Surface Runoff Estimation Of Sind River Basin Using SCS-CN Method And GIS Technology

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Abstract

Rainfall and runoff are significant hydrologic component in the water resources assessment. Rainfall is the primary source of recharge into the ground water. Understanding of rainfall and runoff is necessary for assessment of water availability. The runoff generation procedure is extremely complex. Accurate runoff assessment is carried out for useful management and improvement of water resources. Many methods are available to estimate runoff from rainfall; however, the SCS-CN method still remains the most popular, fruitful and frequently used method. Runoff curve number (CN) is a key factor of the SCS-CN method and it is depends on land use/land cover (LULC), soil type, and antecedent soil moisture (AMC). Different parameters, like land use/land cover, hydrological soil characteristics (HSG), rainfall data (P), Potential Maximum Retention (S), Antecedent Moisture Condition (AMC), Weighted Curve Number (CN), that are the mandatory inputs to SCS model, have been either derived from remote sensing data or from conventional data collection systems. The advance application of Remote Sensing and GIS techniques used to estimate surface runoff based on different parameters. The total area of present study is 26207.02 km² of Sind River Basin, located in the northern part of Madhya Pradesh, India. The daily rainfall data of 23 weather stations (2005-2014) was collected and used to predict the daily runoff from the Sind river basin using SCS-CN method and GIS technique for the duration of 2005-2014, annual average of daily rainfall are 777.07 mm and annual average of daily runoff calculated for Sind river basin are 133.71 mm. The developed rainfall–runoff model has been used to understand the characteristics of the watershed and its runoff.

Introduction

Water is unique source on the planet that no living can survive without it. Water is used in many sectors of our environment that serve human being directly or indirectly. Among others most crucial scopes of water for human beings is drinking, agriculture, energy production or transportation. All land of earth surface is a part of a watershed or river basin and all is formed by the water which flows over it and all the way through it. Runoff is very significant hydrologic component in the water resources assessment. Rainfall characteristics like intensity, duration and distributions are the main factors for the occurrence and quantity of runoff. Water flow which occurs when soil is infiltrated with high capacity and surplus water from precipitation, snowmelt or other sources of water flows over the land called surface runoff. This is a most important element of the hydrologic cycle. The relationship between quantity of precipitation and the consequential quantity of runoff is generally dependent on soil Infiltration. Rainfall-runoff relationship is extremely complex, influenced by various storm and drainage characteristics. There are number of methods available for finding out the runoff such as rational method, Green-Ampt method, and SCS-CN method (Dhvani Tailor and Narendra J. Shrimali, 2016).

In the present study SCS-CN method and GIS techniques used for surface runoff estimation. The Soil Conservation Service-Curve Number (SCS-CN) method developed by National Resources Conservation

Service (NRSC), United States Department of Agriculture (USDA) in 1969, is simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. Numeric catchment characteristics are the foundation of runoff determination in this method. The aim of the process is to find out the precise runoff curve number (CN) that defines the runoff potential. Combination of land use type, soil group and Antecedent Soil Moisture Condition (AMC) used for estimation of runoff curve number. The type of land use, hydrologic situation, agricultural management, soil moisture and distribution of soil type, above all are main components for rainfall runoff analysis. Soil type divided into four Hydrologic Soil Groups (HSG) that is A, B, C and D. Soil type under “A” hydrologic soil group having high infiltration rate, whereas soils having low infiltration rate comes under “D” hydrologic soil group. Remote sensing and GIS techniques are very useful for planning, development and management of natural resources as well as water resources in worldwide research. GIS environment facilitate particular in integrating of various thematic data sets in one platform and perform spatial analysis for decision making.

Study Area

Sind river basin falls in the northern part of Madhya Pradesh, State of Indian country. Its located between 77° 10' 19" to 79° 07' 32" E longitudes and 24° 01' 04" to 26° 47' 01" N latitude and the total area of proposed study is 26207.02 sq km. River Sind originates in Vidisha district and flow in Guna, Ashok Nagar, Shivpuri, Seopur, Datia, Gwalior, Morena and Bhind district and join river Chambal in Etawah district of Uttar Pradesh near Bhind district of Madhya Pradesh. Major tributaries of Sind River are Mahuar, Parbati, Pahuj, and Kunwari. Sind river basin is characterized by hot summer and dryness climatic region except during southwest monsoon season. Soil types of study area can be grouped as under black cotton soil, sandy soil, sandy loam, clayey loam, fine soil and laterite soil.

