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Runoff Estimation by Integration of GIS and SCS-CN Method for Kanari River Watershed

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Abstract: Conventional water management is the only alternative to overcome the gap between demand and supply and for this surface water resource management is interpretative issue. Kanari river watershed, located between 23°33′36.73″N and 80°06′57.49″E at an elevation of about 490 m in Jabalpur district of Madhya Pradesh State, India has been used for the study. The major component of the hydrologic cycle is rainfall, directly related to runoff. Integration of GIS and SCS-CN method can be beneficial to overcome this problem of runoff estimation. The runoff varies from 465.59 to 1119.24 mm (1990–2019). The amount of rainfall varies from 1136.7 to 1592.98 mm in the Kanari river watershed. The calculated average annual runoff was 729.87 mm and average runoff volume for the period of 29 years is 218.36. The model finally depicted the runoff in the area kept on increasing as rainfall kept on increasing following a linear trend which predicted that the infiltration opportunity decrease and ultimately resulting in decreased infiltration rate causing decreased base flow. Artificial recharge structures can be recommended in the study area.

Keywords: Soil conservation service, Curve Number, GIS, Runoff, Water resource management

Remote sensing and Geographic Information System is currently in transition from a descriptive to a quantitative technology. Field measurements are laborious and time consuming but the advantages of remote sensing applications in runoff measurement as a source of spatial information becomes more obvious if sensors are air or space-borne platforms used. Geographic Information Systems (GIS) in addition to SCS-CN method and remote sensing have contributed to applied hydrology in government monitoring and forecasting projects. Rivers are suffering from flow degradation because of numerous possible reasons, including the water usage for agriculture and dam installation. But in most of the cases the depleted flow is mainly due to climate change, including increasing evaporation due to high temperature range and altering rainfall patterns. Dimishing run-off is elevating burden on freshwater resources all over the world and in India, because of high demand rate for water due to increasing population. Spatial data have made it practicable to accurately calculate the runoff has led to significant increases in its use in hydrological and meteorological applications. The curve number method (SCS–CN, 1972) is most adaptable widely used for run-off estimation. This method is most relevant property of the watershed, specifically soil permeability, land use and antecedent soil water conditions which take into consideration (Bans ode et al 2014). Stream gauging data and observations in different parts of India shows that there is visible decline in the non-monsoon flow practically in all river systems. The noticeable decline of flow and drying of rivers in non-monsoon period is observed by smaller hydrologic units (sub-catchments and watersheds). Uncontrolled ground water extraction is the basic cause and foremost problem of ceasing effluent discharge into the water stream. Keeping this in view a comprehensive study was proposed to revive Kanari River in Jabalpur district. The aim of this study is to quantify spatial and quantum recharge requirement to revive the river and for this runoff estimation was key factor.

Study area: Kanari River is a river of Madhya Pradesh state in Central India. The river originates at Ghutehi hill, whose, latitude is 23.56441 and longitude is 80.11622, which is situated in Ghutehi village, Tehsil Sihora, District Jabalpur of State Madhya Pradesh (Fig. 1). Geographically, the origin is located at a distance of about 63 km at northeast of Jabalpur and 32 km at South west of Jabalpur and the location of the area falls on Survey of India Toposheet no. F44C2, F44C3 and F44B15. The average MSL of the Kanari River is 399-401 m and climatically it comes under subtropical region. This river joins the Suhar river, whose, latitude is 23.489271 and longitude is 79.98575, which is situated in Budhi Village, Tehsil Majholi, District Jabalpur of State Madhya Pradesh (Fig. 1). The climate here is mild, and generally warm and temperate. Precipitation here is about 1277 mm/50.3 inch per year. Precipitation is the lowest in April, with an average of 6 mm/0.2 inch. Most precipitation falls in July and August, with an average of 419 mm/16.5 inch. At an average temperature of 33.4 °C/92.1 °F, May is the hottest month of the year. In December and January, the average temperature is 16.5 °C/61.7 °F and is the lowest average temperature of the whole year. According the data collected from 1982-2012, between the driest and wettest months, the difference in precipitation is 413 mm/inch. The wettest is July (244.9 mm a) and windiest is June (5 km/h). The study area consists of a long narrow plain running north-east and south-west, and shut in on all sides by highlands. Topographically, the area has gentle rolling topography with 1-2 metre elevation difference. This plain, which forms an offshoot from the great valley of the Narmada, is covered in its western and southern portions by a rich alluvial deposit of black cotton-soil. At study area, the soil is black cotton soil, and water plentiful near the surface.

