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GIS based Runoff Estimation of Venna River Basin, Maharashtraby SCS Curve Number Method

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Abstract—*Remote sensing and GIS plays a vital role in watershed planning, development and management. Runoff estimation is mandatory for proper planning of storage structures, irrigation schemes, water ways, water harvesting and erosion control structures, ground water development strategies etc. In this study, Soil conservation service curve number method (SCS CN method) integrated with remote sensing and GIS was used to estimate surface runoff. SCS CN method considers watershed parameters as well as climatic factors and combines them in to one entity known as curve number. The Venna river basin, located in Maharashtra, India was the study area chosen. SCS CN methods modified for Indian condition have been used in the present study. Since about 85% of study area is having a slope less than 5%, the standard SCS CN method was used without considering the slope of the terrain. The different thematic layers like land use, hydrologic soil and watershed boundary have been generated in GIS environment and processed to derive curve number. The different thematic maps were prepared using Google earth satellite images and ArcGIS 10.1 software. From the 5 year daily rainfall data (2004-2009) daily runoff was estimated using SCS CN equation considering antecedent moisture condition. It was observed that runoff behavior varies spatially depending on the vegetation and soil permeability characteristics. The rainfall runoff linear regression analysis have been carried out and good correlation was found. The study provided an insight to the complex relationship between rainfall and runoff which will help researchers in better understanding of catchment behavior.*

1. INTRODUCTION

Runoff estimation is obligatory in proper planning and design of hydraulic structures as well as in assessment of water yield potential of catchment. In India most of the watersheds are ungauged, and so the accurate information about runoff is unavailable. The soil conservation service curve number method developed by Unites States Department of Agriculture is one of the widely accepted runoff model which is extensively used by hydrologists, water planners etc. The SCS CN model modified for Indian conditions have been widely used for Indian unguaged watersheds and proved quicker and accurate when comparing with other models (Mishra et al. 2003).SCS CN methodestimatesthe direct surface runoff for a given rainfall event from small agricultural watersheds and itconsiders most of the watershed characteristics such as soil type, land-use, hydrological condition and antecedent moisture condition (AMC).SCS curve number method integrated with GIS enhances in deriving spatial parameters efficiently and thus making the process of runoff estimation quicker. Romulus Costache et al used SCS CN model to highlight the spatial and quantitative changes in runoff depth in Saratel catchment for the period 1990-2006.

The present study was conducted in Venna river basin, Maharashtra using SCS CN method modified for Indian conditions. The standard SCS CN method was used since about 85% area is having a slope 5%. Thematic maps were prepared using satellite images and ArcGIS 10.1 software. The runoff for the period 2004-2009 have been computed using daily rainfall data considering soil moisture, vegetation and soil permeability characteristics.

2. KEY WORDS

Runoff, Soil Conservation Service, GIS, remote sensing, antecedent moisture condition

3. STUDY AREA

The study area, Vennariver basin is located in Maharashtra, India and geographically lies between 21˚01’42.19” and 20˚ 23’0.59” N latitude and78̊18’17.61” and 79 ˚06’12.23” E longitude. Venna, having an approximate area of 5675 km^2 comes under Wardha catchment of Godavari basin. The basin extends over parts of Wardha, Nagpur and Chandrapur districts. The Deccan Traps cover about 95% of the area and comprise rocks of basaltic composition. . Clayey, gravelly clayey loam, gravelly sandy clayey loam, sandy clay loam, silty loam, gravelly clay, gravelly sandy loam are the soils governing the basin. The major land use classes in the area are agriculture, built up area, wastelands, forest and water bodies.

3.1. Climate and rainfall

The climate of the region is characterised by hot summers and a general dryness throughout the year except during south west monsoon. The mean monthly maximum and minimum temperature ranges between 42˚C and 18˚C in the month May and December respectively. The average annual rainfall of the basin is found to be 1090 mm.