Methodology

S. No	Used Data	Scale/Data Resolution	Year / Range	Source
1	Rainfall	2.5° x 2.5°	2005-2014	http://www.globalweather.tamu.edu
2	SOI Toposheet	1:50000	1960	Survey of India, Dehradun.
3	LANDSAT-8	30 M	Sep 2013 & Jan, 2014	USGS Earth Explorer
4	Soil map	1:250000	1976	National Bureau of Soil Survey and Land use Planning, Bhopal.

Table-1: Used data in present study.

Land use/Land cover (LU/LC): This is one of the very important variables for runoff estimation. Land use map prepared by using Landsat-8 satellite imagery using ERDAS Imagine and Arc GIS software's. On screen digitization procedure applied for land use map preparation through visual interpretation of satellite imagery on 1:50000 scale using Arc GIS Software. Various LU/LC classes identified namely agricultural land, built-up area, forest, wastelands and water bodies (Figure-2). The detail statistics of land use/land cover of the study area is shown in Table-4.

Soil: To assess the rainfall water as a surface runoff, Soil texture is very important for hydrologic soil group determination hence needful thematic layer of soil type obtained from National Bureau of Soil Survey & Land Use Planning (NBSS&LUP).

Hydrological Soil Group (HSG): HSG maps of study area were prepared using Arc GIS software on the basis of soil texture. HSG is expressed as four groups; Group A, B, C, and D, according to the soil's minimum infiltration rate.

Curve Number (CN): The overlay operation is performed using the land use map and hydrologic soil group map to identify land use and soil group for each polygon and determine area of every land use classes under same soil group. Curve number (CN) of each unique land use-soil groups are assigned within the basin boundary based on standard SCS curve number method (Table 6).

Rainfall: Rainfall data were downloaded from the National Centers for Environmental Prediction (NCEP), Climate Forecast System Reanalysis (CFSR) dataset (<http://globalweather.tamu.edu>) in comma separated values (.csv) file format which are authenticated data sources (Sharma et al., 2015). CFSR has published daily/monthly rainfall, minimum, maximum & mean temperature, wind speed, relative humidity and solar radiation/sun hours on regular latitude, longitude grid of 2.5x2.5 degree. Daily observed Rainfall data for the period 2005–2014 used for present study which have been recorded by 23 weather stations covering the study area. IDW interpolation technique in Arc GIS software has been used to find out spatial distribution of rainfall in study area.

SCS-CN Model:

Soil Conservation Service Curve Number (SCS-CN) method is the most commonly used experimental method to calculate the direct runoff from a watershed/river basin (USDA, 1972). The Curve Number (SCS-CN) Equation usually a relationship between runoff volume and rainfall volume. The SCS-CN technique explaining the water balance equation can be articulated as given below (Mishra and Singh 2003).

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

Where;

Q is the runoff depth (to get volume, multiply by the basin area)

P is the rainfall depth

Ia is the initial abstraction

S is the basin storage.

All units of depth are in mm.

The amount of rainfall that falls before runoff is initiated can be conceptualized as initial abstraction and this is generally assumed to be 0.2S.

Eq. is usually written as (Dwivedi P. et al, 2017):

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

For the Indian condition the CN is related to S with

$$S = \frac{1000 - 10}{CN} \quad \text{or} \quad S = \frac{25400 - 254}{CN}$$

The CN (dimensionless number ranging from 0 to 100) is determined from a table, based on land use/land cover (LU/LC), hydrological soil group (HSG) and Antecedent moisture conditions (AMC). Hydrologic Soil Group (HSG) is generally divided into four groups (A, B, C and D) with respect to the rate of the soil's infiltration in the watershed area. Antecedent Moisture Condition (AMC) is expressed in three levels (AMC I, AMC II and AMC III), according to precipitation limits for dormant and growing seasons. CN value was adopted from Technical release (USDA, TR-55, 1986). Although, SCS technique is formerly designed for use in watersheds of 15 km², and it has been modified for application to larger watersheds/basin by weighing curve numbers with respect to watershed/basin area.

