff

1. Introduction

The development of techniques for estimating surface runoff from the basin² is the outcome of having most of the agricultural watersheds ungauged with no past records of the rainfall-runoff processes¹. Besides this, the high budgetary requirements for installation of gauging stations are another limiting factor ultimately leading to the use of surface runoff estimation techniques for ungauged watersheds in India. The Soil Conservation Service Curve Number (SCS-CN) (renamed as Natural Resources Conservation Services Curve Number (NRCS-CN), USDA)³ method has been widely applied to ungauged watershed systems and has proved to be rapid and accurate estimator of surface runoff⁴. In addition, when this model

combined with the advanced GIS capabilities automates the process of runoff prediction efficiently and in time. With these advancements, GIS have made it possible to account for this spatial variability of hydrological parameters, thereby enabling the invention and application of distributed models that are superior to the conventional approaches.

Estimation of direct runoff for any watershed is capable of incorporating the watershed hydrologic responses, which are governed by the interaction of precipitation with the topographic, land use and soil physical properties of the land surface. This process becomes more efficient and manageable when the GIS is used for storing, interpreting and displaying the data required in CN-based runoff estimation technique. This technique has been utilized by

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many researchers^{5-8,15} from various regions to estimate runoff Curve Number value. The land use/land cover as an important input parameter of the SCS-CN model was specifically pointed out by Pandy and Sahu⁵. Likewise a good correlation between the measured and estimated runoff depth using GIS and CN was found by Nayak and Jaiswal⁶. Mishra and Singh³, Ramasubramaniam et al.⁹, Ebrahimian and Abdul Malek¹⁰, Amutha and Porchelvan¹¹, Domnita et al.¹², Dhawale¹³, estimated runoff with SCS method and used GIS to obtain the factors for determining runoff depth and curve number and in all of these studies for which the results have been satisfactory. Akhondi¹⁴ pointed out that correlation between observed and estimated discharge using CN method is indirectly proportional to the watershed area. Works done previously on the study of runoff estimation in the ungauged watersheds of Tamil Nadu are very minimal.

Along with these techniques, process-based hydrologic models and empirical approaches, has made the surface runoff estimation more accurate. The use of GIS to develop a data base containing all the information on the ungauged watershed for direct runoff depth estimation using the NRCS-CN model has been emphasized. The objective of this study was to estimate annual runoff of Sub basin of Kodayar, Tamil Nadu (India) using NRCS curve number with GIS.

2. Material and Methods

2.1 Study area Description

The Kodayar sub basin is located in the southernmost land of Tamilnadu, India and covers an area of 638km². It lies between 08° 08' N to 08° 22' N latitude and 77° 08' E to 77° 29' E longitude. The climate of the area is semi-arid to tropical and receives an annual average rainfall of about 1448.6 mm. The elevation of the watershed ranges from 0 to 980m above mean sea level. The sub basin received the rain under the influence of both southwest and northwest monsoons. The southwest monsoon chiefly contributes to the rainfall in the district. The normal annual rainfall over the district varies from about 826 to 1456 mm. The soils in the area vary to be 15 soil series with different soil textures as clay, clay loam, loamy sand, sandy clay loam, sandy loam, and sand. The land use of the watershed consists of forest, agricultural land, cropland, and waste land and water bodies. The index map of the study area is as shown in Figure 1. The area is bounded by Western Ghats in the north and Arabian sea in the south west, Bay of Bengal in

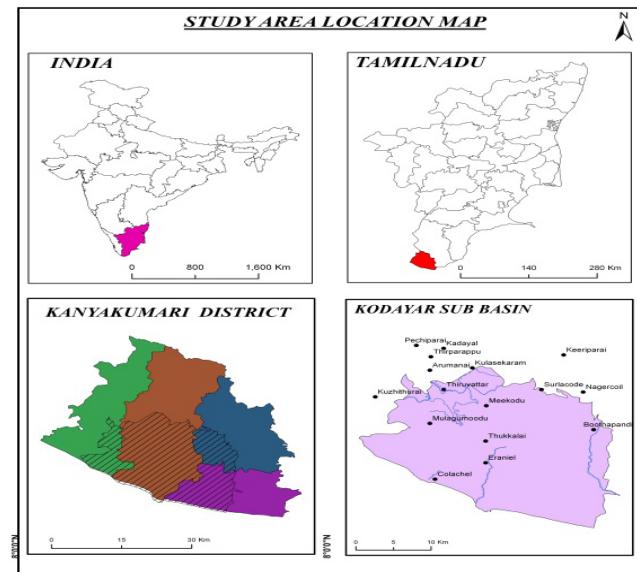


Figure 1. Study area location map.