MATERIAL AND METHODS

The methodology applied for runoff calculation is depicted in Figure 2. The Soil Conservation Service Curve Number approach is usually utilized empirical methods to determine the direct runoff from a drainage basin (USDA 1972) in the Kanari basin. The surface storage are combined with infiltration losses by the relation of

$$Q = (P-Ia)^2 / P-Ia+S \qquad (1)$$

Here, Q – gathered/collected runoff (mm), P – effective rainfall depth (mm), Ia - initial abstraction (mm) (surface storage, interception, and infiltration preceding to runoff in the entire watershed). The empirical relation was obtained in the terms of Ia and is depicted below.

$$Ia = 0.3S \qquad (2)$$

The potential maximum retention (S) for Indian conditions is given by,

$$S = \left(\frac{25400}{CN}\right) - 254 \qquad (3)$$

where,

CN - Curve Number (Source : SCS handbook of Hydrology (NEH-4), section- 4 (USDA 1972))

Rewriting the equation as,

$$Q = (P - 0.3S)^2 / (P + 0.7S) \qquad (4)$$

The runoff from the entire area was calculated in significance of value of CN using Eqs. 3 and 4.

Thematic layers depicted in Figures 3, 4, 5 and 6 were overlayed and the SCS curve number method was used that serves for determination of capability of soils to accommodate infiltrated water in regards of Land use/ Land cover (LU/LC) and antecedent soil moisture condition (AMC) (Amutha and Porchelvan 2009) (Table 1, Fig 3). U.S soil conservation service (SCS) soils distributed the soil into four hydrologic soil groups namely group A, B, C & D in regards of probable rate of runoff and final infiltration. CN, S and P calculated for various years (Table 2).

The different parameters required to compute the runoff were computed and presented. Precipitation data was used

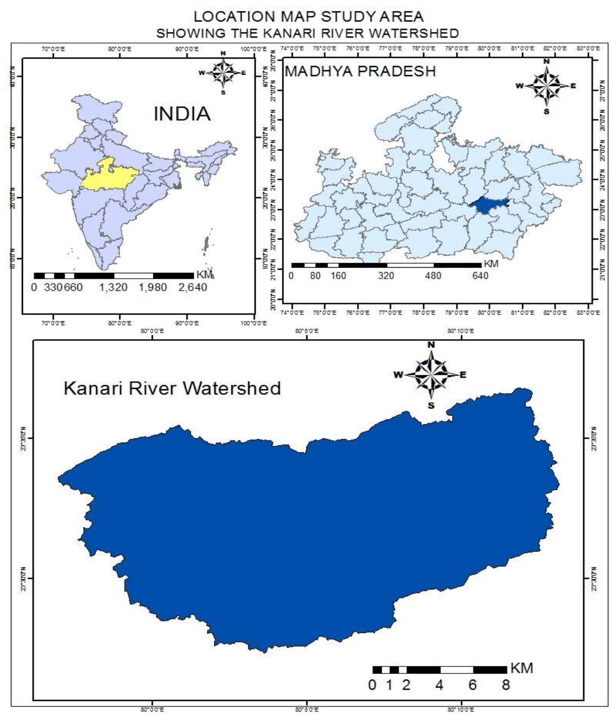

Fig. 1. Location map of the study area

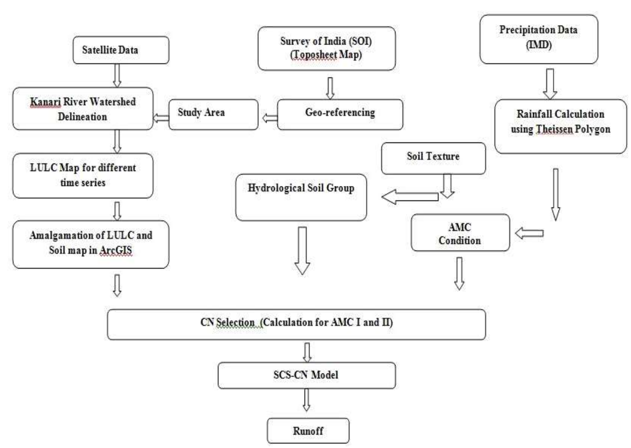

Fig. 2. Methodology for runoff calculation

Table 1. Antecedent soil moisture classes (AMC) group

AMC group	Soil characteristics	Five day antecedent rainfall in mm	
		Dormant season	Growing season
I	Wet condition	Less than 13	Less than 36
I	Average condition	13-28	36-53
III	Heavy rainfalls	Over 28	Over 53