Equation of Weighted Curve Number (CNw) given below;

$$CN_w = \frac{\sum (CN_i * A_i)}{A}$$

Where;

CN_w = Weighted curve number

CN_i = Curve number

A_i = Area with curve number CN_i

Antecedent Moisture Condition (AMC)

AMC refers to the wetness that is present in the soil at the start of the rainfall runoff incident under consideration. It is well recognized that initial abstraction and infiltration are governed by AMC. Three level of AMC are recognized by SCS as given below:

Table 2: Classification of Antecedent Moisture Conditions (AMC)

AMC Class	Soil Characteristics	Total 5 day Antecedent rainfall(mm)	
		Dormant Season	Growing Season
AMC-I	Soils are dry not to wilting point, Cultivation has taken place	< 13 mm	< 36 mm
AMC-II	Average Condition	13-28mm	36 - 53 mm
AMC-III	Heavy or light Rainfall and low temperatures have occurred within the last 5 days; saturated soils	> 28 mm	>53 mm

(Source: Handbook of Hydrology, 1972).

The deviation of CN value under AMC II called CN_{II} for diverse land circumstances are usually found in practice. The alteration of CN_{II} to other two AMC conditions can be complete by the following correlation equations,

For AMC-I

$$CN_I = \frac{4.2 \times CN_{II}}{10 - 0.058 \times CN_{II}}$$

For AMC-III

$$CNI = \frac{23 \times CNII}{10 + 0.13 \times CNII}$$

Table 3: USDA-SCS Soil classification.

Hydrologic Soil Group	Type of Soil	Runoff potential	Infiltration Rate mm/hr	Remarks
Group A	Deep, well drained sands and gravels	Low	>7.5	High rate of water transmission
Group B	Moderately deep, well drained with moderately fine to coarse textures	Moderate	3.8-7.5	Moderate rate of water transmission
Group C	Clay loams, shallow sandy loam, soils with moderately fine to fine textures	Moderate	1.3 – 3.8	Moderate rate of water transmission
Group D	Clay soils that swell significantly when wet, heavy plastic and soils with a permanent high water table	High	< 1.3	Moderate rate of water transmission

Result And Discussion

In the present study, SCS-CN method used for surface runoff estimation. The runoff generation method is extremely complex, nonlinear, dynamic in character, and affected by numerous interconnected physical factors. Precise runoff assessment is carried out for valuable management and development of water resources. In Sind river basin drought like situation prevails every year due to low average annual rainfall and high runoff.

Land use: The basin constitutes different land use/ land cover classes and present research reveals that agriculture is dominant land use class in the study region. LU/LC map shown that nearly 12847.28 km² (49.02%) of the sind river basin area has been used for agricultural purposes, the area of Forest is

6006.21 km² (22.92%), Wasteland area nearly 6523.18 km² (24.89%), Built up area is about 447.86 km² (01.71%) and River/Water bodies observed 382.49 km² (01.46%) in study area.

S. No.	LU/LC Class		Area in km ²	Area in %
1.	Built Up Area	Built-up	447.86	01.71
2.	Agriculture Land	Rabi Crop	4596.56	17.54
3.		Kharif Crop	2091.00	07.98
4.		Double Crop (Kharif+Rabi)	3758.73	14.34
5.		Fellow Land	2400.99	09.16
6.	Forest	Dense Forest	1125.61	04.30
7.		Open Forest	2185.36	08.34
8.		Scrub Forest	2695.23	10.28
9.	Wasteland	Land With Scrub	2883.92	11.00
10.		Land Without Scrub	1452.24	05.54
11.		Barren Rockey/Stony	07.01	00.03
12.		Gullied/Ravenous	2180.02	08.32
13.	River & Water Bodies	Lakes/Ponds	34.68	00.13
14.		Dam/Reservoirs	132.96	00.51
15.		River	214.85	00.82
Total			26207.02	100

Table 4: Land use/Land cover classification Statistics.