the East and Thirunelvelli district in the North east. The chief irrigation sources in the area are the Canals, tanks, wells and tube/bore wells and other sources. The annual mean minimum and maximum temperatures are 23.78°C and 33.95°C respectively. Since the study area chosen is an ungauged watershed an attempt was made to estimate runoff by NRCS-CN model, obtaining model parameters by integrating the thematic maps prepared using SOI topomaps and remotely sensed data on 1: 50,000 scales and analyzing the thematic maps through GIS software.

3. Data Sources and Methods

The base map of the study area has been prepared from the Survey of India (SOI) toposheets numbers 58H4, 58H7 and 58H8 on 1:50,000 scales. Indian remote sensing Resource satellite linear image self-scanning-IV sensor (IRS-1D -LISS IV) data were collected from the Institute of Remote Sensing (IRS), Anna University, and Chennai, India. Daily Rainfall data collected from the Institute of Water Studies of Public Works Department (Government of Tamil Nadu) for the study periods (2000–2009) are used for the estimation of runoff in this watershed. Rainfall data of this ungauged watershed for the period from 2000–2009 is collected and analyzed for recurrence of storm event and annual average of rainfall in this area. The whole basin has been divided in to twelve (12) sub basins in order to fulfill the requirement of NRCS model.

3.1 NRCS-CN Method

The NRCS-CN method is based on the water balance equation and two fundamental hypotheses³. The first hypothesis equates the ratio of the amount of direct surface runoff Q to the total effective rainfall P_e (or maximum potential surface runoff) with the ratio of the amount of infiltration F to the amount of the potential maximum retention S and the mathematical form is,

$$Q/(P-I_a) = F/S$$

Where, P = total rainfall; I_a = initial abstraction; F = cumulative infiltration or actual retention; Q = direct runoff; S = potential maximum retention or infiltration. The total retention for a storm is a function of I_a and S, so the water balance equation can be expressed as,

$$F = (P-I_a) - Q$$

The second hypothesis relates the initial abstraction I to the potential maximum retention. Initial Abstraction, I_a was assumed to be a function of the maximum potential retention, S. An empirical relationship between me and S was expressed as;

$$I_a = 0.2S$$

Combining the water balance equation and proportional equality hypothesis, the NRCS-CN method is represented as:

$$Q = [P-0.2S]^2/[P+0.8S] \quad (1)$$

S is retention parameter. Retention parameter has change spatially with changes in soils, land use, and slope and temporarily due to changes in soil water content and it is defined mathematically as-

$$S = (25400/CN)-254 \quad (2)$$

CN is a dimensionless number and a function of land use, antecedent soil moisture content and other factors effecting runoff and retention of a watershed. For impervious and water surfaces CN = 100; for natural surfaces CN<100.

In this study, the curve numbers are weighed with respect to the micro-watershed area.

$$CN = \sum (CN_i \times A_i)/A \quad (3)$$

Where, CN is weighted curve number, CN_i is the curve number ranging from 1 to 100, A_i is area (of sub basin 1 to 12) with curve number CN_i ; and A is total area of watershed.

3.2 Generation of Hydrologic Soil Group (HSG) Map

Estimation of CN values are depends on hydrologic soil group, which is based on the infiltration rate and the land use conditions of the site. As per the minimum infiltration rate, soils are classified into four groups such as A, B, C and D respectively. Where Group A's generally had the smallest runoff potential and D's the greatest. Group B has a moderate infiltration rate. Group C have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine-to-fine structure. Group D has the highest runoff potential. The hydrological soil grouping of the study area is carried out with the help of the data bank on soil series, their taxonomy, soil permeability and the hydrological soil grouping provided by NRCS. Spatial Analyst and XTools extensions of Arc View 3.3 were applied for map preparation.

3.3 CN Value Estimation

The intersection of HSG and land use field from the soil and land use points, CN values were assigned from the required NRCS table for each sub basin. Composite curve number value for each sub-basin was calculated by multiplying weights according to the area occupied by each land use class and the corresponding curve number. Thereby a single weighted average curve number was calculated for each sub-basin for AMC II (Equation 3).