3.2. River and drainage

The Sub Rivers like Bor, Dham, Pothra, Nand joins the Venna river, which is one of the main sub river of Wardha river, which is the tributary of Godavari river.The major reservoirs in the study area are Pothra dam, Wadgaon dam, Bor dam, Venna reservoir, Lower Wunna dam and Dham dam. The overall drainage pattern is dendritic to sub- dendritic. Paddy is the main Kharif crop while wheat is the mainrabicrop in the watershed. Sugarcane and potato are the main cash crops of the study area.

4. METHODOLOGY

The SCS CN model have been used for runoff estimation of Venna river basin. The watershed consists of 28 sub watersheds and runoff estimation was carried out sub watershed wise.

4.1. SCS CN model

The basic assumptions underlying SCS CN method is that , the ratio of amount of rainfall infiltrated after runoff begins (F) to watershed storage (S) is assumed to be equal to the ratio of actual direct runoff to effective rainfall,

$$\frac{F}{S} = \frac{Q}{P-Ia} \text{.......................................} \quad \text{.................... (1)}$$

Andthe initial abstraction$\boldsymbol{Ia = \lambda . S}$, where $\boldsymbol{\lambda}$is the initial abstraction ratio and varies from 0.1 to 0.3.

Runoff depth **Q** is given by,

$$\boldsymbol{Q} = \frac{(P-0.3S)2}{(P+0.7S)}, \text{ if } P \geq \boldsymbol{Ia} \text{........................} \quad \text{........ (2)}$$

Q = 0, if P < 0

Where$\boldsymbol{Ia}$ = **0.3S,** for Indian conditions. The land use/land cover, soil permeability and soil moisture condition parameters are considered and a dimensionless number known as curve number isdeveloped.

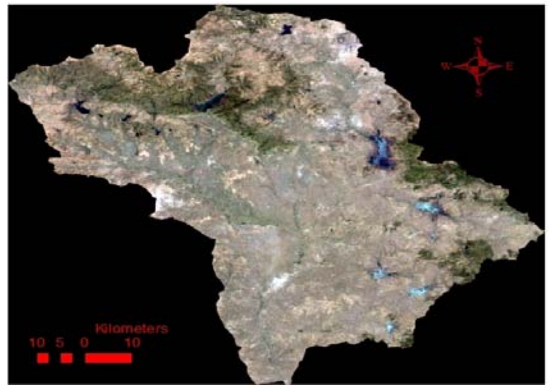
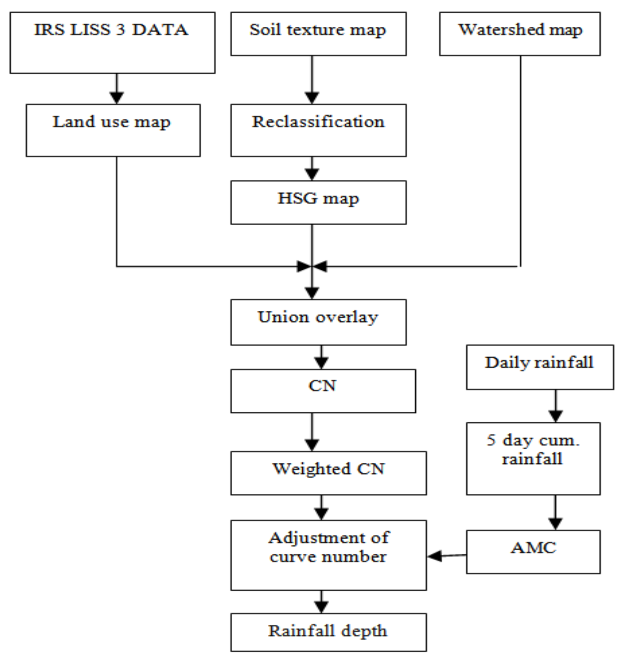


Fig. 1: Satellite image of study area

4.1.1. Land use map

The watershed boundary was digitized from Google earth, and the satellite image was georeferenced. The watershed map was obtained from MRSAC, which consists of 28 sub watersheds. The land use / land cover map of the area was prepared by visual interpretation of satellite images of IRS LISS – III for the year 2007 by MRSAC.