Hydrologic Soil Group: Based on the hydrological soil group, the maximum area of Sind river basin is characterized under group C of hydrological soil that is nearly 17046.04 km² (65.05%), then group B hydrological soil is 7099.08 km² (27.09%), group A hydrological soil observed as 1278.32 km² (04.88%), group D hydrological soil observed as 400.19 km² (01.53%) and nearly 382.49 km² (01.46%) area found as unclassified or river/water bodies in the study area.

S. No.	Hydrological Soil Group	Area in km2	Area in %
1.	Group A	1278.32	04.88
2.	Group B	7099.08	27.09
3.	Group C	17046.04	65.05
4.	Group D	400.19	01.53
5.	River & Water Bodies	382.49	01.46
Total Study Area		26207.02	100

Table 5: Hydrological Soil Group classification Statistics.

Area Weighted Curve Number

Overlay analysis (Union) performed with soil and land use map and hydrological soil group map prepared new PAT (polygon attribute table) using Arc GIS 9.3. The result obtained from this HSG-PAT used to compute the total area weighted curve number of the study area.

S. No.	Soil Type (HSG)	Land use	Area in Sq Km	CN	Area in Hectare	CN*A	WCN
1	Group A	Builtup	21.71	57	2170.9508	123744.1956	AMC I 63.07
2	Group B		89.59	72	8959.0886	645054.3792	
3	Group C		328.96	81	32895.9199	2664569.512	
4	Group D		7.32	86	731.7788	62932.9768	
9	Group A	Dam/Reservoirs	7.13	98	713	69874	AMC II 79.58
10	Group B		33.21	98	3321	325458	
11	Group C		76.18	98	7618	746564	
12	Group D		16.43	98	1643	161014	
13	Group A	Dense Forest	34.94	25	3493.8802	87347.005	AMC III 90.12
14	Group B		977.20	55	97719.8264	5374590.452	
15	Group C		104.51	72	10451.3071	752494.1112	
16	Group D		9.19	77	918.995	70762.615	
17	Group A	Double Crop (Kharif+Rabi)	102.14	65	10214.0257	663911.6705	
18	Group B		140.08	76	14008.061	1064612.636	
19	Group C		2311.42	84	231141.7739	19415909.01	
20	Group D		39.30	88	3930.3636	345871.9968	
21	Group A	Fellow Land	186.71	77	18671.2936	1437689.607	
22	Group B		209.61	86	20961.4798	1802687.263	
23	Group C		3093.75	91	309375.3383	28153155.79	
24	Group D		77.76	94	7776.0982	730953.2308	
25	Group A	Kharif Crop	127.56	65	12756.3974	829165.831	
26	Group B		367.71	76	36771.4297	2794628.657	
27	Group C		1560.62	84	156062.3481	13109237.24	
28	Group D		35.09	88	3508.8128	308775.5264	
29	Group A	Lakes/Ponds	6.73	98	673	65954	
30	Group B		13.32	98	1332	130536	
31	Group C		9.41	98	941	92218	

32	Group D		5.21	98	521	51058
33	Group A	Land With Scrub	179.49	45	17948.9329	807701.9805
34	Group B		313.46	66	31346.3101	2068856.467
35	Group C		2332.34	77	233233.5771	17958985.44
36	Group D		67.90	83	6790.1363	563581.3129
37	Group A	Land Without Scrub	64.36	77	6435.5844	495539.9988
38	Group B		784.60	86	78460.4213	6747596.232
39	Group C		559.98	91	55997.7427	5095794.586
40	Group D		45.39	94	4538.8516	426652.0504
41	Group A	Open Forest	89.35	36	8934.8492	321654.5712
42	Group B		1786.54	61	178654.1986	10897906.11
43	Group C		298.54	73	29854.1982	2179356.469
44	Group D		11.29	79	1129.3765	89220.7435
45	Group A	Rabi Crop	174.94	65	17493.9803	1137108.72
46	Group B		198.86	76	19886.3702	1511364.135
47	Group C		4164.46	84	416446.478	34981504.15
48	Group D		60.06	88	6005.8523	528515.0024
49	Group A	River	33.53	98	3353	328594
50	Group B		47.45	98	4745	465010
51	Group C		116.64	98	11664	1143072
52	Group D		17.24	98	1724	168952
53	Group A	Scrub Forest	198.77	45	19876.7793	894455.0685
54	Group B		2203.69	71	220369.3317	15646222.55
55	Group C		274.37	81	27437.4418	2222432.786
56	Group D		18.66	89	1866.072	166080.408
57	Group A	Wasteland (Barren Rocky/Stony)	0.41	65	40.9908	2664.402
58	Group B		3.40	72	339.9811	24478.6392
59	Group C		3.02	83	301.6243	25034.8169
60	Group D		0.26	88	25.7033	2261.8904