3.4 Antecedent Moisture Condition (AMC)

The term antecedent is an indicator of watershed wetness and availability of soil storage prior to a storm taken from previous 5 day rainfall in the watershed. The NRCS-CN method uses the concept of AMC in to three levels: AMC I, a dry condition; AMC II, an average condition; AMC III, a wet condition. The CN values for AMC II can be converted into CN values for AMC I and AMC III by using the SCS standard tables.

4. Results and Discussion

4.1 Land Use Map

Land-use and land-cover information is very important in the estimation for runoff as well as the soil loss¹⁵. Information on land use and pattern of their spatial distribution is one of the criteria in selecting a Curve Number (CN).

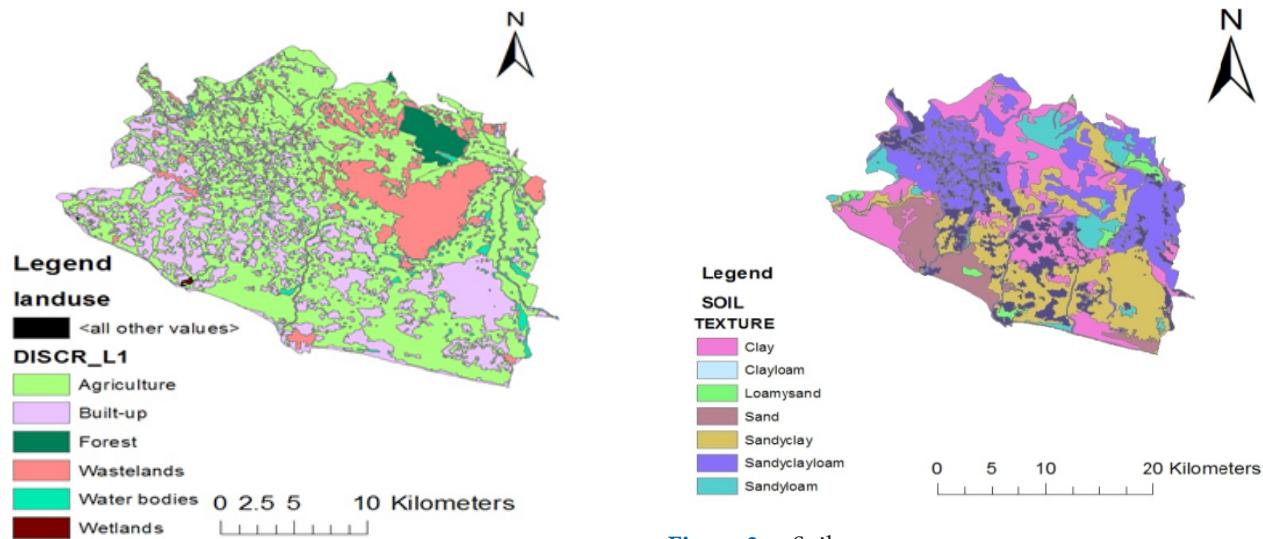


Figure 2. Land use map.

Thus satellites by relatively high spatial resolutions such as Landsat (30 m) and SPOT (10 m) have also been used for coastal studies¹⁶. The major land uses in the study area are: agriculture (56.5%), waste land (11.8%), Built ups (25.98%), water bodies (3.5%), Forest (2.14%) shown in Figure 2. The spatial distribution of the land use types are presented in Table 1. There are seven types of soil texture found in the area, and the spatial distribution is shown in Figure 3.

4.2 HSG Map

The map on hydrologic soil groups and the spatial variation of these groups in the study area is shown in Figure 4 and Table 2 respectively. All four hydrologic groups A, B, C, and D were found in the study area. From the spatial distribution of the HSG map, it is evident that the HSG soil group B (56%) substantially of the region, then followed by group C (27.4%), group D (12.4%) and A (3.9%).