The land use classes were reduced in to classes mainly agriculture, wasteland, water bodies, forest and built up area by using the merge tool in editor in Arc Map 10.1.The watershed map was overlaid land use map by union overlay analysis in Arc Map 10.1.



Flow chart 1. Flow chart showing Methodology to estimate runoff depth by SCS CN model

4.1.2. Hydrologic soil group map

Soils were classified according to recommendations of Natural Resource Conservation Service into four hydrologic soil groups A, B, C and D based on the infiltration characteristics. The soil types governing the basin are mainly clayey, silty clay, gravelly clay, clay loam, gravelly clay loam, gravelly clay loam, silty loam, gravelly sandy loam, sandy loam etc. Each soil type polygon was selected and assigned hydrologic soil classification so that an HSG map with 4 attributes were prepared inArcMap 10.2.2 as per the following.

Group Asoil: soils having high infiltration rate, mainly sand, loamy sand or sandy loam. Infiltration rate ranges from 7.62-11.43 mm/hr when thoroughly wet.

Group Bsoil: soils having moderate infiltration rate, mainly silt loam or loam. Infiltration ranges from 3.82- 7.62 mm/hr when thoroughly wet.

Group C soil: soils having low infiltration rate, includes sandy clay loam. Infiltration rate ranges from 1.27- 3.82 mm/hr when thoroughly wet.

Group D soil: soils having very low infiltration rate, includes clay loam, silty clay loam, sandy clay, silty clay or clay. Infiltration rate ranges from 0.00- 1.27 mm/hr.

4.1.3. Rainfall and antecedent moisture condition

The daily rainfall data for the years 2004-2009 was obtained from IMD Pune. In Venna river basin about 98% of the annual rainfall is received during south west monsoon which sets in middle of June and ends in middle of October. The rainfall data for the watershed wasderived from 8raingaugestations located inside and near by the basin boundary. Using the latitude and longitude values of raingaugestations a point shape file was made in ArcMap, and theissen polygons were made. The mean rainfall for the area wasdetermined by means of theissen polygon method.

Antecedent moisture condition (AMC) represents the moisture content present in the soil, which is having a significant effect on surface runoff. It is determined by the total rainfall in 5 day period preceding a storm. SCS developed three AMC's and represented them as AMC I, II, III according to soil conditions and rainfall limits in both growing as well as dormant seasons.

Table 1: Classification of AMC

SI NO	AMC class	5 day cumulative rainfall	
		Growing season	Dormant season
1	AMC I (dry)	< 36 mm	< 13 mm
2	AMCII (average)	36-53 mm	13- 28 mm
3	AMC III (wet)	>53 mm	> 28 mm

4.1.4. Determination of curve number

Curvenumber (CN) is a measure of retention of water by a given soil vegetation complex whose value varies from 0 to 100. To get CN map, landuse and HSG maps were overlaid by union overlay operation in ArcMap 10.1. CN value for AMC II was taken from Chapter – 7, SCS Hand book of Hydrology (1972), and surface retention is given by

$$S = \frac{(25400)}{CN} - 254 \quad (3)$$

Weighted curve number for each sub watershed was determined as

$$CN = \frac{(CN_i * A_i)}{A} \quad (4)$$

Where CN_i isthe curve number from 1 to any number N;A_i is the area with curve number CN_i; and A the total area of the sub-watershed.

The CN values corresponding to AMCI and AMC III have been computed from the following formulae.

$$CN\text{I} = \frac{CN\text{II}}{2.281 - 0.01281 CN\text{II}} \quad (5)$$

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

5. RESULTS AND DISCUSSION

5.1. Land use map

Among the land use classes agriculture covers about 65 % and it plays an important role in controlling surface runoff.