Table 2. Hydrological and quantative calculations in the watershed

AMC	CN				S				P>0.3S			
	1990	2004	2009	2019	1990	2004	2009	2019	1990	2004	2009	2019
I	67.75	71.33	73.48	75.06	120.88	102.06	91.64	84.38	36.26	30.61	27.49	25.3
II	82.76	85.05	86.37	87.32	52.91	44.63	40.06	36.88	15.86	13.38	12.01	11.0
III	92.00	93.02	93.68	94.16	22.07	19.05	17.10	15.74	6.62	5.71	5.13	4.24

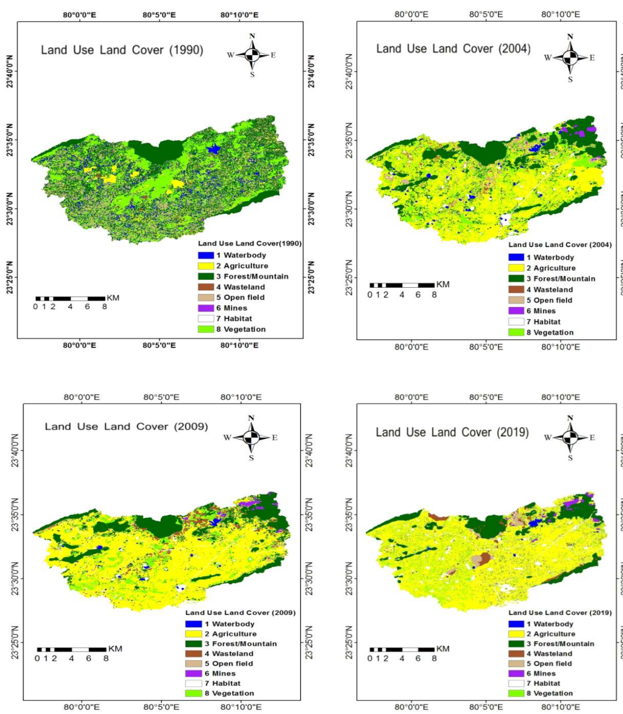

Fig. 3. LULC map for different time series

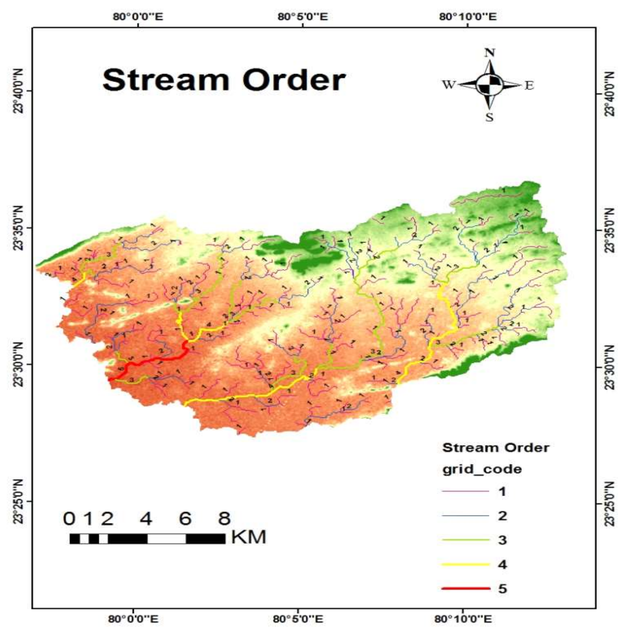

Fig. 4. Stream order map

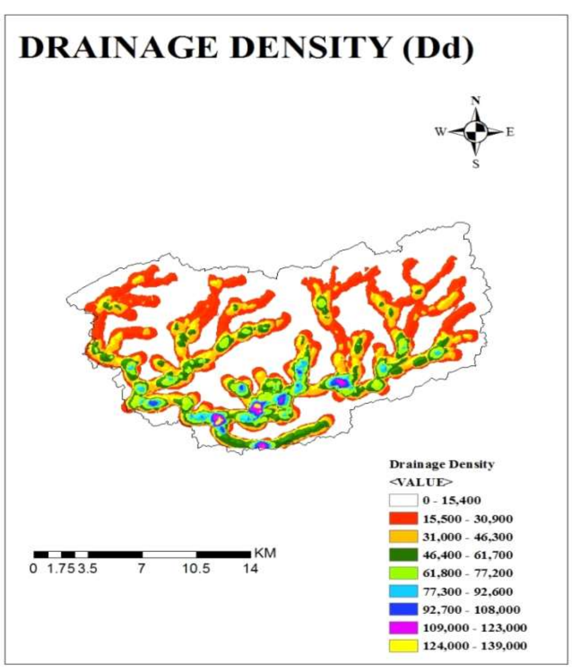

Fig. 5. Drainage density map

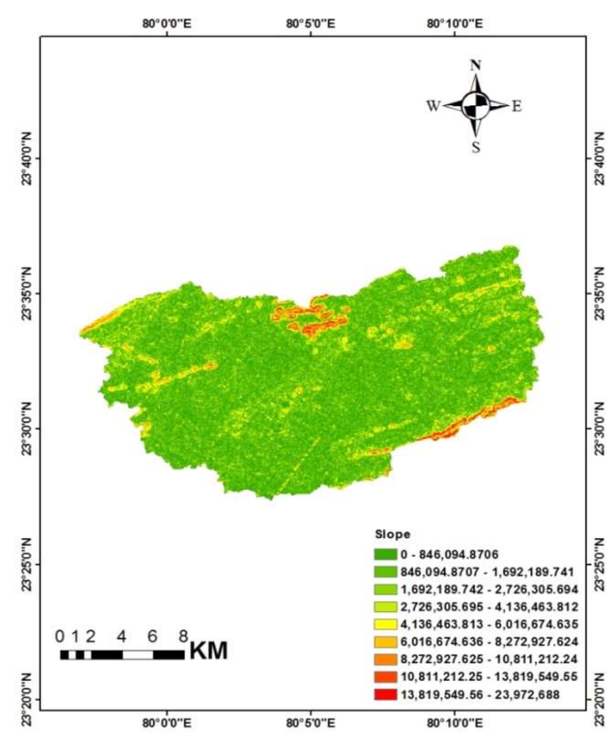

Fig. 6. Slope map

to calculate the antecedent moisture condition for the study period. Soil map was converted into hydrological soil group map and the land use map derived from the satellite data was combined with it to extract the curve number value. The runoff was estimated by knowing the antecedent moisture condition and the curve number. Using the SCS rainfall-runoff relation the daily runoff was computed. The calculation was done on excel spread sheet. The following equation is used in the case of AMC-I and AMC-III:

$$CN\ (I) = \frac{CN\ (II)}{2.281 - 0.128\ CN\ (II)}$$

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

RESULTS AND DISCUSSION

The curve number method is used for estimating the direct surface runoff volume using the recorded rainfall data and weighted curve number of the Kanari river watershed. SCS-curve number method takes into account the parameters characterizing a farm such as land use, soil cover, antecedent moisture condition and wetness for estimating yield from the area. These parameters are used to calculate the curve number for Kanari river watershed as shown in Table 2. The curve number indicates the runoff potential of a complex storm during the particular period. The annual surface runoff depth (465.59 mm) for the year 1990 is multiplied by watershed area (A = 299033962 m^2) provides the total average runoff volume as (139228136.1 m^3). The result for the year 1990 (Table 3). Annual surface runoff depth (597.21 mm) for the year 2004 is multiplied by watershed area (A = 299033962 m^2) provides the total average runoff volume as (178807886.9 m^3). Annual surface runoff depth (737.44 mm) for the year 2009 is multiplied by watershed area (A = 299033962 m^2) provides the total average runoff volume as (220599996.4 m^3).