Table 1. Land use types of study area

Land Use	Area (Sq Km)	Percentage of Area
Agriculture	293.75	46.21
Cropland	65.69	10.33
Buildup's	165.21	25.98
Forest	13.58	2.14
Wastelands	75.13	11.81
Water bodies	22.18	3.48
Wetlands	0.307	0.048
Total	635.87	100

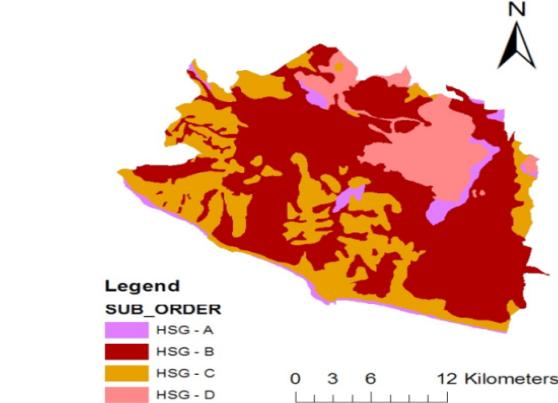


Figure 4. Hydrological soil map.

Table 2. Spatial distribution of HSG type of soil in the study area

Hydrological Soil Group	Area in km ²	Percentage of area
A	25.44	3.93
B	358.25	56.29
C	174.25	27.36
D	78.38	12.42
Total	636.3	100

4.3 Weighted Curve Number

The study area is divided in to 12 sub basins of each area less than 150km². CN values is calculated and the values for each sub basin are presented in Table 3. The range of

Table 3. Curve numbers of various land uses and HSGs in the sub basins of the study area

Watershed ID	Land use	Hydrologic Soil Group				CN value
		A	B	C	D	
1	Agriculture	2.67	49.19	23.04	0.47	74
	Built-up	2.22	10.49	15.49		
	Waste lands	0.50	12.31	2.02	9.63	
	Water bodies	0.37	3.31	0.79		
2	Agriculture	0.62	37.99	22.03		78
	Built-up	2.25	26.54	9.77		
	Waste lands		0.41	0.64		
	Water bodies	0.01	1.66	0.60		
3	Agriculture	0.06	8.89	2.41		80
	Built-up	0.29	10.77	0.36		
	Waste lands		0.27	0.28		
	Water bodies		2.44	0.00		
4	Agriculture	0.16	9.79	7.79	0.01	75
	Built-up		0.66	0.82		
	Waste lands	0.37	0.06	0.30	1.74	
	Water bodies	0.05	1.15	1.25	0.01	
5	Agriculture	1.70	25.02		0.30	69
	Forest				1.12	
	Built-up	0.70	7.44	0.02	0.08	
	Waste lands	6.29	1.62			
	Water bodies	0.71	3.77	0.05	0.07	
6	Agriculture	0.52	3.04	0.15	7.36	69
	Forest		0.19	0.01	9.98	
	Built-up		0.11		0.02	
	Waste lands	0.02	0.49	0.07		
	Water bodies	0.04	0.14		0.61	
7	Agriculture	2.30	20.86	3.24	8.83	70
	Forest		0.50		0.31	
	Built-up	0.08	2.08	0.66		
	Waste lands	0.17	4.54	0.09		
	Water bodies	0.02	0.47	0.31	0.02	
8	Agriculture		15.21	6.77		72
	Forest		0.96	0.11	0.41	
	Built-up		1.03	1.50	0.48	
	Waste lands		5.12	0.61	0.46	
	Water bodies		0.27	0.16	0.45	
9	Agriculture		21.58	9.11		78
	Built-up		8.34	11.44		
	Waste lands		0.32	1.44		
	Water bodies		1.13	0.33		
10	Agriculture	0.66	2.78	3.62		77
	Built-up	0.09	1.37	1.22		
	Waste lands	0.04	0.10	0.59		
	Water bodies	0.01	0.39	0.27		
11	Agriculture	0.13	22.71	7.94		79
	Built-up	0.15	16.41	11.40		
	Waste lands		0.15	0.52		
	Water bodies		0.81	0.30		
12	Agriculture	0.13	22.71	7.94		78
	Built-up	0.15	16.41	11.40		
	Waste lands		0.15	0.52		
	Water bodies		0.81	0.30		

CN values obtained for the sub basin are between 69 to 80. Weighted average CN value is estimated for the whole basin and it is found to be 75 which are shown in Table 4. With the finalized CN value, the storage retention of the area (S) is calculated using the Equation (2). In this study the value of S is found to be 85.

4.4 Estimation of Runoff Depth

The daily rainfall database of study area from 2000 to 2009 (for 10 years) and the area weighted curve number were inputs to the NRCS CN model and the runoff depth is estimated using the Equation (1) from the daily and annual values are presented in Table 5. Four rainfall events were selected during the study period and corresponding runoff values are also estimated and given in Table 6 and Table 7. The annual and event based rainfall runoff trend of the study area is shown in Figure 5 and Figure 6 respectively.