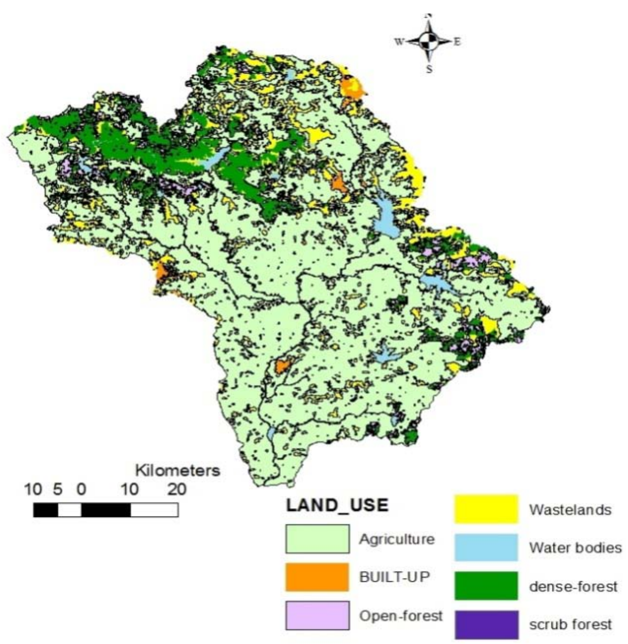


Fig. 2: Land use map of Venna river basin

5.2. Hydrological soil group

The soils in the basin were classified under hydrologic soil groups as given below.

Group A; gravelly sandy loam and sandy loam

Group C; gravelly clay loam, gravelly sandy clay loam, silty clay loam and silty loam

Group D; clay loam, clayey, gravelly clay and silty clay

About 58% of total basin area covers group D soil, which is having high runoff potential. Remaining 32% includes group C, 5% group A and 3% water bodies.

Presence of group D soil will lead to a higher value of CN value.

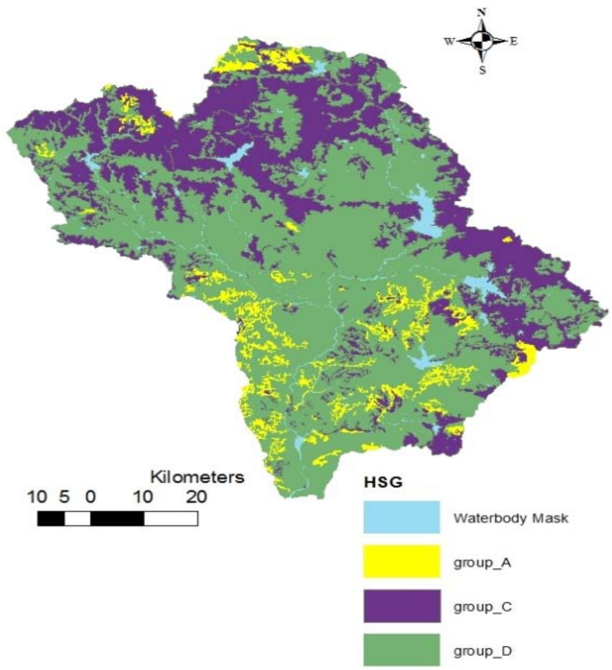


Fig. 3: Hydrological soil map of Venna river basin

5.3. Computation of curve number

The curve numbers for different soil- vegetation complex for average antecedent condition are given below (taken from Chapter – 7, SCS Hand book of Hydrology (1972)).

Table 3: Curve numbers for different land use-hydrological soil groups

SI NO	Land use class	Hydrological soil group			
		A	B	C	D
1	dense forest	26	40	58	61
2	open forest	28	44	60	64
3	scrub forest	33	47	64	67
4	wasteland	71	80	85	88
5	built up area	77	85	90	92
6	agriculture	76	86	90	93
7	water bodies	98	98	98	98

Each sub watershed consists of different curve numbers according different land use soil combinations. The weighted curve numbers for each sub watershed corresponding to three antecedent moisture conditions are given in the table. The runoff computation mainly relies on CN value which is a function of land use, soil and AMC properties of area. High CN value reflects high runoff potential and low water retention. Low CN value indicates high water retention potential and so little runoff. From table 4 it is clear that the sub watershed WRWBD-7 is having a higher CNvalueandWRWBD-4 is having a low CN value. For the same rainfall input these two sub watersheds may give different runoff values, since the vegetation and soil distribution differs.