61	Group A	Wasteland (Gullied/ Ravenous)	97.92	77	9792.3542	754011.2734
62	Group B		24.22	86	2422.1496	208304.8656
63	Group C		2015.09	91	201509	18337319
64	Group D		27.97	94	2796.6183	262882.1202
Total			26207.02		2620702.07	208543883.5

Table 6: Weighted Curve Number for Sind river basin.

Rainfall

The average annual rainfall is not consistent in this region. Rainfall data from the year of 2005 to 2014 has been used in present study. The average annual rainfall from the year of 2005–2014 observed as 777.07 mm/year where as high average annual rainfall observed as 995.16 mm in the year of 2011 and the lowest average annual rainfall observed as 606.69 mm in the year of 2006.

Runoff Calculation

Available daily rain fall data from the year 2005 to 2014 has been evaluated in this study. Below Table shows the annual rainfall and runoff for Sind river basin for the period of 2005 to 2014. SCS Curve number method used in this study for runoff estimation. The average annual runoff from the year of 2005–2014 observed as 133.71 mm/year whereas, the maximum runoff for the river basin estimated 231.43 mm in the year 2009 and minimum runoff of 32.41 mm in the year 2006 which is shown in Table 7.

S. No.	Year	Rainfall (mm)	Runoff (mm)
1.	2005	704.61	119.46
2.	2006	606.69	32.41
3.	2007	629.41	88.39
4.	2008	897.06	148.36
5.	2009	927.24	231.43
6.	2010	859.17	117.81
7.	2011	995.16	219.86
8.	2012	763.12	157.29
9.	2013	705.74	80.50
10.	2014	682.50	141.61
Total		7770.71	1337.12

Table 7: Result of Rainfall - Runoff.

Conclusion

Present study clearly indicate that SCS-CN method integrated with GIS techniques is very useful for estimation of runoff and this method can be used in watershed management effectively. Variation in runoff potential can be observed in obtained result with different land use/land cover and with different soil conditions in the study area. Most of the river basin is indicating high curve number value which is more than 70, that indicates high runoff in the Sind river basin. The average annual runoff from the year of 2005–2014 observed as 133.71 mm/year whereas; the maximum runoff for the river basin estimated 231.43 mm in the year of 2009 and minimum runoff of 32.41 mm in the year of 2006. Available daily rainfall data from the year of 2005 to 2014 has been evaluated in this study. The average annual rainfall observed as 777.07 mm/year whereas; the maximum rainfall is 995.16 mm in year of 2009 and minimum rainfall is 606.69 mm in the year of 2006. Land use of the study area classified into five major classes that is built up, agriculture land, forest, wasteland and river/water bodies. Land use map clearly indicate that agriculture is dominant land use class in the sind river basin. The soil of the study area classified into four hydrological soil groups A, B, C and D with minimum infiltration rate. Soil map indicate that most of the study area covered by group C of hydrological soil group.

Declarations

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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Figures

Figure 1

Location map of the study area.

Figure 2

Land use map of the study area.

Figure 3

Soil map of the study area.

Figure 4

Hydrologic Soil Group map of the study area.

Figure 5

Curve Number map of the study area.

Figure 6

Rainfall distribution map of the study area.