Annual surface runoff depth (1319.24 mm) for the year 2019 is multiplied by watershed area (A = 299033962 m^2) provides the total average runoff volume as (361883866 m^3). The runoff varies 465.59 to 1319.24 mm (1990-2019) (Table 7). The amount of rainfall varies between 1136.7 to 2466.9 mm in the Kanari river watershed. The calculated average

Table 3. Aimed weighted curve number (WCN) at Kanari river watershed (1990)

Land use cover	Soil type (HSG)	Area in ha	Area in m^2	CN	Area	Area * CN	Weighted Curve Number (WCN)
Waterbody	D	2265.4	22654000	100	0.075757	7.575728	AMC I - 67.75 AMC II - 82.76 AMC III - 92.00
Agriculture	D	2941.15	29411500	90	0.098355	8.851954	
Forest/Mountain	D	12028.5	120285000	77	0.402245	30.97289	
Wasteland	D	119.827	1198270	94	0.004007	0.376671	
Openfield	D	3780.12	37801200	84	0.126411	10.61853	
Mines	D	46.7092	467092	95	0.001562	0.14839	
Habitat	D	149.38	1493800	86	0.004995	0.429606	
Vegetation	D	8572.31	85723100	83	0.286667	23.79334	
Total			299033962			82.76711	

Table 4. Aimed Weighted curve number (WCN) at Kanari river watershed (2004)

Land use cover	Soil type (HSG)	Area in ha	Area in m^2	CN	Area	Area * CN	Weighted Curve Number (WCN)
Waterbody	D	400.68	4006800	100	0.013383	1.33827	AMC I - 71.33 AMC II - 85.05 AMC III - 93.02
Agriculture	D	12891.8	128918000	90	0.430586	38.75272	
Forest/Mountain	D	7675.83	76758300	77	0.256373	19.74069	
Wasteland	D	347.58	3475800	94	0.011609	1.091261	
Openfield	D	1212.84	12128400	84	0.040509	3.402742	
Mines	D	263.16	2631600	95	0.00879	0.835006	
Habitat	D	770.67	7706700	86	0.02574	2.213671	
Vegetation	D	6377.58	63775800	83	0.213011	17.67992	
Total			299033962			85.05428	

annual runoff is found to be 779.87 mm and average runoff volume for the period of 29 years is 225129971.3 m^3 depicting rising linear trend in aspect of both the parameters simultaneously decreasing opportunity time and hence infiltration decreasing base flow of the area.

Runoff and volume was determined by SCS-CN method and was further analyzed on yearly basis for the year 1990,

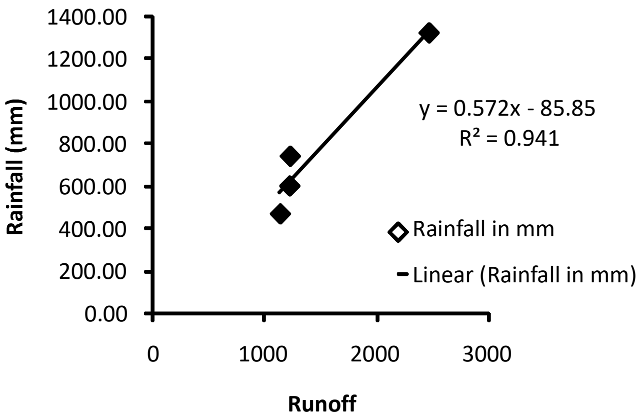

Fig. 7. Scatter plot between the rainfall and calculated runoff

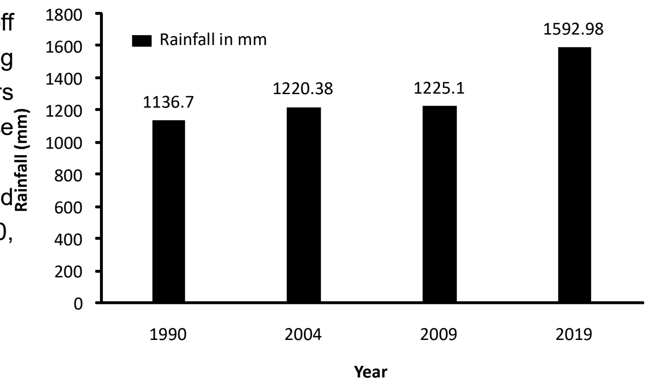

Fig. 8. Rainfall variation in Kanari Watershed

Table 7. Annual average runoff depth and volume

Year	Rainfall in mm	Runoff in mm	Volume (MCM) = (Runoff*area)	Runoff Co.= (RO/RF)
1990	1136.7	465.59	139.22	0.4
2004	1220.38	597.22	178.80	0.48
2009	1225.1	737.44	220.59	0.6
2019	1592.98	1119.25	334.86	0.49
Average	1293.79	729.87	218.36	0.49

Table 5. Aimed Weighted curve number (WCN) at Kanari river watershed (2009)