Table 4: Weighted curve numbers of sub watersheds

Sub watershed	CN(AMC2)	CN(AMC1)	CN(AMC3)
WRW-1	90.03	79.83	95.48
WRW-2	89.64	79.14	95.30
WRW-3	92.38	84.16	96.60
WRW-4	89.22	78.39	95.09
WRW-5	87.58	75.56	94.29
WRW-5A	90.01	79.80	95.48
WRW-6	87.55	75.51	94.28
WRW-6A	90.89	81.39	95.90
WRW-7	91.56	82.63	96.21
WRW-8	82.53	67.44	91.71
WRWB-1	74.18	55.74	87.06
WRWB-2	79.86	63.48	90.28
WRWB-3	87.5	75.42	94.25
WRWB-4	81.82	66.36	91.33
WRWBD-1	88.37	76.91	94.68
WRWBD-2	89.71	79.26	95.33
WRWBD-3	76.97	59.44	88.67
WRWBD-4	72.56	53.69	86.10
WRWBD-5	80.51	64.43	90.63
WRWBD-6	78.3	61.27	89.42
WRWBD-7	93.08	85.50	96.92
WRWI	91	81.59	95.95
WRWN-1	81.2	65.44	91.00
WRWN-2	85.39	71.93	93.19
WRWN-3	89.96	79.71	95.45
WRWP-1	88.17	76.57	94.58
WRWP-2	89.95	79.69	95.45
WRWPL-1	81.08	65.26	90.94

5.4. Runoff depth estimation

The theissen weights were assigned for each rainguage stations for each sub watersheds and mean daily rainfall was calculated for the years 2004- 2009 and daily runoff depth was found out.

Annual rainfall and runoff for the year 2007 for all sub watersheds are given in table. The annual rainfall is very less in the year 2004 and comparatively high in 2007, and so runoff. A maximum runoff of 69% of rainfall have been found in the year 2004 in WRWBD-7and a minimum of 9.1% in WRWBD-4. The average annual rainfall in 2007 for whole of the basin was 1344.33mm.

Table 5: Annual rainfall- runoff for sub watersheds

Sub watershed	Annual rainfall(mm)	Annual runoff(mm)
WRW-1	1383.10	796.98
WRW-2	1418.95	792.32
WRW-3	1626.40	1116.32
WRW-4	1618.71	1011.82
WRW-5	1027.38	460.86
WRW-5A	1388.22	798.26
WRW-6	1144.07	508.33
WRW-6A	1383.10	501.14
WRW-7	1367.07	741.68
WRW-8	1241.78	508.29
WRWB-1	1108.10	314.85
WRWB-2	1251.40	430.31
WRWB-3	1634.08	1007.22
WRWB-4	1343.30	583.69
WRWBD-1	1553.58	932.19
WRWBD-2	1167.30	587.18
WRWBD-3	1083.33	333.99
WRWBD-4	1096.00	295.04
WRWBD-5	1082.91	395.63
WRWBD-6	1177.60	404.01
WRWBD-7	1639.20	1172.37
WRW1	1383.10	820.66
WRWN-1	1459.37	678.69
WRWN-2	1466.00	798.65
WRWN-3	1427.94	749.11
WRWP-1	1387.25	750.42
WRWP-2	1383.10	795.41
WRWPL-1	1398.85	607.85

6. CONCLUSION

For better watershed management system, runoff estimation by SCS CN method integrated with GIS is proved as an effective method, especially in ungauaged watersheds, where discharge data is unavailable. The runoff behavior of sub watersheds varies spatially according to land use and soil conditions.

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