The average annual runoff fluctuated more throughout the computed years. The rainfall runoff result of the trend line shows that there is high runoff in the study period and the trend line for the future runoff is predicted to increase progressively. For the reason which there has been moderate rainfall and normal temperature existing in this area in recent years. The annual rainfall runoff relationship for sub basin of Kodayar watershed is shown in

Table 4. Weighted Curve Number for the Kodayar sub basin

Watershed ID	Area in km ²	CN value	Ai * CN
WS1	122.508896	74	9065.658
WS2	102.514058	78	7996.097
WS3	25.762255	80	2060.98
WS4	24.139546	75	1810.466
WS5	61.40538	69	4236.971
WS6	27.903043	69	1925.31
WS7	50.242148	70	3516.95
WS8	46.258559	72	3330.616
WS9	53.693405	78	4188.086
WS10	11.138187	76	846.5022
WS11	60.522992	79	4781.316
WS12	50.522992	78	3940.793
Total	636.611461		47699.75
Weighted CN Value	$CN_w = (\sum Ai * CNi) / \sum A = 75$		

Table 5. Estimated Annual Runoff from the study area

Year	Rainfall (P) in mm	Runoff (Q) In mm
2000	1080.58	984.87
2001	1245.98	1149.48
2002	1064.43	968.81
2003	653.75	561.76
2004	1102.90	1007.07
2005	1236.67	1140.21
2006	1199.60	1103.30
2007	1265.36	1168.77
2008	1323.09	1226.28
2009	974.08	879.01

Table 6. Daily based estimated runoff

Event	Rainfall P in mm	Runoff Q in mm
20/6/2003	26	0.862
21/6/2003	34	2.833
22/6/2003	15	0.048
23/6/2003	25	0.688
21/10/2003	15.38	0.032
22/10/2003	5.3	1.856
23/10/2003	16.79	0.001
24/10/2003	28.03	1.266
25/10/2003	19.55	0.074
14/10/2006	15.38	0.031
15/10/2006	35.97	3.460
16/10/2006	29.08	1.504
17/10/2006	41.93	5.652
18/10/2006	9.92	0.642
19/10/2006	16.76	0.001
20/10/2006	28.94	1.471

Table 7. Event based estimated Runoff

Event	Rainfall P in mm	Runoff Q in mm
13/6/2003 to 23/6/2003	125	60.43523
25/10/2006 to 30/10/2006	201	125.8587
20/10/2008 to 26/10/2008	340	255.7083
5/11/2009 to 11/11/2009	155	85.3991

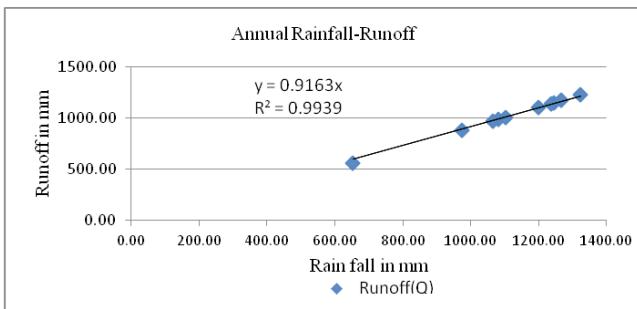


Figure 5. Rainfall Runoff comparisons.

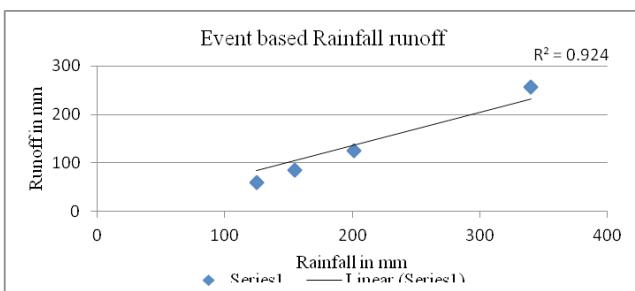


Figure 6. Event based Rainfall Runoff Map of the study area.