Land use cover	Soil type (HSG)	Area in ha	Area in m^2	CN	Area	Area * CN	Weighted Curve Number (WCN)
Waterbody	D	268.38	2683800	100	0.008972	0.897168	AMC I - 73.48 AMC II - 86.37 AMC III - 93.68
Agriculture	D	16981.5	169815000	90	0.567675	51.09072	
Forest/Mountain	D	6535.08	65350800	77	0.218461	16.82152	
Wasteland	D	862.11	8621100	94	0.028819	2.709031	
Openfield	D	1052.01	10520100	84	0.035168	2.954083	
Mines	D	316.44	3164400	95	0.010578	1.004936	
Habitat	D	803.79	8037900	86	0.02687	2.310812	
Vegetation	D	3094.83	30948300	83	0.103457	8.586939	
Total			299033962			86.3752	

Table 6. Aimed weighted curve number (WCN) at Kanari river watershed (2019)

Land use cover	Soil type (HSG)	Area in ha	Area in m^2	CN	Area	Area * CN	Weighted Curve Number (WCN)
Waterbody	D	187.11	1871100	100	0.006254	0.625402	AMC I - 75.06 AMC II - 87.32 AMC III - 94.16
Agriculture	D	18507.1	185071000	90	0.618587	55.67284	
Forest/Mountain	D	4417.92	44179200	77	0.147666	11.37028	
Wasteland	D	1205.64	12056400	94	0.040298	3.787983	
Openfield	D	591.75	5917500	84	0.019779	1.661422	
Mines	D	360.63	3606300	95	0.012054	1.145112	
Habitat	D	1617.8	16178000	86	0.054074	4.650352	
Vegetation	D	3030.39	30303900	83	0.101289	8.406963	
Total			299033962			87.32035	

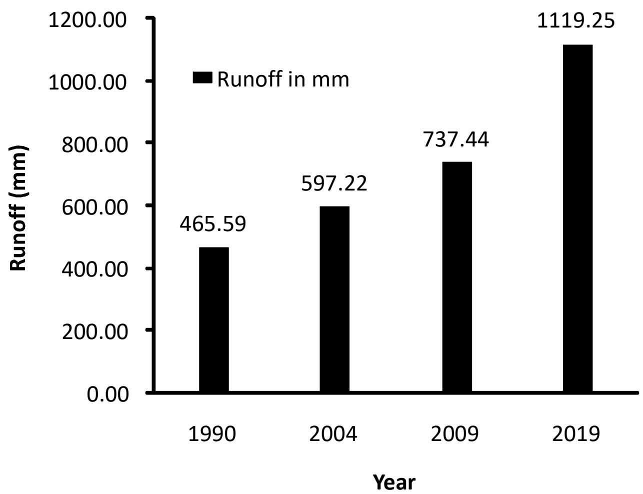

Fig. 9. Runoff variation in Kanari Watershed

2004, 2009 and 2019. The same were inserted in tabular format and histograms were prepared for the purpose of interpretation. Farther the graphs were processed depicting linear rainfall-runoff variation, based on this the correlation coefficients were estimated. The runoff varies 465.59 to 1119.24 mm (1990–2019) (Table 7). The amount of rainfall varies between 1136.7 to 1592.98 mm in Kanari river watershed (Table 7). The calculated average annual runoff is found to be 729.87 mm and the average runoff volume for period of 29 years is 218.36 MCM. The rainfall-runoff relationship is presented (Fig. 7) for the Kanari watershed. Rainfall and Runoff variation in Kanari Watershed (Fig. 8 and Fig. 9) respectively depicts rising linear trend in aspect of both the parameters simultaneously decreasing opportunity time and hence infiltration decreasing base flow of the area.

CONCLUSION

Curve number estimation was performedusing extracted geo-morphological data including thematic layers of such as land use, soil type, drainage order, etc under the environment of RS and GIS. In the study it was found that integration of SCS-CN method with environment RS and GIS can enhance model performance significantly. It was also found that GIS is the most effective and efficient tool for thematic map preparation as an input for SCS-curve number method. GIS was utilized to find out the weighted curve number for antecedent moisture condition-II for year 1990, 2004, 2009 and 2019 was found for the watershed. It was noted that SCS-CN method was formulated for humid type catchments, yet it is found to be a suitable method for sub humid regions of Madhya Pradesh. Finally it was concluded in this study that curve number method in integration with environment of RS and GIS techniques is very effective and efficient method for simulating rainfall-runoff and to determine total surface runoff.

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