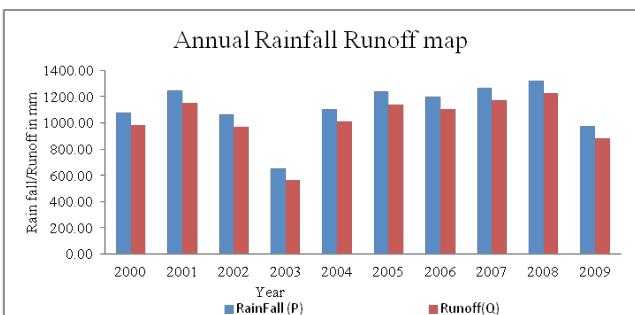


Figure 7. Annual Rainfall runoff comparison map (2000-2009).

Figure 7. The rainfall and runoff are strongly correlated with correlation coefficient (r^2) value being 0.99.

5. Conclusion

It is concluded that the rainfall, vegetation cover, soil condition are most of the important factors in surface runoff estimation. The combination of remote sensing and NRCS CN model makes the runoff estimate more accurate and fast; GIS arises as an efficient tool for the preparation of the input data required by the NRCS-CN model; the

estimated runoff using this curve number model is more acceptable than the runoff measured by the conventional methods. The model has been applied to four rainfall events of watershed and the Runoff was estimated for this ungauged sub basin of Kodayar, Tamil Nadu.

6. References

1. Sarangi A, Bhattacharya AK. Comparison of artificial neural network and regression models for sediment loss prediction from Banha watershed in India. *Agr Water Manag*. 2005; 78:195–208.
2. Chattopadhyay G S; Choudhury S. Application of GIS and remote sensing for watershed development project - A case study. 2006. Available from: <http://www.gisdevelopment.netS>
3. United States Department of Agriculture (USDA). National Engineering Handbook. Section 4. Hydrology. Washington, DC: Soil Conservation Service, US Government Printing Office; 1972.
4. Mishra SK, Singh VP. Soil conservation service curve number methodology. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2003.
5. Pandey A, Sahu AK. Generation of curve number using remote sensing and geographic information system. *Map India Conference on Water Resources*. 2002. Available from: mapindia2002@gisdevelopment.netS
6. Nayak TR, Jaiswal RK. Rainfall-runoff modeling using satellite data and GIS for Bebas River in Madhya Pradesh. *IEI Journal*. 2003; 84:47–50.
7. Zhan X, Huang ML. ArcCN runoff: An ArcGIS tool for generating curve number and runoff maps. *Environ Model Software*. 2004; 19(10):875–9.
8. Gandini ML, Usunoff EJ. SCS Curve Number estimation using remote sensing NDVI in a GIS environment. *Environmental Hydrology*. 2004; 121:9.
9. Ramakrishna D, Rao DHV, Tiwari KC. Integrated approach of remote sensing and GIS in delineation of sites for water harvesting structures, Kali Watershed. Dohad, Gujarat, India: *Geocarto International*. 2008; 23(2):95–108.
10. Ebrahimian M, Abdul Malek I. Application of natural resources conservation service curve number method for runoff estimation with GIS in the Kardeh Watershed, Iran. *Eur J Sci Res*. 2009; 34(4):575–90.
11. Amutha R, Porchelvan P. Estimation of surface runoff in Malatter Sub-watershed using SCS-CN method. *Journal of Indian Society Remote Sensing*. 2009 Jun 37; 291–304.
12. Domnita M, Ionut Craciun A, Haidu I, Magyari Saska Z. GIS used for determination of the maximum discharge in very small basins (under 2km²). *WSEAS Transactions on Environment and Development*. 2010; 6:468–77.

13. Dhawale AW. Runoff estimation for Darewadi watershed using RS and GIS. International Journal of Recent Technology and Engineering. 2013; 1(6):46–50.
14. Akhondi S. An investigation of curve number model in flood estimation using Geographical Information System (GIS) [MSc thesis]. Iran: Tarbiat Modares University; 2001.
15. Pal B, Samntha S. Estimation of soil loss using remote sensing and geographic information system techniques (Case study of Kaliaghai River basin, Purba and Paschim Medinipur District, West Bengal, India). Indian Journal of Science and Technology. 2011 Oct; 4(10):1202–7.
16. Kazemzadeh MB, Ayyoubzadeh SA, MoridnezhadA. Remote sensing of temporal and spatial variations of suspended sediment concentration in Bahmanshir Estuary, Iran. Indian Journal of Science and Technology. 2013 Aug; 6(8):5036–45.